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Critical Assessment of Data Visualization from the Electronic Horizon in the Context of a Deceleration Assistance System

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Zusammenfassung

Die Integration von unterschiedlichen Informationsquellen erlaubt es in Zukunft, den Fahrer in einer Vielzahl von unterschiedlichen Situationen noch besser zu unterstützen; gleichzeitig kommt es hierbei auch zu neuen Herausforderungen. Abgesehen von technischen Schwierigkeiten ist die Art und Weise, wie diese Information dem Fahrer präsentiert wird von entscheidender Bedeutung. Fähigkeiten und Grenzen des Fahrers (sog. Human Factors) müssen beachtet werden, um den Nutzen dieser Informationen auch in einer realen Umgebung gewährleisten zu können.

Im Kontext der oben genannten Datenintegration behandelt die vorliegende Arbeit die Visualisierung von Verkehrsdaten außerhalb der Sichtweite des Fahrers sowie Probleme, die bei nicht korrekter Datenlage auftreten können. Als Fallbeispiel diente ein Verzögerungsassistent: ein System, das den Fahrer bei der Verbrauchsreduzierung unterstützt sowie zur Verkehrssicherheit beiträgt. Dies geschieht, indem es dem Fahrer Informationen über bevorstehende Verzögerungsstiuationen präsentiert und ihm entsprechende Handlungsvorschläge unterbreitet (z.B.: 60 km/h, "vom Gas gehen").

In einem ersten Schritt wurden sechs unterschiedliche Visualisierungen entwickelt und in einer Benutzerstudie mit Hilfe eines Video-Experiments evaluiert. Das Ergebnis waren zwei Visualisierungsalternativen: eine Bird's Eye View Visualisierung (BEV), die dem Fahrer die vorausliegende Situation aus einer virtuellen Vogelperspektive zeigt, und eine ikonische Darstellung, welche die Verzögerungssituation durch ein offizielles Verkehrszeichen visualisiert. Eine ausführliche Evaluierung der beiden Varianten erfolgte anschließend in einer umfangreichen Usability-Studie im Rahmen eines Fahrsimulator-Experiments. Ergebnisse, vor allem bzgl. der BEV, zeigten eine hohe Akzeptanz sowie eine positive Wirkung auf den Kraftstoffverbrauch und die Verkehrssicherheit.

Im nächsten Schritt wurde die Frage geklärt, welche Auswirkungen ein Systemfehler auf die Reaktion des Fahrers hat. Hierzu wurde zuerst gezeigt, dass es sich bei dem Verzögerungsassistenten um ein System mit niedrigem Automationsniveau handelt. Ergebnisse aus einer anschließender Benutzerstudie wiesen darauf hin, dass es durch einen Automationsfehler (Nichtanzeigen einer Verzögerungssituation) zu einer verlangsamten Reaktion des Fahrers kommt.

Abschließend wurde ein erster Schritt unternommen, um mit einer unsicheren Datenlage aus Mensch-Maschine-Interaktions (MMI) Sicht umzugehen. Als Fallbeispiel wurde eine unsichere Information bzgl. der nächsten Geschwindigkeitsbegrenzung in einem Verzögerungsassistenten gewählt. Die durchgeführte Studie zeigte eine hohe Benutzerakzeptanz bei der Visualisierung unsicherer Informationen bzgl. bevorstehender Geschwindigkeitsbegrenzungen durch ein Fragezeichen.

Abstract

The integration of information sources in the automotive context can lead to great new possibilities to support the driver in a variety of situations; but at the same time new challenges arise. Apart from technical difficulties, the way, how this information is presented to the driver is crucial. In order to ensure a real life benefit of this additional information, abilities and limitations of the driver ("Human Factors") have to be considered.

In the context of the above mentioned data integration, this work thematized the visualization of information from beyond the visibility range of the driver as well as problems that can occur in case of bad data reliability. As a use case, a deceleration assistance system was chosen: a system that supports the driver in a fuel efficient driving style and contributes to traffic safety. This is done by presenting information to the driver about upcoming deceleration situations and providing an appropriate course of action (e.g.: 60 km/h, "step off gas").

In a first step, six different visualization possibilities were developed and evaluated in a user study with the help of a video experiment. The result was two visualization alternatives, a Bird's Eye View visualization (BEV), which showed the driver the upcoming traffic situation from a bird's eye perspective and an "Iconic" visualization, which used an official traffic sign to visualize the deceleration situation. These visualizations subsequently were evaluated in an in-depth usability study in a driving simulator experiment. Results, especially on the BEV, indicated a high acceptance rate and a positive effect on fuel efficiency and traffic safety.

In a following step, the consequences of a system failure regarding the reaction of the driver were examined. In order to do so, it was shown that a deceleration assistance system is a system with a low level of automation. Results of the subsequent user study indicated that even in such a system, an automation failure (miss of a deceleration situation) can lead to a delayed reaction of the driver.

Finally, a first step was made that illustrated a possible way to deal with unreliable data from a Man-Machine-Interaction (MMI) point of view. As a use case uncertain information about an upcoming speed limit in a deceleration assistance system was chosen. The conducted user study showed a high acceptance rate of visualizing uncertain information about upcoming speed limits with the use of a question mark.

Preface

In 2008 I had the possibility to continue a work I learned to love during my diploma thesis, the development and evaluation of visualizations for driver assistance systems. I had the possibility to be part in a Car@TUM project called "Intelligent Support for Prospective Action" (ISPA) initiated by the BMW Forschung & Technik GmbH.

I like to thank the BMW Forschung & Technik GmbH, especially Mr. Bengler and Mr. Wisselmann for funding the research.
I have been fortunate to receive the support of many people in completing this dissertation. A special thanks goes to you, Gudrun, for always having an open mind about my work and for the support you gave me.
Thank you to my ISPA team, Darya Popiv, Florian Laquai, Kerstin Sommer and of course Mariana Just. This work would not be possible without them.
Also thank you to colleagues at the former chair, Marcus Tönnis my diploma thesis supervisor, Simon Nestler my predecessor in the ISPA project and Christian Wächter. I also want to thank my colleagues at the ZT-3 MMI team, Martin Knobel, Felix Schwarz, Wolfgang Spiesl, Lars Tönnert, Boris Israel, Sonja Rümeli and Melanie Lamara for the assistance and discussions you always were willing to participate in. Special thanks goes to Willi, who kept me laughing and provided some valuable distraction during the last years.
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Special thanks to my parents ;-) .... and of course last but certainly not least to you Kerstin, well .... you know.

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1. Introduction

Enlarging the visual horizon to an electronic horizon with the help of new information sources. An approach to visualize information from the electronic horizon and dealing with problems of failure and uncertainty.

The evolution of the automotive industry from an analogue, mechanical industry to a digital, electrified industry throughout the past decades is undeniable. This development is evident in a large amount of aspects in a modern vehicle. From the electrification of the drive train to the information visualization inside the vehicle and last but not least in the ever enlarging amount of information that is available from new sources of information. Not only the automotive industry has changed, the demands of the customer have changed as well: apart from pure horsepower, comfort and design, which were the main sales arguments in the past, today aspects like fuel consumption and safety are equally important.
With the use of new information sources like digital maps, the Global Positioning System (GPS) and the Car2X infrastructure, it is now possible to support the driver in an even wider range of situations. Along new possibilities, new challenges arise. Especially in the automotive environment, a safety critical environment, it is not possible to simply visualize every new piece of information that is available; a more thorough approach is necessary. Human factors engineering (HFE) methods allow us to utilize new information sources and design a system with regard to human abilities and limitations that is able to enrich the driving experience while creating a real world advantage (e.g. fuel reduction and increase of traffic safety).
The following work presents an approach to utilize newly available information sources to assist the driver in a fuel-saving driving style by enhancing his anticipation beyond his visual horizon to the so-called electronic horizon. Scientific object of the presented work are three questions: How can we best visualize information from the electronic horizon? What are the consequences if information is not correct and how can we best approach these consequences from an MMI standpoint of view?

1.1. Motivation

State-of-the-art advanced driver assistance systems (ADAS) (e.g. Adaptive Cruise Control, Emergency Brake Systems, Lane Departure Warning) currently cover the visual horizon of the driver. With the use of sensors, like RAdio Detection And Ranging (RADAR), Light Detection And Ranging (LIDAR), camera systems, etc., they are able to react on events that are, most of the time, visible to the driver. A great potential, regarding traffic safety as well as fuel saving, lies in the possibility to extend this range to the so-called electronic horizon. This means to have information about events that are either occluded or simply too far ahead of the driver's current position, which makes it impossible for her/him to see them or react on them. Information sources of the electronic horizon are the typical sensors used in today's cars in combination with digital maps, GPS and the Car2X infrastructure. By integrating these sources, a more holistic and far reaching view of the driver's current situation is possible. Amongst others, four interesting questions/challenges are:

1. How can we use this newly available information?
2. How do we visualize the newly acquired information?
3. What are the consequences of a possible system failure in such a system?
4. How can we best visualize information to reduce negative effects in case of a system failure?

Regarding (1): Several applications are thinkable: in the Car2X-CC-Manifesto [12] several use cases for Car2X data are presented. They include cooperative forward collision warning, pre-crash sensing and warning, enhanced route guidance and green light optimal speed advisory. A different use case was mentioned by Reichart et al. [142], who calculated fuel saving potential in different driving situations in regard to the deceleration distance. They showed that the longer the deceleration distance, the higher the fuel saving potential. In such situations, information from the electronic horizon is able to assist the driver in early deceleration by informing her/him about events beyond her/his visual horizon. Regarding the amount of green house gases emitted by the transport sector, a reduction of fuel consumption is a big and necessary step to a sustainable development in the automotive industry.

Regarding (2): Many current ADASs only use information from on-board sensors. Adaptive Cruise Control (ACC) for example uses RADAR and LIDAR in order to adjust the vehicle's speed with regard to the traffic ahead. By using on-board sensors, the cause for a system action almost always lies within the driver's visual horizon, e.g. ACC is reducing the speed due to a slower vehicle in front. New information sources allow us to inform the driver about events beyond her/his visual horizon. This e.g. includes information about upcoming speed limits or an accident behind a bend. In such a case no physical representation of the virtual information is available to the driver. An interesting question that arises is: How do we present this information to the driver? Another question regarding the representation of the information is, whether the visual channel, which already is heavily in use during driving, is the appropriate way to display this information or if it is necessary to incorporate other modalities.

Regarding (3): Apart from developing a visualization, it is necessary to test the visualization at and beyond the system boundaries. A visualization that shows information from the electronic horizon is an information presentation system, and therefore, a system with a low level of automation. Hence, the question of automation failure is of interest. In highly automated systems, failure and the performance consequences of such failures (keyword: "out-of-the-loop") are well documented. Thus, performance consequences in case of an automation failure in a low level automated system need to be researched.

Regarding (4): Because of the negative effects on performance consequences in case of an automation failure, it is necessary to approach this problem. A possible first step is the visualization of uncertain data. In a work on air traffic management by Nicholls [123] (p.3) it is stated that it "was apparent that [...] a proper appreciation of uncertainty could help in decision-making, by providing a more complete picture of the situation. [...] a certain amount of uncertainty in the system is essential if the human is to maintain interest, attention, situation awareness and enjoyment in the job". This indicates that it is possible to positively influence the subjective perception by including uncertainty information in data visualization.

1.2. Objective and Scope of this Work

The focus of this work was the development and evaluation of an interface that is able to visualize information from the electronic horizon and supports the driver in early deceleration. The development of a multi-modal approach exceeds the scope of this work. A multi-modal approach for supporting prospective action can be found in Popiv et al. [135].
Regarding negative performance consequences in case of a system failure, the objective of this work was to verify possible negative effects in the above mentioned deceleration assistance system (a low level automated system). This was done by the means of two exemplary situations, a partial and a complete miss situation. No fundamental research in automation failure was conducted, nor was the transferability to other situations or real-life traffic scenarios researched.
Finally, a visualization for uncertain data in the scope of a deceleration assistance system has been developed. The visualization of an upcoming speed limit sign was chosen due to the uncritical nature of this use case. Again, no fundamental research on visualizing uncertain data nor transferability to other use cases were conducted.

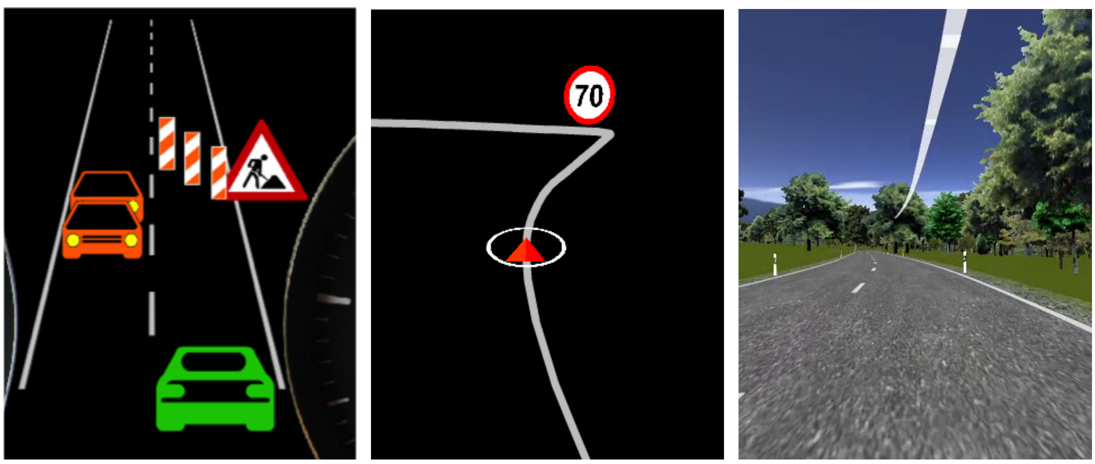
1.3. Approach and Preview of Evaluations

A deceleration assistance system - a system that supports the driver in an ecological driving style by providing information about upcoming deceleration situations - is an adequate use case to research the above mentioned questions. In such a system, a large variety of information can be displayed, from simple speed limit information to highly complex situations involving other vehicles.
A two step process was chosen to develop a visualization that is able to support the driver in early deceleration. In a first step, several visual variants were developed. The first one is a Bird's Eye Visualization (BEV) (Figure 1.1a), i.e. a visualization that presents information from the electronic horizon on a piece of virtual street in the instrument cluster. In this visualization, all relevant information is presented in a natural way that is easy to comprehend and process for the driver. The second visualization is the "Virtual Racing Line" (VRL) (Figure 1.1c), a contact analogue visualization that uses the advantages of this technology to support the driver in the task of early deceleration by visualizing the request of action via a color change of a contact analogue racing line (implemented as augmented simulated reality). The third one is called Navimap (Figure 1.1b) and is a combination of a navigational view and the BEV, which uses these different views in order to present information to the driver depending on the complexity of the situation. "Complex" situations (e.g. lane precise situations including other vehicles) are displayed in the more detailed BEV, while "simple" situations (e.g. speed limits) are displayed in the visually simpler navigational view. All visualizations were evaluated in a video experiment in order to reduce the number of variants for a second driving simulator experiment.

In the next step, two visualizations (the BEV and an Iconic visualization) were taken to a second, in-depth, driving simulator experiment. The main focus lay on the questions of likability, usability, overall acceptance and distraction. Also, the age and driving experience distribution of the subjects were thoroughly taken care of. 29 subjects participated in the experiment, in which they were confronted with two visualizations and a baseline drive. The evaluation verified that the BEV is a well accepted visualization for supporting early deceleration and that it is not only an issue of how much information is presented but rather a question of how it is visualized.

The first two evaluations were conducted in a simulator environment with perfect knowledge about the environment (e.g. distance and position of other vehicles). In real-life traffic, such a knowledge is far from reality. Therefore, it was necessary to conduct a further experiment, which investigated the performance consequences in case of a system failure. In this experiment, a partial and a complete miss situation (miss of an oncoming vehicle and miss of a complete situation) were integrated into the driving simulator's test course. Results showed that a partial miss did not lead to negative effects regarding reaction time when compared to a baseline drive. In a complete miss situation, however, a worse anticipation and delayed brake reaction (compared to the baseline) were observed.

In order to be able to use the information from the electronic horizon, it is necessary to research possibilities to reduce negative effects in case of a system failure and to visualize the available information with the most benefit for the driver. A possible strategy is the development of an approach to visualize uncertain information. As a use case, the speed limit visualization in a deceleration assistance system was chosen. This use case allowed us to research the question of uncertainty visualization without the influence of safety critical situations. A large variety of concepts were developed, tested and reduced in short interactive driving simulation situations as well as in a focus group. Afterwards, the most promising visualization (a visualization with a question mark "?" for indicating uncertainty) was integrated into a deceleration assistance system. Results showed that the visualization of uncertain information was well accepted by the subjects, and that the chosen visualization with a "?" was understood intuitively.



(a) The BEV (b) The Navimap (c) The VRL - augmented simulated reality

Figure 1.1.: The three developed visualization

1.4. Structure of this Document

This document is divided into three parts.

I. Chapter 2 to 6 present the development and evaluation of a visualization for a deceleration assistance system.

II. Chapter 7 to 8 cover the different levels of automation, the consequences of automation failure and an evaluation of automation failure in a deceleration assistant system that is using the BEV.

III. Chapter 9 to 10 show concepts for visualizing uncertain data and a subsequent evaluation in a driving simulator experiment.

Chapter 2 provides background information on how to approach the development of a user interface in the automobile context by introducing HFE and how it can help to develop a human machine interface. In order to fully understand the interaction between human and machine, knowledge on both sides of the system is necessary. Therefore, a short introduction on human perception as well as a short overview on the information sources, including the Car2X infrastructure, is given. Finally, the driving task and how ADASs do support that task, are described.

Chapter 3 provides an overview of the energy saving potential in a modern vehicle. It includes approaches at the powertrain, but primarily covers possibilities that aim at the driving style to reduce fuel consumption. Related work from several sources is presented. This includes the Situation Adaptive Drive Train Management (SAM) by Dorrer et al. [55], a prospective consumption assistance system by Samper and Kuhn [147] and the Fuel-Efficiency Support Tool (FEST) by Van der Voort and van Maarseveen [177]. In a work by Reichart et al. [142], it is shown that especially situations with a large deceleration distance have the highest fuel saving potential.

In Chapter 4, concepts of three possible visualizations to support early deceleration are presented. This includes the idea of a predictive display as well as the conceptional work on the BEV. Finally, the idea and concept of the VRL and the Navimap as well as related work are presented.

In Chapter 5, a video experiment with the purpose of reducing the amount of visual variants is presented. Three visualizations (the BEV, the VRL and the Navimap) were evaluated. In Chapter 6, two visualizations, the BEV and the Iconic visualization, are evaluated in an interactive driving simulator experiment regarding the questions of usability, likability and distraction in a deceleration assistance system.

Exploring the system boundaries in the second part of this work starts with Chapter 7, which shows that information presentation is considered a low level of automation. Also, the consequences of automation failure are shown, by presenting related work on automation failures in high level automation systems.

In Chapter 8, the consequences of a partial and a complete miss in the use case of a deceleration assistance system are shown. Driving data, including brake and gas pedal position as well as reaction time are presented.

The final part of this work starts with Chapter 9 and explains the meaning of the term uncertainty and its influence on the the visualization pipeline. Possibilities to visualize uncertain data as well as sources of uncertainty in the vehicle are also presented in this chapter. Finally, conceptional work on how to visualize uncertain data in the use case of an upcoming speed limit is presented.

In Chapter 10, the concept for visualizing uncertain information with a question mark is evaluated in a driving simulator environment regarding the question of overall acceptance.

In the Appendix, detailed descriptions of the situations used in the driving simulator experiments, detailed statistical results and the questionnaires used in the evaluation can be found.

2. Theoretical Background

Definitions and guidelines for developing Human-Machine Interfaces (HMI). Human information processing, definition and classification of advanced driver assistance systems (ADAS). Information overflow in the car.

In this work approaches are presented to visualize large amounts of information in the instrument cluster of a vehicle while driving. In order to do this the best possible way, it is necessary to keep human abilities and limitations in mind during the development stage of a product.
This chapter gives a short introduction to "Human Factors Engineering" (HFE) and according principles that can help to design user interfaces while keeping human abilities and limitations in mind.
In order to develop a HMI, it is necessary to have knowledge on both sides of the human-machine system. This chapter gives background information on human information processing and points out special requirements of the human while performing the task of driving. Also an insight on the sources of information that are available inside and outside the vehicle, including an introduction of the visual and electronic horizon, is provided.
Finally, the function and possible classifications of ADAS is presented.

2.1. Human Factors Engineering

In the early ages of automation and computerization, human abilities and limitations often were a less attended issue. Systems for humans were purely designed with regard to functional aspects. Ignoring the human in the human-machine system can lead from frustrated users to catastrophic failures. Starting with plane crashes without technical failure in World War II, a multitude of examples can be found throughout the years. The Three Mile Island accident on the 28th of March 1979, which resulted in a partial melt-down of one reactor core due to wrong interpretation of the plant's indicators regarding the water level, is a prominent and daunting example for what can happen if faulty system design leads to human error and catastrophic results. In this case the operators were not able to interpret the current state of the plant correctly. The operators only concentrated on one (incorrect) alert while ignoring several other correct cues and therefore chose wrong counter action e.g. [194].
HFE is a discipline, which tries to incorporate human abilities and limitations in the design process of the human-machine system, with the goal to maximize human-machine performance and reduce human errors. This is done by methods, guidelines and principles during and after the design process.
The following section gives a definition of HFE. It then describes aspects and principles,

like usability, and evaluation methods in HFE and finally shows how to put these principles into practice. Of course only an excerpt of HFE is covered in this section, for more detailed information please refer to e.g. [194][196].

2.1.1. Definitions and Goals

Multiple definitions of HFE can be found. Meister [112] for example states that it is "the study of how humans accomplish work-related tasks in the context of human-machine system operation, and how behavioral and non-behavioral variables affect that accomplishment". Adams [3] can be quoted that "[t]he field of human factors engineering uses scientific knowledge about human behavior in specifying the design and use of a human-machine system. The aim is to improve system efficiency by minimizing human error."
HFE is a multidisciplinary field with contributions from different scientific fields like psychology, engineering, industrial design and anthropometry.
It has to be stated that HFE is not the only term commonly used. Usability, Ergonomics, Human Computer Interaction, Engineering Psychology and others are also widely used expressions for similar areas of research. Delimitations between those terms mentioned is possible, a complete delimitation of these terms would easily exceed the scope of this work. Readers with further interest in the definitions are referred to Licht et al. [106] and Wickens & Hollands [194].
While the definition of HFE can be rather vague, specific goals can be drawn. Following a list of goals associated with HFE:

- "to apply knowledge in designing systems that work, accommodating the limits of human performance and exploiting the advantages of the human operator in the process" [194]
- "Enhances performance" [196]
- "[I]ncreased safety" [196]
- "[I]ncreased user satisfaction" [196]

2.1.2. Principles and Guidelines

An important aspect for this work is how a display should be designed. HFE provides general principles that can be used as a guideline for this task.
ISO 9241[46] states that "[u]sability is a measure of the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in a particular environment."
Several different principles and guidelines can be found in the literature that should lead to good usability. This paragraph shows guidelines and principles for usability engineering from Quesenber [139] and Norman [127] .

Quesenber [139] focuses on "the 5Es of usability". These five Es are:

- **Effective:** How completely and accurately the work or experience is completed or goals reached.
- **Efficient:** How quickly this work can be completed.

- **Engaging:** How well the interface draws the user into the interaction and how pleasant and satisfying it is to use.
- **Error tolerant:** How well the product prevents errors and can help the user recover from mistakes that do occur.
- **Easy to learn:** How well the product supports both the initial orientation and continued learning throughout the complete lifetime of use.

Norman [127] defined principles that make interaction with things easier. Two goals for object design are: 1) Make things visible, meaning that designers should make the function of an object visible. 2) Provide a conceptual model which means that by looking at an object, the functionality should be clear to the user.
To achieve these objectives, Norman provides four principles.

- **Affordances:** Features of an object that make it possible to figure out how an object is intended to be use by looking at it. The typical example is a door that should tell the user by design, if it should be pushed or pulled and on which side the hinge is. If "pull" or "push" needs to be printed on the door, affordance is not achieved.
- **Principle of feedback:** A feedback to an input should be provided. The system tells the user something in response to the user input.
- **Natural Mapping:** A mapping of controls and their actions, e.g steering a car, when steering to the left, the car turns to the left.
- **Constraints:** Using constraints on an object often simplifies its use. A good example for constraints is a car with automatic transmission that cannot be started unless in park or neutral.

Norman [127] also coined the terms “gulf of execution” and “gulf of evaluation”. On one side, the gulf of execution describes “the differences between the intentions of the users and what the system allows them to do or how well the system supports those actions". On the other side, the gulf of evaluation describes “the degree to which the system/artifact provide representations that can be directly perceived and interpreted in terms of the expectations and intentions of the user".

2.1.3. Human Factors Evaluation Methods

Not only principles, constructs and guidelines are useful assets of HFE, another important tool are evaluation methods which help to quantify differences after developing a product.
An important aspect of HFE evaluation methods is that results should be quantifiable, i.e. results should not only state, System A is "better" or "worse" than System B, but should rather include quantifiable units. For example one can have a 5% reduced error rate using display A instead of display B.
Chapanis & van Cott [40] in their work mentioned that “when we make a test or an evaluation, what we hope is that the outcome of the test will enable us to make valid statements about how the system will perform in the real world.” Chapanis & van Cott also provided an overview on typical test techniques with different fidelity and flexibility. These techniques were:

- **Mathematical Models:** models of the system, very well manipulatable, easy to change and repeatable at low cost.
- **Laboratory Experiments:** controlled environment, well repeatable, well manipulatable.
- **Simulations:** highly realistic simulations of the real world a possible, still very controllable and manipulable. The more realistic the simulation the better it's fidelity.
- **Field Studies:** Very good fidelity, still artificial situations. High costs, and not as well manipulable.
- **Observations of the Real World:** Highest fidelity, highest cost, hardly controllable and manipulable.

The fidelity and the ease of execution often runs oppositional.

2.2. The Electronic Horizon

Currently available ADASs mainly utilize information form on-vehicle sensors. This allows the system to act in a time-frame up to approximately 5 seconds, depending on the sensor and situation. New sources of information allow to enlarge this time frame. Figure 2.1 schematically shows the time frame that is covered by current on-vehicle sensors (blue indication) and the time frame that is covered by new sources of information (red indication). Of special interest in this context is information from beyond the driver's visual horizon, e.g. events behind a bend or a hill (as in Figure 2.1). Concrete limits for the time frame are hard to define due to the large variety of possible situations (e.g. information about an upcoming speed limit might be known several minutes ahead of time, while dynamic situations involving other vehicles have a shorter time frame).
The electronic horizon exceeds the visual horizon and can be defined as an "enhanced map data for the road ahead" [143]. Information in the electronic horizon comes from technical sources like RADAR, LIDAR (both in combination with the Car2X infrastructure), Global Positioning System (GPS) and digital maps. This information then can beused in a wide range of scenarios. The following section provides information on the technical sources for the electronic horizon as well as possible use cases. More technical details and accuracies can be found in Section 9.4.

2.2.1. Sources of Information

In order to be able to fill the EH with useful information, according sources are needed. For the EH, these include typical on-vehicle sensors, digital maps and GPS. In the near future, the Car2X infrastructure is a great way to integrate and expand these sources of information to an extended data base.

Digital Maps and GPS Digital maps and the GPS are widely used in today's automotive environment, with navigation as their main functionality. Additional information like current speed limit and traffic jam warnings are also available. GPS, with its geo-stationary satellites, provides the possibility to pinpoint one's location on the digital map. GPS-acccuracy

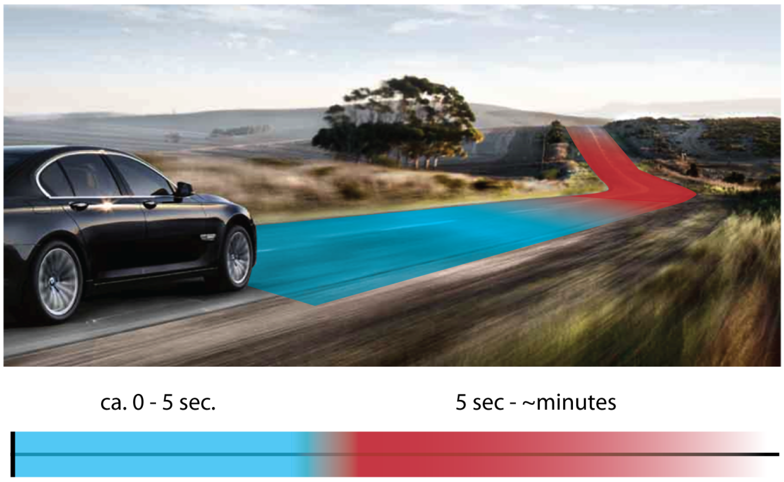


Figure 2.1.: Schematic view on the currently available information sources (blue) and the enlarging of this horizon to an electronic horizon with the help of new information sources (red) like digital maps or the Car2X infrastructure

is 5 to 10 m in 95% of the time [5]. The European counterpart, Galileo, with accuracy of 10 m horizontally for the mass market and 4 m for safety critical applications [18], has a similar performance. Projects like Actmap [15] try to implement real time capabilities into the statical digital maps. Another project founded by the EU called Nextmap [129] researched the necessary advances digital maps need to make in order to be of use in ADASs development. Possible use cases are the support for upcoming traffic signs, road curvature warnings and support for safe overtaking [109].

Vehicle Sensors Typical sensors used in the vehicle today are: RADAR, LIDAR and cameras. More details on the technical aspects of these three sensors can be found in [73], [201] [166] and [125]. Adaptive Cruise Control (ACC), night vision, park-assistance systems, blind spot detection etc. are typical use cases for such sensors.

Car2X Infrastructure A rather new source of information is the Car2X infrastructure. This infrastructure extends the possibilities of the above mentioned vehicle sensors and allows to combine information from other vehicles and the traffic infrastructure to a more complete view of the current traffic situation. A typical scenario can be seen in Figure 2.2, in which the communication between public transport, private transport and the infrastructure makes it possible to receive a complete picture on the vehicle's current situation.

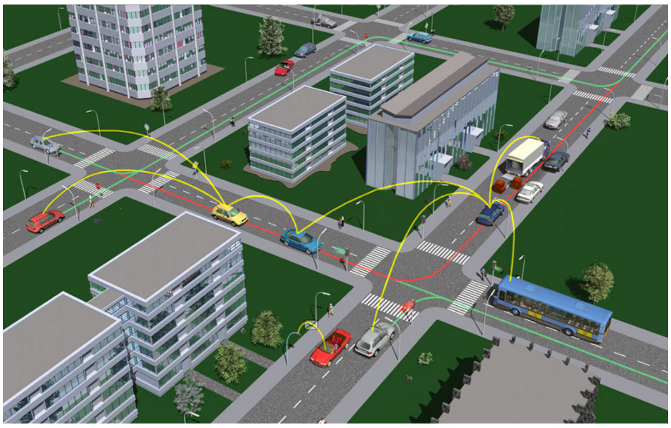


Figure 2.2.: Car2X-Communication Scenario, communication between vehicle, public transport and infrastructure; Baldessari et al. [12]

For the communication between vehicles an own Institute of Electrical Engineers (IEEE) standard 802.11p ([90] [205]), which is based on the well distributed standards for wireless communication 802.11 a/g/n, was introduced. Information is broadcast via Dedicated Short Range Communication DSRC on the 5.9 GHz band and has a bandwidth of 75Hz. The typical range is about 1000 meters.

Apart from the possibilities new challenges arise. Trust in an information source, visualization of information sources that are not visible through the windshield, accuracy, etc. are just a few to name.

2.2.2. Use Cases

Increase of traffic safety and improvement of fuel efficiency are two main categories of situations that can serve as use cases for information from the electronic horizon.

Quoting the Car2X-CC-Manifesto [12], possible use cases of Car2X information are:

- **Cooperative Forward Collision Warning:** Sharing the parameter position, speed and heading, it is possible to visually, acustically or haptically warn the driver against rear-end collision.
- **Pre-Crash Sensing/Warning:** When an accident is no longer preventable, it is possible to optimize the usage of actuators such as air bags, motorized seat belt pre-tensioners, and extendable bumpers.
- **Enhanced Route Guidance and Navigation:** The infrastructure owner can deliver route information to the driver in order to inform him about expected delays or alternative routes.
- **Green Light Optimal Speed Advisory:** Traffic lights can send information about their status to the driver in order to make their driver smoother and avoid stopping.

Reichart et al. [142] in their work calculated energy saving potential in each driving situation over the distance in the electronic horizon. Figure 2.3 shows that early situation detection offers the most energy saving potential by utilizing coasting time.

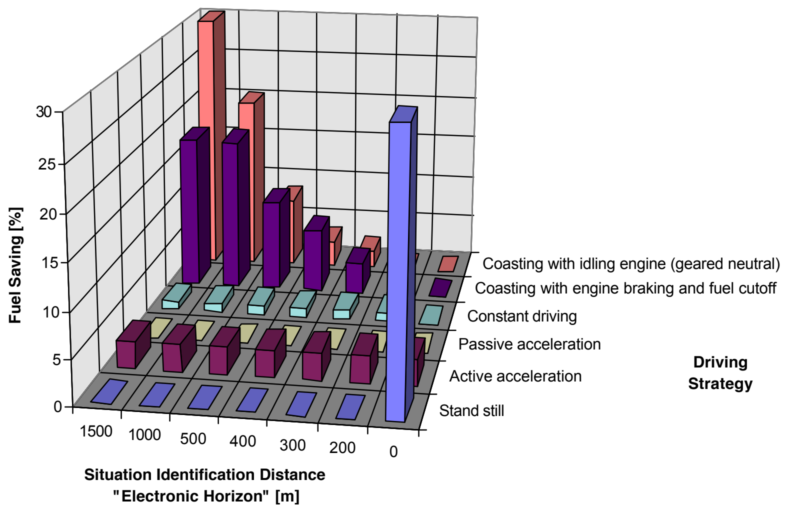


Figure 2.3.: Potential of different situations; The higher the distance the identification distance, the higher to potential energy saving potential, especially while coasting; from Reichert et al. [142]

2.3. The Human and His Limitations

Human information processing begins with receiving signals from the environment with the use of different senses. The sensory input is then transported via the nervous system to the brain where information is processed in the according region. Information is stored in different regions, to be either available for a short or long term. Using this information lets the human decide what kind of action is applicable in a certain situation and to form a mental image of the world and how it works. This section describes the information process from the sensory input to forming a mental model of the world in order to predicting the outcome of one's action.

2.3.1. Human Perception

Humans perceive information from a lot of different sensory channels. Today's physiology differentiates nine different senses [64]. The visual, auditory and haptic channel are the three most important channels in the context of controlling a vehicle. All senses have different properties, advantages and limitations. Knowledge of these senses can be used to develop ADASs that use the advantages and avoid their limitations. The following section will describe how the visual, auditory and the haptic sense work, and what properties they have. Also reaction time of the different senses will be of issue. For further details on human senses and information processing please refer to Eysenck and Keane [64] or Goldstein [77].

The Visual Perception The sensor for visual perception is the eye. 80-90% of all information while driving is received through the visual system [2]. The eye is the only far reaching receptor which can be actively directed.
To be able to see, lightwaves pass the lens of the eye and then trigger the optical nerves on the retina. These nerves are called rods and cones. The most rods are distributed around the fovea, which accommodates about 2° around the center of the eye. Rods are responsible for sharp color seeing. The cones, on the other hand, majorly located on the parafovea and responsible for detecting movement, are mainly of use in low light conditions.

The driver perceives his surroundings mainly through the visual channel. This includes other traffic participants, their position, their assumed action, lanes, traffic signs, the flashing of the indicator and many more [96].

Auditory and Haptic Perception The ear fulfills three main functions when receiving auditory information (e.g. Abendroth & Bruder [2]): **Adaptation**: the regulation of the auditory threshold, **recognition of auditory pattern**, necessary for speech recognition and **identification of sounds and spatial orientation** through binaural hearing.
The structure of the ear includes the pinnea, which is the outer structure and determines the location of the sound, the auditory channel, enhancing the intensity of the sound through resonance, the middle ear, which transfers the sound waves from low density (air) to high density (inner-ear water) and the inner ear.

The last sense that is covered in this section is the **haptic** sense. Different sub categories of the haptic sense can be defined. The **tactile** receptors are located in the epidermis and the dermis. Different kind of receptors are e.g. responsible for detecting fine details, touch, pressure, changes in texture or tension deep in the skin. The **kinesthesis** or proprioception senses the relative position of neighboring parts of the body and therefore enables the human to detect changes in body position without relying on information of the other senses.

Reaction Times Different sensors have different reaction times. A general statement of the differences in reaction times is difficult due the large number of factors that can influence the reaction time like: distraction, pre-learning, movement necessary to react, and many more. Postman & Egan [138] in their work provided an overview on the different reaction times of the different senses in pure laboratory conditions with no movement involved and testing only practiced subjects under the most favorable conditions. Results showed a difference of 20-50 ms between a visual stimulus and a touch or auditory stimulus.
The channel for an assistance system has to be chosen very carefully, and reaction time is not the only and most important variable, especially if the small differences are considered.

2.3.2. Information Processing Models

When the stimulus reaches the human brain, information has to be processed. With the help of the information processing model by Wickens & Hollands [195], the following section describes the interaction and information processing process.
As one can see in Figure 2.4, the model describes the interaction between a human and a machine as a closed loop, in which the operator perceives a state from the environment.

Via his/her senses the human is able to perceive the information from the environment and make a decision on how to response to the perceived information. Stored memory from previous experiences do influence the perception as well as the decision stage. Newly acquired information does get saved in the memory and might influence future information processing. After the decision is made a response is executed and the system provides feedback, which can be sensed by the human; the loop starts over. For the perception, decision, response stage and for storing/retrieving information in/from memory mental resources are necessary.

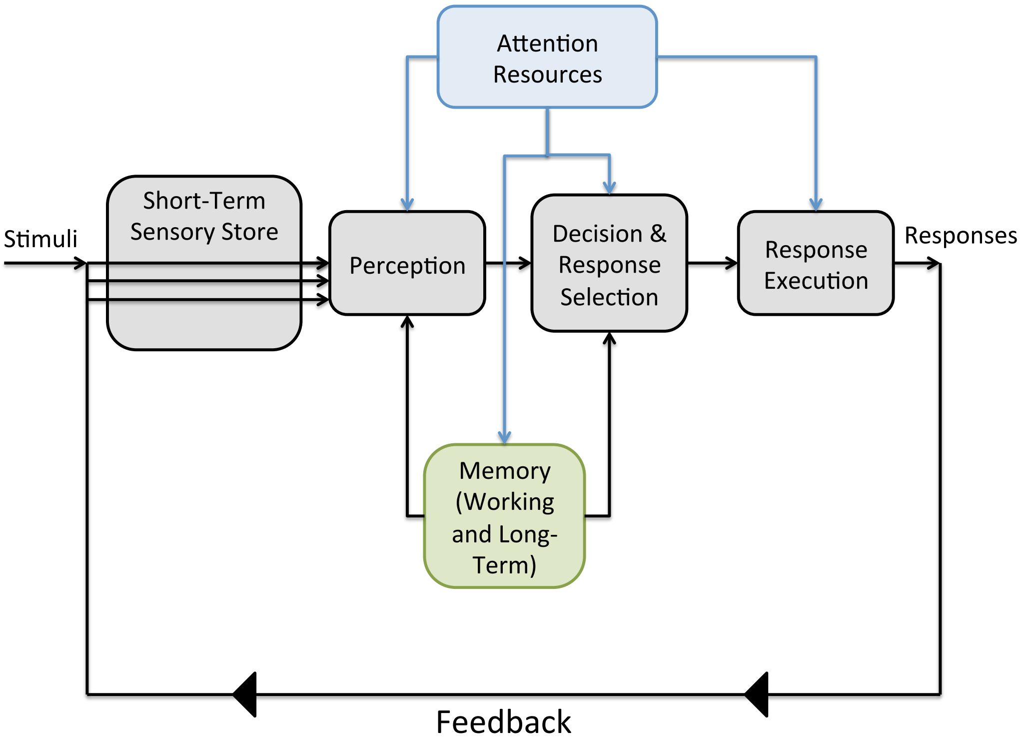


Figure 2.4.: Information processing model: a stimulus is received via the human sensors, it is perceived, a decision is made, a response is executed and finally a feedback is given; adapted from Wickens & Hollands [195]

Another information processing model that also describes the closed control loop for human-machine interaction, stems from Endsley [57]. It includes the term situation awareness in the information processing loop.

2.3.3. Mental Models and Anticipation

When humans deal with a system, a mental model, on how the system works in reality, is formed. This mental model is the basis for SA, a concept that describes how humans perceive the situations they are currently in and how their action will influence this situation. In the following section the concept of mental models as well as the concept of SA is described.

Mental Models When humans deal with a system, a mental model of the system and on how the system works is formed in their brain. Problems arise when the mental model and the real model do not match.
The term ″mental model″ is believed to be first introduced by Craik [42]. After a definition from Boer & Liu [23] , "a mental model is the internal representation employed to encode, predict, evaluate, and communicate the consequences of perceived and intended changes to the operator's current state within its dynamic environment". Mental models are based on a small set of fundamental assumptions which distinguishes them from other proposed representations in the psychology of reasoning [33]. To be able to capture mental models, their structure usually is much simpler than the real model. The gathering of environmental information via vision, audio and touch is necessary for humans to create a mental model. It also helps to identify and direct the human attention to the most important aspect of our surrounding. Norman [126] proposed that mental models are incomplete, unstable with no firm boundaries and that people's ability to ′run′ mental models are limited.

Anticipation A definition of anticipation can e.g. be found in Dahmen-Zimmer & Gründl [43]. It is described as the ability to predict changes and future states. Matched onto the automobile traffic, anticipation can be defined as the competence to correctly predict future traffic situations based on knowledge and current perception. In contrast to SA, anticipation relates to clear and stable and well visible stimuli and concentrates on the most possible development, whereas SA includes all potentially relevant stimuli, for example vehicles in the rear mirror (cf. Rauch [141]). During driving constant anticipation in a highly dynamic environment is necessary. The upper bound in which the driver is able to anticipate lies at about 10 s Time to Collision (TTC).

2.3.4. Mental Workload

Mental workload is an important concept in order to understand the limitations of the human when driving. It can be defined as the amount of (limited) resources one needs in order to accomplish a task. The finite resources can be concentrated either on one or on multiple tasks and workload is the amount of resources used [188].
If the demand on resources exceeds the available amount, performance declines or the human tries to adapt. The amount of workload depends on several factors, one of which is the skill level of the operator [104]: a more experienced operator needs less resources, which results in a low workload.

An important consideration regarding mental workload while driving is that lower does not automatically equals better. DeWaard [51] proposed six regions of demand and the corresponding workload and performance (Figure 2.5). In the first region D (for deactivation), high workload and low performance are the results of a monotonous task, which leads to a reduction of capacity. With an increase in demand (e.g. by "trying harder") the performance increases while the workload decreases (Region A1). With a further increase in demand in region A2, workload and performance are at an optimal level: the operator does not have any difficulties to perform his task. In region A3 the demand rises further which now leads to an increase in workload. The performance can be kept at an high level due to mobilizing extra effort. Finally, in region B and C the demand is too high which results in an high mental workload and decreasing performance.

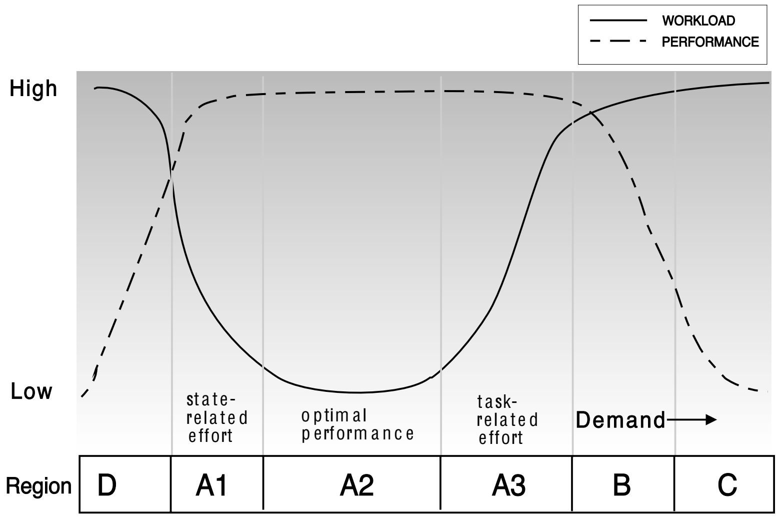


Figure 2.5.: Relation between demand,mental workload and performance. Categorized into six sections of demand. Optimal performance and workload only at perfectly balanced demand; form DeWaard [51]

In order to influence user interface design, it is necessary to measure mental workload. Several different techniques are possible to do so, from self-reported measures and performance tests to physiological measures. Kern & Schmidt [93] mentioned that "[i]ndependent of which kind of functionality is introduced into the car, the associated workload level (physical, visual and mental) has to be considered for safety reasons. Thus, new functionalities in cars should be as minimally distracting as possible".

2.3.5. Risk Assessment

Apart from workload, risk assessment is a key factor for decision making during the driving task. Risk can be defined as the possibility that an unwanted event occurs. Several different models try to explain how driver behavior is related to the perceived risk. Two prominent examples are the zero risk model by Näätänen & Summala [120], which proposes that the driver always tries to keep the risk at a minimum level, while the risk-homeostasis theory after Wilde [200] postulates that humans adapt their behavior in order to maintain a certain risk level. The risk-homeostasis theory applied to the automotive industry would mean that for every system that should increase the driver's safety, the driver would react with an increasingly risky driving style.
Although both theories are highly controversial, the risk-homeostasis theory is widespread in the automotive industry and among traffic safety officials.

2.3.6. Information Overload

How Much Information a Human Can Cope With A main challenge while driving on today's roads is the huge amount of information that is presented to the driver. Within a few minutes of driving, the driver is confronted with dozens of route guidance elements [105].

The result of this information overload is that the human driver sometimes is simply not able to cope with the amount of visual information presented to him. The reason for this limitation lies in the structure of the human brain, which can handle four [41] to seven [118] pieces of information at a time. Beside the information from road signs and the overall traffic, the driver receives information from different tasks inside the vehicle like controlling the air conditioning, navigation or discussion with other passengers. When the amount of information becomes overwhelming, negative effects on the driving behavior can be the result, which then can lead to slow driving, making late maneuvers, ignoring critical information and failing to monitor other traffic [105]. The solution to that problem is not to simply reduce the information, but to reduce the amount of perceived information by e.g. information clustering or presenting information in a way that is more easy to process. As Lerner [105] mentioned: "Information load is largely determined by what the driver does with the displayed information", meaning that it is not the amount but a combination of the amount, unfamiliarity and way of presentation which is responsible for information overload.
An overview of the amount of information and the sources of information are part of the following section.

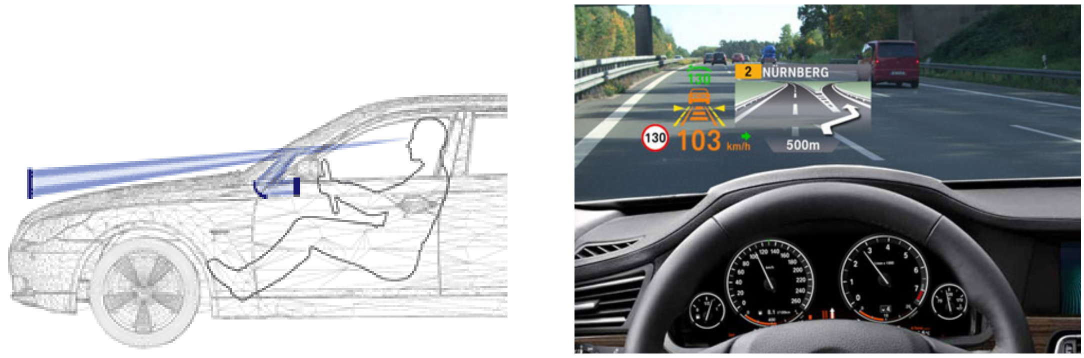
Displays Inside a Vehicle Information sources are not only signs and events on the streets, but also inside the vehicle. Due to the ever increasing amount of ADASs, more and more information about the vehicles' state is pouring onto the driver. Of course each information has a good reason to be displayed, but it makes the challenge even harder for the engineer, to present the information in a non-distracting manner to the driver.
In a modern vehicle three main types of displays are available. The instrument cluster (IC), the Central Information Display (CID) and the Head-Up Display (HUD). Although, the latter one is currently only available in a low number of cars, the HUD, as a display of the future, will be also be described in this paragraph.

Instrument Cluster Formerly two pieces of information were presented, in current production line vehicles the IC functions as a multi information display. Information ranges from the current speed, RPM, light and engine indictors, amount of fuel, remaining milage to handbrake status and many more. Information that is shown in the IC mainly concerns the secondary driving task, meaning information that supports the primary driving task. (cf. Chapter 2.4.1)

Central Information Display Information that is shown in the CID is mainly related to the tertiary driving task. A large array of information can be displayed. From the air-ventilation over entertainment-control to settings for the driver seat. Information that is presented in the CID does not primarily supporting the primary driving task. (cf. Chapter 2.4.1)

HUD Apart from the IC and the CID, the HUD is a the third possible display in today's vehicles. Although only present on a low number of current vehicles, this technology is a part of the future. The general concept behind the HUD technology, is to present the image in the direct field of view of the driver. This is achieved via an image emitting unit, generally integrated in the the vehicle's dashboard. The image then is reflected via mirrors and a virtual picture is generated at the end of the hood, which is about 2.2 meter in front of the

driver. Figure 2.6a illustrates the basic concept.
In current HUDs, mainly redundant content is visualized. In Figure 2.6b one can see BMW 2011 5 series HUD which shows the current speed, status of the Adaptive Cruise Control (ACC), speed limit information and navigational information.
The main advantage of the HUD is that the driver does not need to take his eyes off the road and, due to virtual picture, the eye of observer does not need to accommodate while getting this information. As one can see in Figure 2.6b the amount is already quite large while the usable space is limited.



(a) Abstract visualization of a reflections and virtual image of a HUD

(b) BMW 5 series 2011 HUD, visualization of speed sign recognition, ACC information, lane departure warning and navigation

Figure 2.6.: The HUD concept and possible visualizations in a BMW HUD

This paragraph provided an overview on the amount of information that is visualized inside the car and is available to the driver plus a rough overview on which display shows which information. Apart from information from displays it should be mentioned that other passengers can also be sources of information, too.

2.4. The Driving Task

After Deutschl [50], traffic is a system consisting of the environment, the driver and the vehicle. In this system, the driver determines the driving strategy including route, speed, lane, etc. according to the driving status and the environment. With the help of his controls (gas pedal, brake pedal and steering wheel) he implements his strategies. As a feedback he receives the vehicle's reaction with his senses and adapts his actions. This describes a similar control loop as previously mentioned in the Endsly model presented in Section 2.3.3. ADAS help to implement those driving strategies and can be seen as a form of automation in the Endsley model.
The driving task is a highly complex interaction between the human, a mechanical system (the car) and the traffic environment. Several different tasks have to be performed concurrently. This section describes the interaction between the human and the car, what tasks have to be performed and how they can be structured.

2.4.1. Modeling the Driving Task

Several different model exist that describe and model the driving task. A popular model by Geiser [74] divides the driving task into three different task categories. Differentiation is done after primary, secondary and tertiary task. Primary driving tasks are tasks that are absolutely necessary to drive (e.g. pushing the gas pedal and steering). These tasks are mainly influenced by the course of the road and the other traffic. Secondary tasks include tasks that support the primary tasks, like indication of way and blowing the horn. Tertiary tasks do not, or rather should not, influence the primary driving task. They include e.g. controlling the air condition and the radio. Toennis et al. [173] associate the different tasks with different regions of the dashboard as can be seen in Figure 2.7. Primary tasks are referenced outside the windshield, secondary tasks around the steering wheel and tertiary tasks around the center dash.

Figure 2.7.: Distribution of the primary (out the window), secondary (steering wheel & IC) and tertiary task (center dash) in a 7 series BMW, from Toennis et al. [173]

Another model by Bernotat [19] describes the driving task by dividing it into three stages, which can be seen as different control-loops the driver is in. These three stages are:

- **Navigation:** planing the route
- **Maneuvering:** deciding on the lane and speed
- **Stabilizing:** reacting to influences to get the vehicle back in the correct values.

Figure 2.8 shows the control loop of the driving task with the influences of the environment, a separation of the driving task into the three stages and the feedback from the vehicle. One also can see the three categories of the traffic system (environment, driving task and vehicle) and how they influence each other on the three different stages. For example, the road network (environment) influences the navigation stage of the driving task, as does the sight and weather with the stabilizing stage.
In this model the timing of the three stages is an issue, too. The navigational task is timed with t » 10 s, the maneuver task with t = 2-10 s and the stabilizing task with t < 2 s.

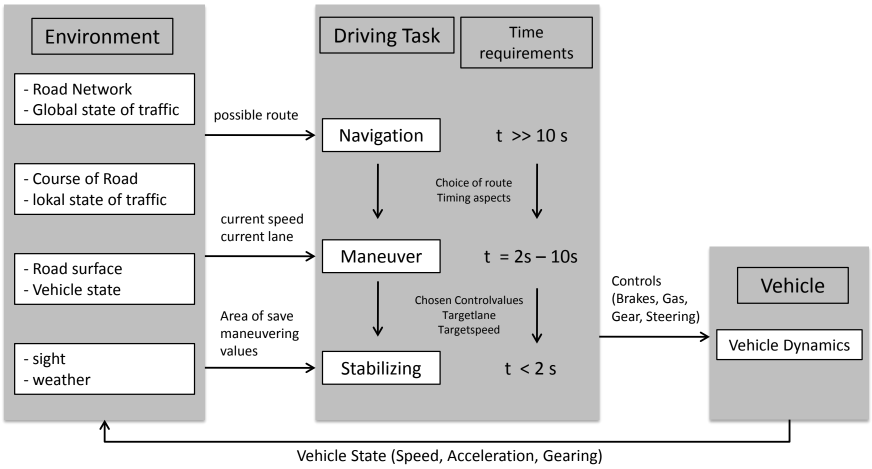


Figure 2.8.: The three layer model distributed over the environment, the driving task and the vehicle; Including timing aspects; after Bernotat [19] from Deutschl [50]

The model is based on a similar behavioral model by Rasmussen [140], which proposes that an action is either skill based, rule-based or knowledge-based. Skill-based behavior does not require cognitive effort, but signals are directly transferred from the input to an action. This behavior is not goal orientated and hardly any feedback is considered. Rule-based behavior are e.g. actions in familiar situations in which one recognizes the situation and choses the best strategy due to experience. On the last level, knowledge-based behavior, actions in an unfamiliar situation are executed. An abstract goal is set and different strategies are implemented in order to master the situation. Figure 2.9 shows the three levels and how action strategies are decided.

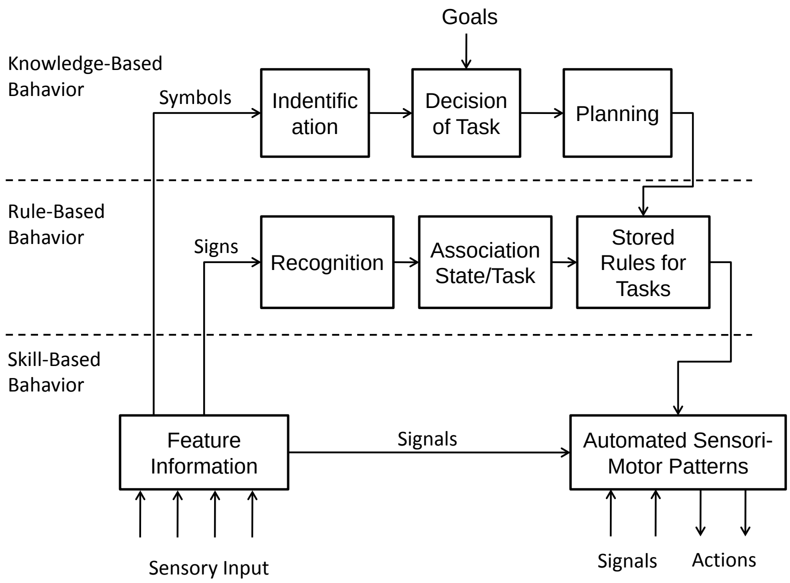


Figure 2.9.: Three levels of behavior; After a sensory input, action can either be skill-based, rule-based or knowledge-based, with differing amount of cognitive effort; after Rasmussen [140]

The three stages of the Bernotat model basically can be mapped to the three levels of the Rasmussen model, though as Table 2.1 shows there are deviations from this rule (Gründl [81]). On the navigational stage, the driver's performance is knowledge based: the driver has a set of strategies, like the knowledge of how to read road signs, and uses this knowledge in order to reach his goal. Actions on the maneuvering stage are rule based: the driver has still to think about what he is doing but situations are familiar and actions are chosen on previous experience. Finally, stabilizing the vehicle is performed with no cognitive effort and therefore on a skill-based level: the driver does not need to think when he adjusts the speed or bypasses an obstacle. Table 2.1 shows that this mapping is basically correct, but exceptions can be found. The daily navigation task when driving to the workplace for example can be classified as skill based due to the low cognitive effort that is necessary. Another example would be stabilizing a vehicle for a learner: a task which is not already skill based but still knowledge based.

	Skill-based	Rule-based	Knowledge-Based
Stabilizing	driving curves de-clutch	Driving an unknown vehicle	Learner in his first lesson
Maneuvering	Turning on a known intersection	Overtaking, lane change	Maneuvering on icy-roads
Navigating	Route used for daily commute	Choosing between known routes	Navigating in unfamiliar area

Table 2.1.: Mapping of the three stages model Bernotat [19] and Rasmussens [140] behavioral model on the task of driving, from Gründl [81]

2.4.2. Advanced Driver Assistance Systems

To prevent accidents, two different approaches are common: on one side, passive safety, which means doing everything to reduce the harm that results from an accident. The airbag and improving stiffness of the passenger cell are classical examples. On the other side is active safety, which includes all measures to prevent accidents from happening in the first place.
Figure 2.10 shows the three parts of the traffic system (the environment, the driver and the vehicle) and explains where and how a driver assistance system is integrated in this system. The system lies parallel to the driver between the environment and the vehicle. Like the driver, it gets information from the environment via sensors and sends actions to the vehicle via actuators. Also sensors are used to receive feedback from the vehicle. A MMI, which can be visual, auditory or any other modality is used to inform the driver and receives inputs from him.

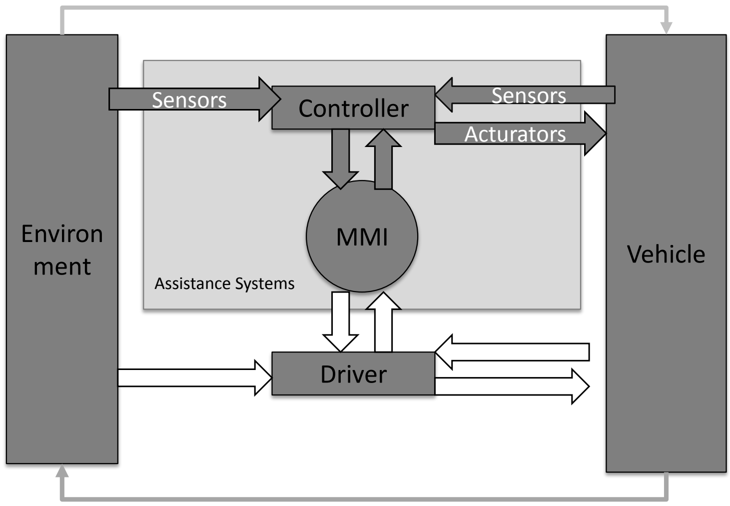


Figure 2.10.: Control Circuit ADAS: displaying the function and interaction of an ADAS between the environment, the MMI, the driver and the vehicel; from Deutschl [50]

Definition Due to the multiple nature, functions and aspects, it is hard to find a simple definition of driver assistance systems. Driver Assistance Systems have the goal to support the driver in the primary driving task. They should increase comfort and reduce workload by stabilizing or maneuvering the vehicle. ADAS are a subset of driver assistance systems and are characterized by the following properties (from Schwarz [155]):

- Provide active support for lateral and/or longitudinal control with or without warnings
- Detect and evaluate the vehicle environment
- Use complex signal processing
- Direct interaction between the driver and the system

Goals of ADAS The primary goal of an assistance system is to assist the driver. Deutschle [50] in his work mentions that not only elderly drivers have problems with controlling the car. Fastenmeier et al. [65] stressed that a lag of information can be observed. Therefore, an abstract goal of ADASs can be defined as: reliefing the driver and counterbalancing deficiencies. ADASs often target special groups like older or unexperienced drivers, who often have difficulties in controlling the car. After Deutschle [50], goals for ADAS are: **Increasing driving comfort:** The driver should be supported in monotone and boring driving tasks. Adaptive Cruise Control (ACC) and the navigation system are good examples. The saved mental resources are available for other tasks like the observation of other traffic. **Increasing traffic safety:** ADAS like anti-lock braking system (ABS) and Dynamic Stability Control (DSC), interfere at the stabilizing level and partially or fully take over the control of the vehicle. The driver himself does not necessary has the possibility to switch those features on or off. **Increasing traffic efficiency:** Car2X information or up to date digital maps can be used to prevent traffic jams and provide a better overall flow and usage of the road network. **Increasing fuel efficiency** by providing the driver with information that s/he can use for prospective driving.

Classifications of ADAS Classification of ADAS again has multiple possibilities. In this section possible classifications after the three stages of Bernotat, the degree of automation and timing are presented.

Classification: Degree of Automation A definition by Parasuraman & Viktor [131] stated that automation is the execution of a function by a machine agent that was previously carried out by a human. There are different degrees of automation from information, warning, partial automation to full-automation. A detailed definition on automation as well as a detailed description of the different automation level can be found in chapter 7.1.

- **Information**: The assistance system gets the information, and provides the user with additional information. The reaction and interpretation of the information is left to the user, s/he can decide whether or not to react on the information that was given.
- **Warning**: The assistance system gets the information, analyses it and provides a course of action for the user. If and how to implement the warning is left to the user.
- **Partial Automation**: The assistance system gets the information, analyses it and partially implements the strategy.
- **Full Automation**: The assistance system gets the information, analyses it and fully implements the strategy. Autonomic driving is not included.

Another possibility to classify ADAS is the stage in which they assist the driver. A classification of existing ADAS according to their automation degree and the three stages of Bernotat can be found in from Gründel [81].
Classification after timing is not a complete different type of classification, as the timing aspect can be included in the Bernotat model (Figure 2.8). The timing with $t < 2$ s, $t = 2\text{-}10$ s and $t > 10$ s can be seen as different measurement for the three stages.

3. Approaches to Reduce Fuel Consumption

Systems to support the driver in anticipatory driving. From a rulebook for the driver to highly automated longitudinal control.

The personal vehicle is an important factor in today's society, not only is it a status symbol but also the perfect personal transportation for a majority of people. Depending on which source one refers to, there are around 900 million cars in the world, and the emitted greenhouse gases are a huge problem. 900 million just equals 13% of the world's population of 6.5 billion. An increase to 1.2 billion in 2020 and to 1.6 billion in 2030 is expected [170]. Today the transport sector is responsible for ca. 15% of all greenhouse gases emitted and for 20% of CO2 emissions [1] (23.1% of CO2 emission within the EU-27 in 2010 [63]).
We as a society have the responsibility to leave the planet in a livable state for future generations. Therefore, possibilities to reduce the greenhouse gas emission in the transport sector need to be explored. The following chapter shows want kind of countermeasures can be realized in order to reduce fuel emissions.
The main target for decades was to reduce fuel consumption by improving efficiency in the powertrain. Another possible approach is targeting the driver, respectively the driving style, which has a huge potential to reduce fuel consumption. Both approaches will be presented in this chapter and results with attention on the latter will be given.

3.1. The Car - Improving Efficiency at the Powertrain

Over the past two decades, a lot of money was spent and research was done to lower the vehicle's emission by reducing the amount of fuel the combustion engine uses. Different segments of the vehicle have been improved, from an aerodynamic design, more efficient combustion engines to the recuperation of the the brake and the exhaust energy.

3.1.1. Approaches

Over the last ten years overall fuel consumption decreased by 40% [170], mainly due to engine combustion efficiency, transmission efficiency and road load. A lot of different approaches were responsible for achieving that goal. Main targets for reducing energy losses in the car are: air resistance, coasting resistance, heat loss in the combustion engine, energy loss in the powertrain, acceleration and braking as well as additional consumption like lights, air conditioner or heating. Thermal energy loss lies between 65% and 75% during normal driving with a theoretical minimum of 40%. Other attempts are the recuperation of lost energy. Stribrsky et al. [167] e.g. tried to recuperate energy from the suspension, as 2.1% of the energy is lost this way [144]. Others like Frank [68] explored an exhaust recovery system and achieved about 7% of fuel reduction.

3.1.2. Conclusion

A lot of improvement in fuel consumption has be achieved using technological advances and new possibilities. It has to be said, that realizing each of these measures is an expensive and long taking adventure and of course all these measures are not helping to reduce the emissions by the vehicles that are already on the streets. Figure 3.1 from Reichart et al. [142] shows the fuel reduction potentials that are possible in conventional fields like the powertrain and driving resistance as well as in potentially new fields, like route planning and driver behavior. For example up to 45% of fuel can be saved by targeting the driver and his driving style.

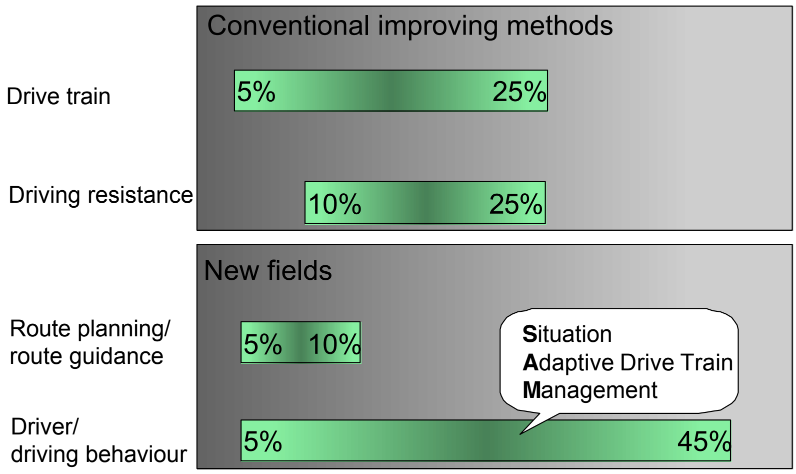


Figure 3.1.: Conventional and new fields of fuel reduction possibilities, showing huge energy saving possibilities at the driving behavior; from Reichart et al. [142]

3.2. Fuel Saving Systems - From a Rule Book to ADASs

As one can see in Figure 3.1 a large potential in fuel saving lies at the driver or to be more precise, in his driving behavior. Several attempts were made to impose fuel efficient driving behavior. Low-tech attempts to achieve better fuel efficiency can be summarized as a "non-assisted rule book", meaning to assist the driver by given him a set of rules to follow in order to drive more fuel efficient. EcoDrive [25] is an example for such an attempt and included tips concerning anticipation, gear changing, trip preparation, cruise instead of brake and many more.

One problem concerning those tips is that the driver is left alone to implement them as well as situations in which the driver cannot be sure about the right action to perform. These and other problems can be approached by using ADASs to assist the driver in driving environmentally friendly. The following section does provide an overview on some technological advanced systems that are able to support the driver in ecological driving.

3.2.1. Situation Adaptive Drive Train Management - SAM

"Situation Adaptive Drive Train Management" (SAM) is a system proposed for the BMW AG by Neunzig & Benmimoun [122] and Dorrer et al. [55] that provided longitudinal drive train decisions by scanning the environment in front of the vehicle and evaluating the information. Possible information sources for the system were digital maps or information from the ACC sensors. Having used that information, a virtual piece of street was generated, which stored all relevant information along the upcoming road. Depending on the driving situation, the system realized an appropriate strategy. During **constant driving**, the system just chose the most energy efficient gear; during **deceleration** the system took several factors into account to calculate the earliest possible point of deceleration in order to take advantage of the longest possible coasting time. Deceleration was mentioned as the driving situation with the most fuel saving potential. During **acceleration**, the system tried the keep the gas pedal in the most energy efficient position. Finally, a start-stop automatic was realized during **stand-still**.The communication of the strategy was realized via an active gas pedal and a display for visual feedback.
Depending on the driving situation, different results were achieved. For a downhill drive the saving potential lied between 15-45% due to the utilization of coasting time. In a distinctive altitude profile the results lied between 0-25%. During acceleration with a subsequent use of a slope, a fuel saving potential between 5 and 15% was observed. The same results were observed with deceleration and utilizing increased altitude for prospective braking. During a common drive, fuel saving between 5-12% was shown [122].
Another interesting work done by Reichart et al. [142] is the classification of different deceleration situations. Figure 3.2 shows different situations and their categories and how the information can be obtained. The two categories are object location, which either can be fixed or variable and speed to aim for, which also can be either fixed or variable. Situations with fixed speed and fixed location are the least complex situations as they are the simplest to react to. These situations are also simple to detect e.g. by utilizing information from digital maps. Situations with fixed location and variable speed can also be located by the use of digital maps, but Car2X communication or advanced camera systems are necessary to detect the variable speed. The last type of situation with variable location and variable speed is the hardest to detect and all information of location and speed must come from either the Car2X infrastructure or camera systems.

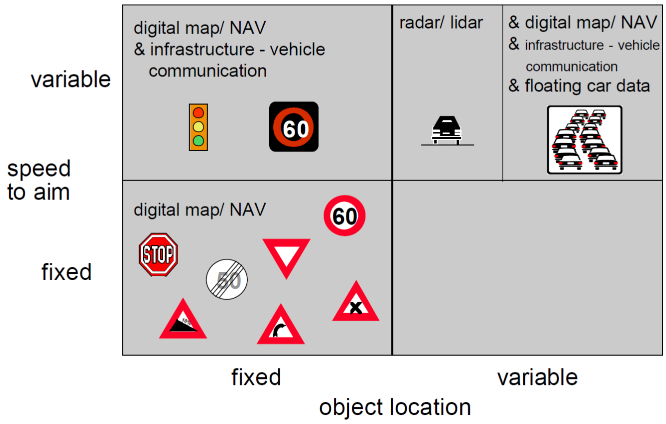


Figure 3.2.: Classification for deceleration situations with two dimensions: speed to aim (variable & fixed) and object location (fixed & variable) by Reichert et al. [142]

Reichart et al. [142] concluded, that "[a]ll these individual situations affect driving in some way, and many of them interact to create particular driving behavior. The driver does an incredible job of dealing with all these different factors at the same time. So it is a demanding but necessary task to offer additional advantages to the driver using this system. The only way to do so is to extend the detection and situation processing facilities beyond the driver's visual horizon".

3.2.2. Prospective Consumption-Assistance

In another work, Samper & Kuhn [147] researched the possibilities to "Reduce the Fuel Consumption of a Passenger Vehicle Using a Forward-Looking Assistant". The objective of the project was to analyze an assistance which computes the best and therefore most energy efficient driving strategy for the upcoming road. Hereby the main focus was the development of a user interface to communicate the strategy to the driver and enable him/her to implement the suggested strategy.
Three different visualizations were realized and can be seen in Figure 3.3. The deceleration phase was broken down into three sub-phases: Initiation of the situation, coasting and signaling the end of the situation. All three visualizations were realized in the speedometer. In variant MMI1, flashing LEDs on the speedometer indicated the start of the deceleration phase. During the deceleration phase just the current speed and the target speed were indicated and when the target speed was reached, the ring around the speedometer flashed two times. In variant MMI2, the indication for the start of the deceleration phase was realized using the active gas pedal, the other two phases are similar to the first version. In the third version (MMI3) the indication also was done via the active gas pedal but in contrast to the second version the regulation object (60 km/h speed limit sign in case of Figure 3.3) for deceleration is also indicated.

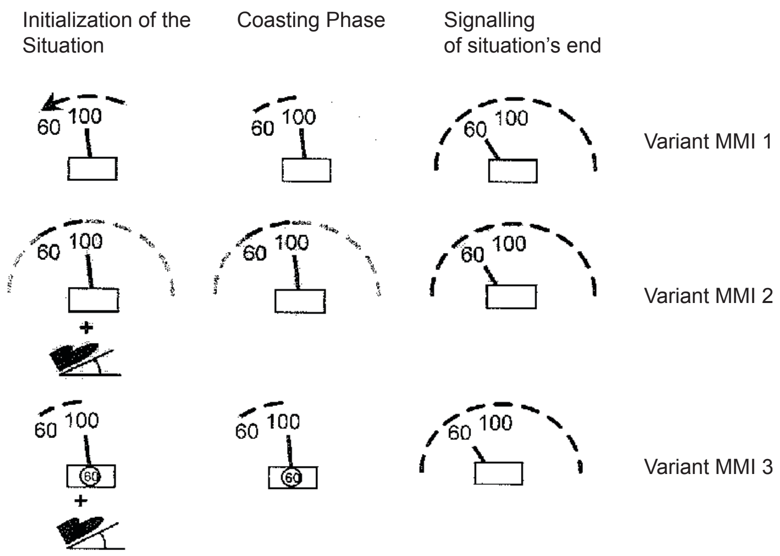


Figure 3.3.: Three MMI variants for assisting the driver in early deceleration. Indication in the speedometer and two variants with the support of an active gas pedal, by Samper & Kuhn [147]

Results showed that using a visualization did result in improved fuel consumption and longer traveling time. In the pure visual version (MMI1) energy saving was 7% compared to the baseline and traveling time increased by 2.5%. In contrast to that, results with the active gas pedal showed an increase in fuel efficiency by 10% and an increase in traveling time by 4.3%. Samper explained this difference between the versions by the reaction time of the driver on the MMI indication, which was 2.3 seconds with the pure visual version (MMI1) and just 0.7 seconds with MMI2 and MMI3. Other interesting results were the fact that subjects did find the visualization of the regulation object (MMI3) useful, but a trend was shown that the coasting time was too long. The overall acceptance of the system was good, the MMI concepts were well visible, understandable, self-describing and neither distracting nor annoying. The versions with the haptic feedback were described as less distracting.

3.2.3. Fuel-Efficency Support Tool - FEST

In a work by van der Voort & van Maarseveen[178] and van der Voort [177], a system called Fuel-Efficiency Support Tool (FEST) was implemented to support the driver to drive fuel efficient. The System consisted of three major components: inputs, a data processing module and an HMI. Input data was separated into two categories: The first category was "measured inputs" like vehicle speed, engine speed, gas pedal position, etc. The second category included engine related parameters (like fuel consumption map, engine characteristics, etc.) and driving behavior related parameters (speed limits, how long an advice should be displayed, etc.). The data processing module was based on a concept called normative model. It described the optimal behavior in each driving state (costing, idling, decelerating, acceleration, gear changing).
The HMI consisted of a small TFT monitor, where detailed advice was given to the driver. An advice would e.g be "Shift earlier from the 2nd to the 3rd gear".

Results of a study conducted in a driving simulator showed that 16% overall fuel reduction was achieved with 23% fuel reduction in an urban environment. In a subsequent field study with 36 subjects over a 2.5 day period, 11% fuel reduction for the total trip was achieved and 20% fuel reduction in an urban environment. Using the FEST did put an additional demand on the subjects but did not "exceeded the level of rather present mental effort" [177]. Van der Voort concluded that using the FEST is save to be combined with the driving task. Another positive effect was a smoother driving and that subjects anticipation towards the oncoming traffic situation did improve, which was concluded due to no quick variations in speed. In the driving simulator the FEST also had the effect that small TTCs were reduced.
Van der Voort concluded that the FEST is an efficient system with the ability to reduce fuel consumption. The increase in fuel saving within an urban environment is an interesting effect and stands in contradiction to the potentials calculated by Reichart et al. [142] (Figure 3.1) which shows a large potential of distant situations, typically not associated with an urban environment. This might be explained by the the system itself which does not include far reaching sensors, but just vehicle internal parameters.

3.3. Route Planing

A very different part of driving with fuel saving potential is route planing, which corresponds to the navigational stage of the Bernotat model.

3.3.1. Road Traffic Prediction

In a work by Dong et al. [54], the objective was to support route planing by improving traffic state prediction, using a maximum entropy (ME) approach. This was achieved by dividing a traffic state into six levels, which described the degree of utilization of a road. The level ranged from A: minimum degree of utilization (vehicles do not get close to each other) to F: The capacity of the infrastructure is not enough (traffic jam). He then used a ME model to predict the future level. Results showed about 77% accuracy for both five and ten minutes prediction time.
Although this work does not provide any feedback to the driver, the work can be used as an information source for an on-vehicle system by providing fuel saving information to the driver.

3.3.2. The Most Fuel Efficient Route

The effects of a fuel efficient route were evaluated by Ericsson et al. [61]. In her work she evaluated 109 trips with a duration greater than five minutes. Then, a comparison between the most fuel efficient and the actual route was performed. Results showed that in 46% of all cases, the driver did not take the most fuel efficient route and that an average of 8.6% of fuel could have been saved by choosing the most fuel efficient route. Ericsson also found out that the less disturbances (e.g. stops that exceed 80s), the less fuel saving potential the drive has. Therefore, she concluded that "real-time traffic information has the potential of fuel-saving in more congested areas, if a sufficiently large proportion of the disturbance events can be identified and reported in real-time".

This sections provided an overview about what research has been done to reduce fuel consumption in the route planing phase. Of course measures in this phase are different from measures on the maneuvering stage. The work presented, can be seen as an information source for on-vehicle systems.

4. Creating a Suitable MMI for Supporting Prospective Driving

Choosing a proper visualization for assisting prospective driving. The viewpoints decides on local guidance or global awareness. The tethered Bird's eye view as a solution.

The Car2X infrastructure will allow us to enlarge the driver's visual horizon to an electric horizon. This information has a lot of potential and can be used for different applications. As mentioned in Chapter 3.2.1 far reaching information can be especially useful in early deceleration situations in order to improve fuel efficiency. As the visual channel is already heavily in use during the driving task, it is necessary to design an interface appropriate for the task and suitable for the human operator. In the following chapter guidelines and principles from user interface design as well as guidelines for developing automotive user interfaces will be an issue. Conceptional work for a visualization that is able to support the driver in early deceleration will be shown and design rationales will be explained.

4.1. Background

When creating an MMI, the superior principle is: the display and the controls have to fit the task [29]. To achieve this abstract goal, it is necessary to incorporate human capabilities, characteristics as well human limitations into the design. Guidelines and engineering standards help to develop and realize user interfaces.

4.1.1. Guidelines

Designing a display means to deal with guidelines, engineering standards and principles. Often, these guidelines are not a simple rulebook to follow but have to be adapted to fit the needs. This section gives an overview on existing guidelines, which are applicable when designing an user interface. Not all of the guidelines are adoptable when designing an automotive interface, but often the idea behind it can give us a good lead on what to do and, sometimes even more importantly, what not to do.

Thirteen Principles of Display Design To start off, thirteen principles by Wickens et al. [196] are introduced. These are principles for display design and are categorized into four main categories: perceptual principles, mental model principles, principles based on attention and memory principles. These principles are often not directly relevant for the development of an automotive display, therefore, only selected principles are described in detail, the rest can be found in Wickens et al. [196].

Perceptual Principles: Five principles deal with perceptual aspects. One principle states **"Make displays legible or audible"**. A display's legibility is critical and necessary for designing a usable display. If the characters or objects being displayed cannot be discerned, then the operator cannot effectively make use of them.
Another principle is called **"Top-down processing"**. It states that signals are likely perceived and interpreted in accordance with what is expected, based on a user's past experience. If a signal is presented contrary to the user's expectation, more physical evidence of that signal may need to be presented to assure that it is understood correctly.
"Avoid absolute judgment limits": Instead of showing gradually changing colors, it is better to show discrete changing of colors (e.g. 5-7 distinct level) in order to be easy distinguishable.
"Redundancy gains": In poor perceptional conditions, information is more likely to be interpreted correctly when presented more than once.
"Similarity causes confusion": When two pieces of information are presented in a similar way, information is likely to be confused. For critical information designers should eliminate similarities as much as possible.

Mental Model Principles: One basic principle for display visualization is Wickens' guideline of display compatibility [191], which states that there are three levels of presentation that must be compatible for a proper interaction. These three levels are the physical object, the mental representation (mental model) and the interface between those two. If this precondition is fulfilled, it is possible to predict the future state of a system [76].
The principle of pictorial realism and the dynamic properties of motion are two important aspects to be considered when creating a display.

- **"Principle of pictorial realism"**: A display should look like the variable that it represents (e.g. high temperature on a thermometer shown as a higher vertical level). If there are multiple elements, they can be configured in a manner that looks like it would in the represented environment.
- **"Principle of the moving part"**: Moving elements should move in a pattern and direction compatible with the user's mental model of how it actually moves in the system. For example, the moving element on an altimeter should move upward with increasing altitude.

Principles Based on Attention: Three principles are considering the human attention capabilities. **"The proximity compatibility principle (PCP)"** is a principle by Carswell & Wickens [36] which describes how a multitude of information can be represented to be easily mentally integrated in order to perform a certain task but still be able to be separately accessible. There are different possibilities to support that ease of mental integration (to reduce the information access cost): One is by display proximity, meaning to represent associating information as closely to each other as possible (high display proximity helps to achieve a task with high mental proximity). Another option is the use of color, shapes and orientation. With the use of PCP it is possible to access all the system's dimensions at the

same time, e.g. reading the value of a certain gauge while being able to tell the overall system status. A problem that can arise is display clutter.
Other principles based on attention are: **"Minimizing information access cost"** and the **"Principle of multiple resources"**.

Memory Principles: Finally, three principles are memory principles. The **"Principle of consistency"** proposes that old habits from other displays will easily transfer to support processing of new displays, if they are designed in a consistent manner. A user's long-term memory will trigger actions that are expected to be appropriate. A design must accept this fact and utilize consistency among different displays.
Other Memory Principles are: **"Replace memory with visual information"** and the **"Principle of predictive aiding"**.

When reading these principles, it rapidly becomes clear that most often it is not possible to fulfill all the guidelines mentioned above. Some of the suggestions even are contradictory.

Eight Golden Rules of Interface design Another guideline comes from Shneiderman, found in Shneiderman & Plaisant [158] and consists of eight golden rules of interface design. These rules are more applicable to computer user interface design e.g. designing a website, but three of the eight rules can also be of help when designing an interface for an ADAS. Following, these three rules are presented (Shneiderman & Plaisant [158] p.74-75).

I. **Strive for consistency**: "Consistent sequences of actions should be required in similar situations; identical terminology should be used in prompts, menus, and help screens; and consistent commands should be employed throughout".

II. **Offer informative feedback**: "For every user action, there should be some system feedback. For frequent and minor actions, the response can be modest, while for infrequent and major actions, the response should be more substantial".

III. **Reduce short-term memory load**: "The limitation of human information processing in short-term memory requires that displays be kept simple, multiple page displays be consolidated, window-motion frequency be reduced, and sufficient training time be allotted for codes, mnemonics, and sequences of actions". Especially Miller's [118] magical number seven has to be taken into account.

The other five rules: **"Enable frequent users to use shortcuts"**, **"Design dialog to yield closure"**, **"Offer simple error handling"**, **"Permit easy reversal of actions"**, **"Support internal locus of control"**, are not applicable for an information presentation display but rather for an interactive system, which in the automotive environment can e.g. be the entertainment system.

4.1.2. The Automotive User Interface

All the guidelines just mentioned are generic guidelines for display development. In this work a display for a specific domain, the automotive environment, is developed. Therefore,

it is necessary to have a closer look at specific requirements of that domain. The following section provides an excerpt of the challenges and special requirements of the task to develop an automotive user interface.
As Schmidt et al. [151] stated, the automotive interface is a special interface. The main aspect that makes the automotive interface special, is the context, which does not allow a trail and error principle (like e.g. in the computer software domain) but requires to be spot on the first time, with the possibility of dramatic effects in case of a failure. Therefore, it is not only a matter of faster performance and likability to provide an intuitive and failure robust display but sometimes a matter of life and death.
Another aspect to consider is the user of an automotive interface. S/he usually performs several tasks at once. Interacting or even just looking at the interface is not the most important one. Hence, an important question for the designer is how to present information to the driver and what impact this information has on the driver and his primary task - driving. Having additional information available for the driver most of the times puts additional cognitive load on the driver. Therefore, it is necessary to trade the possible additional traffic safety against the possible additional cognitive load and decide, whether it is possible for the driver to handle the additional load and what benefits s/he has on it.
Another important aspect is the modality of the interface: 80% of all information a driver receives, is received via the visual channel. Hence the question is: How much more attention from that channel should be used to transport more information?
Furthermore, a special challenge for the automotive user interface designer is the global focus of the industry. This makes it necessary to include cultural differences into the interface design. Possible differences that can effect the interface design range from different reading direction to different meaning regarding certain colors (Krum et al. [99]). Also due to the international focus, the problem of international variety arises: e.g. different roadways traffic patterns, legal issues or different traffic signs. Finally, different social attitudes have to considered, like the attitude towards automation, where one nation does not have a problem with a parallel parking assistance while the other might feel offended.
Different OEMs and designers of devices, like navigation systems or mp3 players, influence the automotive user interface. And, last but not least, the context in which the driver uses his car, commuting or pleasure, makes the development of an automotive user interface especially challenging.
Again guidelines and evaluations can help to rule out bad user interfaces and provide a good possibility to design a system that makes driving safer while at the same time considering all the user's needs.

Guidelines on How to Develop an Automotive User Interface From the "Handbuch Fahrerassistenz" [29] a set of guidelines can be found on how to successfully develop an interface for the automotive environment. These are not a completely new set of guidelines but a combination of guidelines fitted to the automotive environment.
The six ergonomic **goals**, summarized in DIN EN 894-1 [49], describe how an interface should be designed. It starts off with the principle that an interface should be **task suitable**, meaning that an interface has to be suitable to assist the user to achieve his task in a safe and effective manner. This includes aspects like display and control grouping to achieve ease of use. Other aspects to consider when making a display task suitable are the consideration of complexity, which should be kept as low as possible and a reasonable distribution

of tasks between human and machine.
The norm also states that a display should be **self-describing**. This means that a human should not only receive the information that a display visualizes, but also should be able to understand the system behind it; this way the user can cope easily with new situations. The guideline that an interface should be **controllable**, means that the human should be able to control the machine and should not have the feeling that the machine controls him/her. Principles that help to achieve this guideline are: All controllers and switches should be easily accessible for all kinds of user. Also, the option for additional displays should be provided. Another important guideline is that the **expectation of the user should be met**. This means that the expectation a user has from former use of a system or training should be met. Consistency between the elements can help to achieve this. **Error robustness**, meaning it is possible to reach a goal despite a faulty input or with only a small correction demand, is also a useful guideline to achieve good interface design. Due to the fact that interaction with the system is not the primary task of the user, this guideline is of great interest when it comes to interface design in the automotive environment. Finally, a user interface should be **adjustable and learnable**, meaning it should have the possibility to adjust to the user's needs. For example an ADAS should be able to adjust automatically or by the user to suit his way of driving.

To achieve these goals when developing an automotive interface, design principles can be useful. Bruder & Didier [29] mentioned six principles:

I. **Compatibility**: Spatial, motion and conceptual compatibility are three compatibilities that support human information processing. If these compatibilities are met, the perception, cognition, memorization of and reaction to an information is easily achievable. An example for this would be the increase of a value when turning a controller clockwise.

II. **Consistency**: Consistent composition of the interface supports the information processing process. Results are faster learning, less errors and faster task accomplishment. For example, an action should have the same effect with no concern in which submenu one is.

III. **Spatial Alignment**: Objects with the same content or function should be grouped. It is also of concern, how often an item is used and in which sequence the actions are performed. The use of the different possible displays in the car can help to distribute the content in a better way.

IV. **Balanced Workload**: Especially important for the task of driving is a balanced workload (as already mentioned in Chapter 2.3.4). An ADAS should relieve the driver in mentally demanding situations. Important when designing the interface for an ADAS is the counterbalance between mental overload and underload. An important aspect is that the driver still should be informed about the action of the ADAS.

V. **Joy of Use**: "If joy of use is given, acceptance will follow", is a simple principle but sometimes hard to follow. Especially when it comes to safety critical systems, joy of use often is not the number one priority. Nonetheless, it is important not only to have a driver working place but a driver experience place.

VI. **Consideration of the Complete System**: Within the last years the number of possible ADASs dramatically increased and the Car2X infrastructure will bring even more systems into the vehicle of tomorrow. One main problem is that it is not possible to have a separated display and control for each of those systems. Therefore, the integration of systems will become a main task for the future development of ADASs.

On one side, the principles just mentioned are of course not true exclusively for an automotive user interface, but can also be found in other areas as well. For example, the principle of consistency can also be found in Ben Shneiderman's eight golden rules for user interface design. On the other side, the last three guidelines are focused on the automotive environment. Finally, Bruder & Didier [29] gave a guideline on how to develop an automotive display, as can be seen in Figure 4.1.
The first question to be answered is: What **requirements** does a display have and for what purposes the display is used? Possible purposes could be the surveillance of a value or the control of an input. Aspects like accuracy of information, content of information and amount of information should also be defined in this stage. Afterwards, the question of **modality** should be answered, with the different channels of the human of consideration. Aspects like channel usage, differentiability, reaction time and acceptance should be taken into account. After the modality is decided, the **type** of information that is presented is of question. Here, the human abilities should be the basis for the information presentation. The choice between analog and digital, between sound and language should be decided. **Information assignment** is the next step, in which physical or functional similarities should be considered when assigning information to specific displays. After that, in the **alignment** step, it is necessary to align the displays in a way that differentiability and error prevention is considered. The displays also should integrate well into the overall environment. Last, the **level of detail** of the display design needs to be worked out. This concerns elements like contrast, font size, color and frequencies. Again, ergonomic guidelines can help in this stage to make the best design choices.

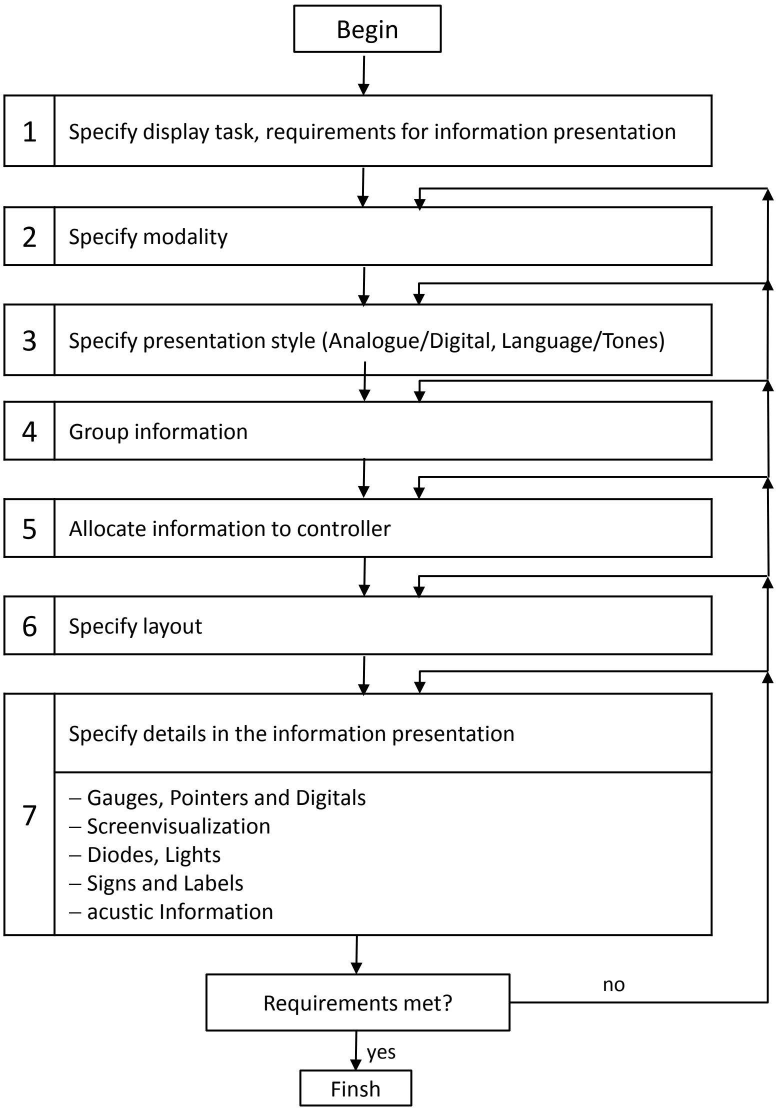


Figure 4.1.: The process of creating an automotive user interface in seven stages, form defining the requirements to implementing specific details; by Kirchner & Baum [94]

4.1.3. Colors in the Automotive Context

Usually, colors in a visualization make an image more vivid. When it comes to information visualization, colors do also have the purpose to highlight certain information and improve overall readability. When choosing the right colors for information visualization in the automotive context even more considerations have to be made. Apart from a nice look and improved readability, colors in the automotive environment also serve the purpose of indicating safety status. A typical example would be the color red, which in the traffic environment represents "danger". This, in combination with the fact that the automotive industry is a global, and therefore, multicultural industry, makes the usage of colors in an automotive visualization specially challenging.

ISO Norm 2575 [47] states under the use of colors in an automotive visualization the following: "The colors red, yellow and green have predefined meaning and can be used as optical indicators or tell-tales." The meaning of these colors are:

- "**Red**: danger to person or very serious damage to equipment immediate or imminent"
- "**Yellow** or **amber**: caution, outside normal operating limits, vehicle system malfunction, damage to vehicle likely, or other condition which may produce hards in the long term"
- "**Green**: safe, normal operating condition (where blue or yellow is not required)"

Colors for specific tell-tales are:

- "**Blue**: e.g. headlight (main) beam"
- "**Green**: e.g. turn signals"
- "**Yellow**: e.g. failure of anti-lock braking system"
- "**Red**: e.g. hazard warning"

The same ISO Norm also states that the color **white** should be used where none of the above mentioned conditions apply and that the colors green, yellow and red "are also required for other tell-tales by various countries".
DIN EN ISO 15008 [48] gives guidelines to color-combinations and color differentiation. Considering color-combinations the norm gives guidelines on which combinations should be used and which should be avoided. The recommendations are due to physiological reasons. For example a "very good" combination would be white/black or white/blue, "good" combinations are red/black, green/black or yellow and blue and finally "not acceptable" combinations would be yellow/white, red/yellow or orange/blue. The norm also states that pure red and blue should not be used, due to a possible focusing problem of the eye. As for the differentiation of the colors, the color difference must be at least $\Delta E_{UV} = 20$. This value is on the basis of color differentiating matrix after the Norm CIE 1976 color space model CIELUV [45].

State of the Art Colors in Automotive Environments Regarding the automotive user interface a lot of examples can be found, which use various colors in accordance to the above mentioned guidelines. A good example is BMW's I-Brake symbol [22], a red car flashing when the car detects a potential frontal crash scenario, or the red blinking engine symbol, which indicates an engine failure [22]. Regarding research, Spies et al. [164] presented a survey on the braking bar, they use the colors green and red to indicate either an acceptable or unacceptable distance to the preceding vehicle.

4.1.4. Animation in the Automotive Context

Animation in an automotive interface is a difficult topic. On the one hand, animation in user interface design is promoted to improve the system's usability. On the other hand guidelines ([56], [62]) recommend that no animation should be used in vehicles and that a system should not entertain the driver.

Related Work - Animation Broy [28] investigated animation in an Information Visualization System (IVIS). The results showed that there is no evidence that animation per se can be considered distracting regarding lane deviance and view distraction. Overall, subjects preferred a system with animation over a system without animation, but while some found it helpful, some perceived it as distracting. Considering an animation in an IVIS, results showed that the time for an animation was considered crucial, and should be around 300 ms.
Milicic [117] used animation in a HUD to guide the users' attention. The length of the animation again was 300 ms. Results showed that all but one subject (35 subjects total) did like the animation.
Even though animation, in current guidelines, is not considered as useful, there is evidence that animation can be used even in the automotive environment. However, it should be applied with care.

4.2. Related Work

When designing a new interface it is not enough to look at the state of the art, but it is necessary to enlarge one's horizon with research and work from other fields of research. This section should gives an overview on work and influences that were of consideration when developing a user interface to assist early anticipation and improve fuel efficiency.

4.2.1. The Predictive Display

Not only in automotive traffic, good anticipation and early actions are of advantage. The nautical and the aviation industry have to deal with the same problems. Especially in the nautical industry with slow reaction times and long braking distances, a good anticipation is of value. The following related work about nautical and aviation visualization (Chapter 4.2.1.1 and chapter 4.2.1.2) was mainly researched by my predecessor in the ISPA project Prof. Dr. Simon Nestler.

4.2.1.1. Nautical Visualization

Sullivan et al. [168] have researched the support potential of a predictive display. The display showed the helmsmen the actual position and the predicted position in ten seconds time (Figure 4.2). In an experiment, novice and experienced helmsmen were tested in the task of steering a pre-defined figure-of-eight course. The dependent variable was the deviation for the ideal line.

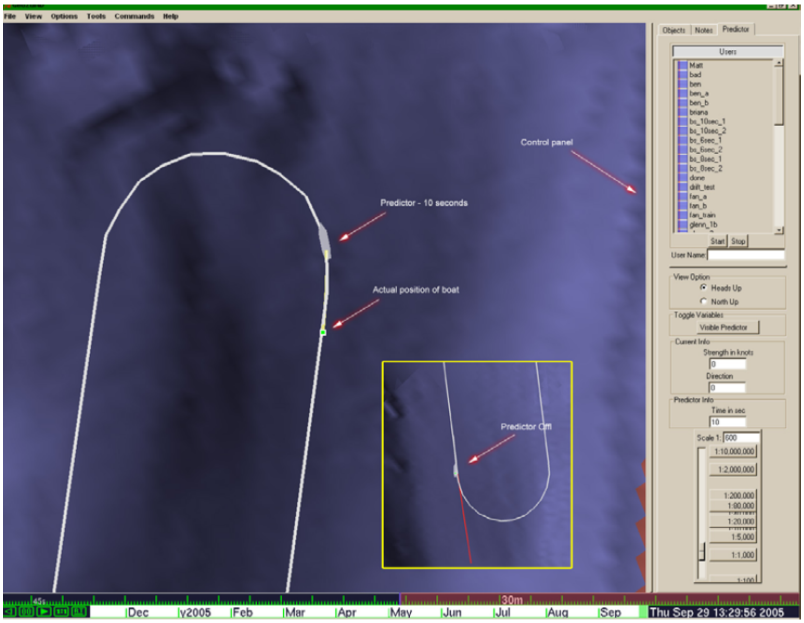
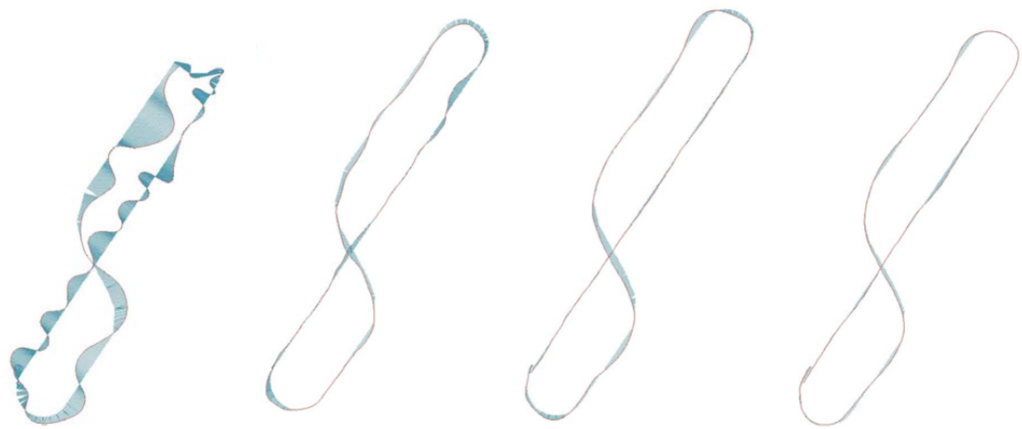


Figure 4.2.: Predictive Display: showing actual position and predicted position in ten seconds time, from Sullivan et al. [168]

Figure 4.3 shows the results separated in novice and experienced as well as with and without predictive display. They demonstrated an improved performance especially for novice helmsmen, which were able to reach the performance of experienced helmsmen with the use of the predictive display.



(a) novice helmsmen without predictor

(b) novice helmsmen with predictor

(c) experienced helmsmen without predictor

(d) experienced helmsmen with predictor

Figure 4.3.: Cross track distance for a figure 8 course, comparison between novice and experienced helmsmen, with and without predictor display, from Sullivan et al. [168]

Another visualization to support prospective action in the shipping industry comes from Porathe [136] and Porathe & Sivertun [137]. They proposed a virtual 3D visualization especially for big and heavy vessels. The visualization (Figure 4.4) has the same viewpoint as the captain from the bridge. It extends the view with additional information. The red area to the left and to the right are not directly reachable despite any maneuver. The border of the red region to the front left and right ,therefore, also indicates the course using the maximum rudder position. The information was shown in real time and the green line indicated the planned course. Using this visualization, it is possible to help the captain by highlighting the decision space in front of the vessel and by predicting the vessel's future position for up to a few minutes.

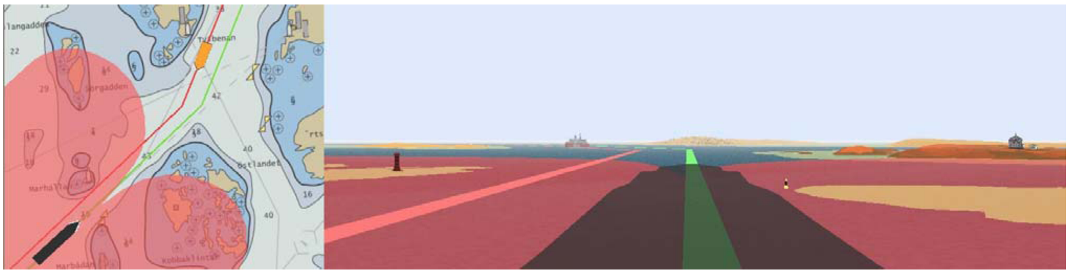


Figure 4.4.: Real-time 3D nautical chart: Red areas or non-reachable, the trumpet in front of the vessel indicates the maximum turning angle, from Proathe [136]

Porathe suggests that using this visualization, mainly slow moving large vessels with bad maneuverability could benefit.

4.2.1.2. Visualization in Aviation

Gempler & Wickens [75] proposed a predictive display as Cockpit Display of Traffic Information (CDTI). It is used as a free-flight display and allows the pilot to change altitude and course without having to contact air traffic controlling. The display typically shows the current position of the own plane and the current position of other planes in a "2-D coplanar display with a top-down and forward looking view of the surrounding airspace". In his work Gempler & Wickens proposed that the current position, the current position of a possible intruder as well as the future pathway of the own ship are certain information. For the uncertain information about the future pathway of the intruder, Gempler & Wickens proposed a wedge, which indicated the possible future position with a 95% certainty (Figure 4.5).

The concept is comparable to the 3D visualization by Porathe & Sivertun [137] (Figure 4.4), which also indicates the possible turning angle by use of a visual "trumpet".
This section showed that predictive displays can help the user anticipate a future state by indication of the current state and a computer based prediction of the future state.

4.2.2. Point of View

Choosing the correct Point of View (POV) for a display is an interesting task. As seen in the previous section, different POVs are possible. Sullivan et al. [168] used a 2D co-planar dis-

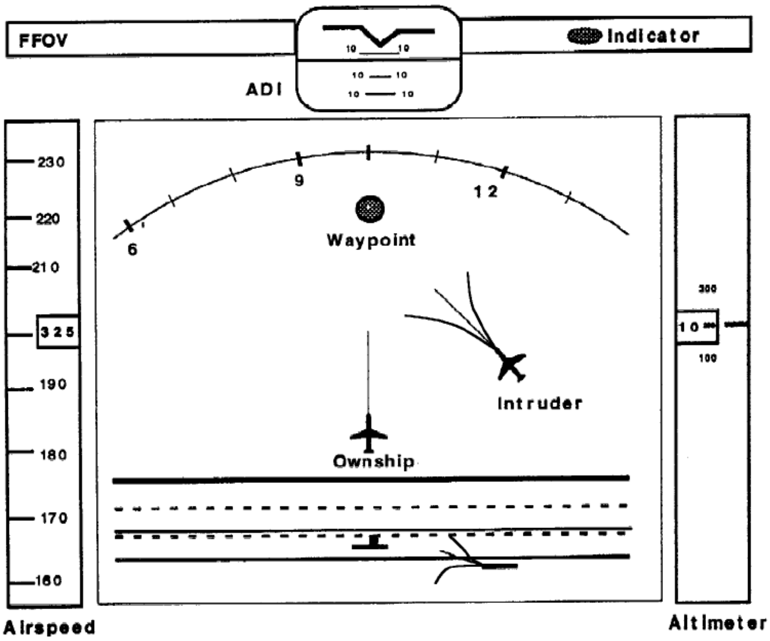


Figure 4.5.: Wegde Predictor Display: Shows "ownship" position with predicted path, as well as the intruder's most likely path visualized by a wedge, from Gempler et al. [75]

play as did Gempler & Wickens [75] to provide the user with a predictive display. Porathe [136] and Porathe & Sivertun [137] on the other side suggested a 3D egocentric visualization in his work.
This section provides an overview of the different possible POVs, their advantages and disadvantages as well as related work on POVs.

The Egocentric/Exocentric Continuum Milgram & Kishino [116] proposed the existence of an egocentric/exocentric continuum, which can be seen in Figure 4.6. The two leftmost examples do have an egocentric POV, with the point of reference for the virtual camera being the observer (the driver). In the pure egocentric POV (leftmost example) the camera is located at the head position of the driver, while in the second egocentric POV the camera is situated behind and above the driver, which is called a tethered POV. The point of reference in the second example is the driver, not the world, meaning the camera moves when the driver is moving. The third POV is an world referenced POV, which means that the virtual camera is referenced in the virtual world and not to the driver. The last POV again is world referenced and exocentric, it shows the scene straight from above, and therefore, delimits the dimension from three to two, a typical example is a 2D navigational map.

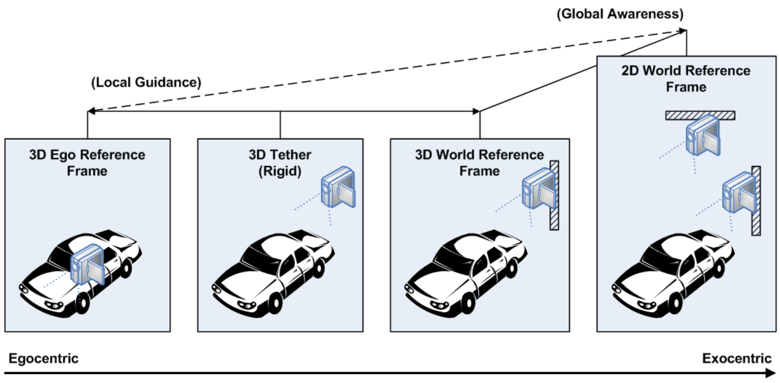
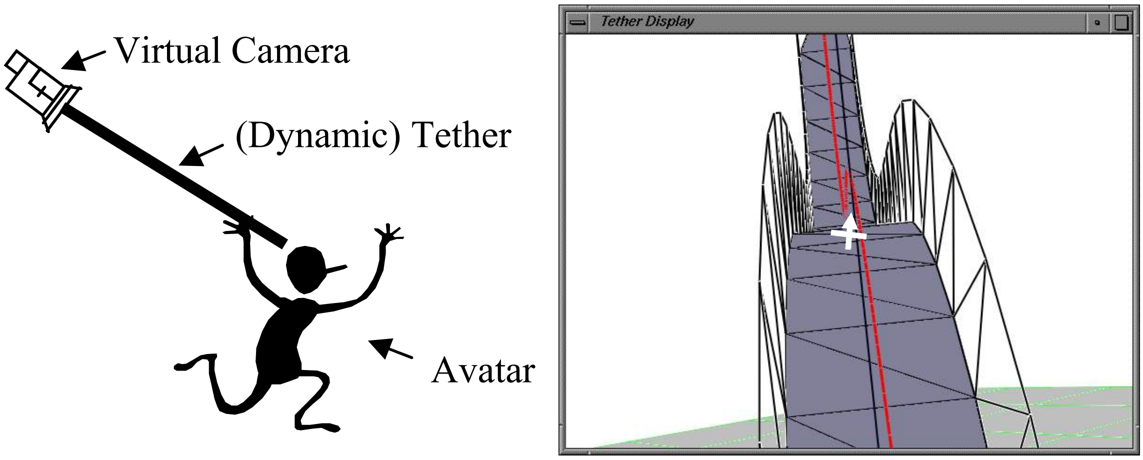


Figure 4.6.: The egocentric-exocentric continuum, from a 3D ego referenced frame to a 2D world referenced frame; adapted from Milgram & Colquhoun[115], from Nestler et al. [121]

Dis-/Advantages Ego-/Exocentric Point of Views All the above mentioned POVs have advantages and disadvantages: While an egocentric POV gives the user better local guidance, an exocentric POV provides better global awareness. This means, that when one is having an exocentric POV, one is provided with a better understanding of the world and to terms that have an exocentric point of reference like North, South, East and West (Wickens et al. [197]). When using an egocentric perspective, it is easier to respond to terms that have an egocentric point of reference e.g. terms that correspond to the position and the orientation of the user like "left" and "right". Typical use cases for an egocentric POV are navigation checking, following a path or navigating to an object, i.e., in every task that requires checking between reality and visualization. In such situations an egocentric POV has the advantage that, compared to an exocentric POV, fewer mental transformations [194] are needed. Disadvantages of an egocentric POV can be the loss of 3D object features, due to a low perspective and that objects behind obstacles cannot be visualized (Green & Williams [78]).

Related Work - Point of View The tethered POV is used in different applications as a trade-off between local guidance and global awareness. This sections shows how Wang & Milgram [184] used the tethered POV in virtual navigation tasks, different viewpoints for the teleoperator and video games as well as work in aviation research on POVs by Alexander & Wickens [7] and Hickox & Wickens [86].

The Dynamic Tethered Camera Using a tethered POV in order to assist the user to navigate a small virtual plane through a large virtual environment (Figure 4.7), was evaluated by Wang & Milgram [184], [186], [185], [187], [182], [183].



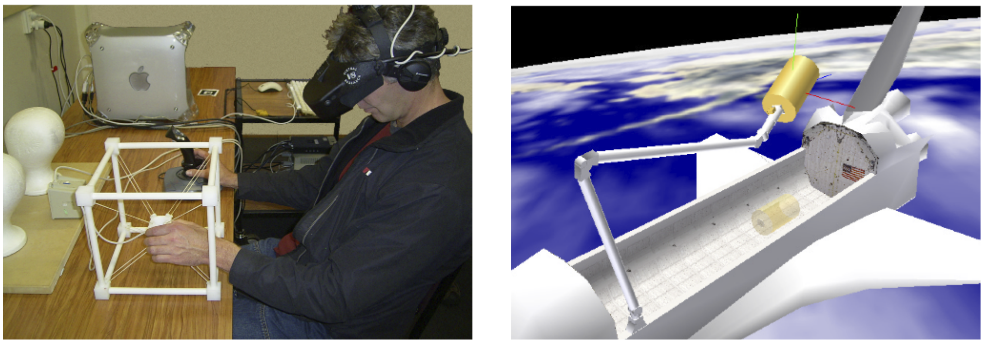
(a) The dynamically tethered virtual camera observing an avatar from an ego referenced POV

(b) Navigation task through a virtual tunnel with a small white plane that is observed by tethered POV

Figure 4.7.: The dynamically tethered camera by Wang & Milgram [186]

In the experiment local guidance and global awareness were evaluated and the “springiness” of the tether was used as an independent variable. Global awareness was evaluated by the ability of the subjects to recognize the shape of the tunnel out of six possible shapes that were presented afterwards. Local guidance was evaluated by the deviation from a perfect center lined flight of the plane through the tunnel. Only a significant difference in the local guidance task was found between an under-damped, a critically-damped and over-damped condition, in favor of the critically-damped condition. No significant difference in global awareness was found [185].

The Teleoperator Another relevant research field for viewpoint optimization is the teleoperation, which means to control a machine remotely via an input mechanism and a screen. The viewpoint from which the machine is presented can have an influence on the ability to control the machine. Lamb & Owen [100] conducted a study were different viewpoints in a teleoperator environment for a Space Shuttle Remote Manipulation System (SRMS) were examined (Figure 4.8). One independent variable was the viewpoint of the operator: In the first condition, the viewpoint was fixed and located near the forward bulkhead of the cargo bay. In the second condition a mobile POV, situated at the end of the manipulator arm, was used, with the movements of the POV coupled to the movements of the manipulator arm. 38 subjects had to perform a pick and place task, in which the manipulator arm had to be moved from a rest-position to an object, the object then had to be picked up and placed in the cargo-bay of the space shuttle. The virtual reality was presented to the subjects via a head mounted display (HMD), and the subjects did control the virtual manipulator via a two hand controller. Dependent variables were the time to complete the task, efficiency during maneuvering, manipulation errors and control effort. Results showed that the mobile viewpoint gave a lower overall performance but decreased the number of collisions between the arm and stationary objects in contrast to a fixed exocentric viewpoint.

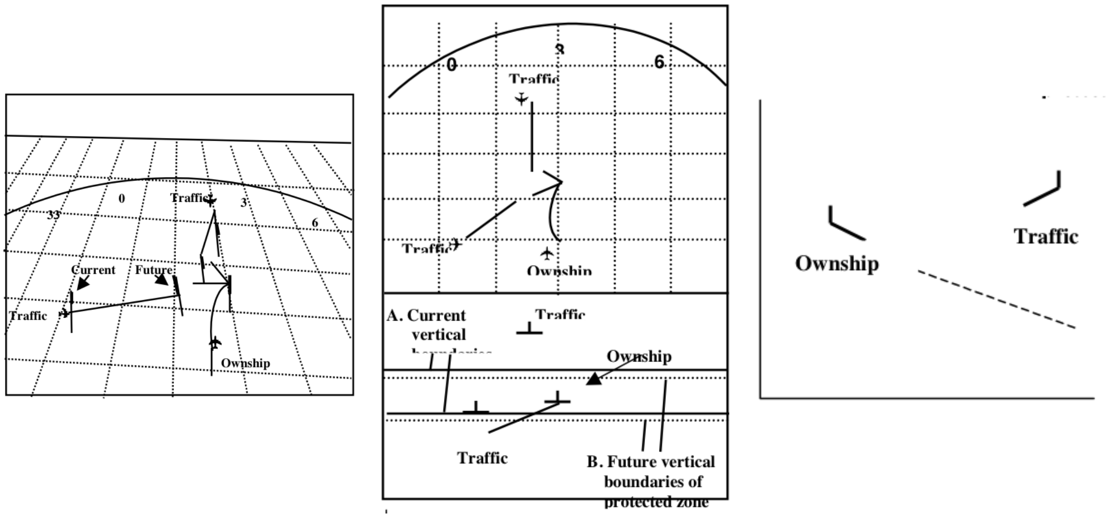


(a) Setup for experiment, the uses a HMD and two joysticks in order to control the SRMS

(b) Virtual test scenario, with the cargo bay of the space shuttle and manipulator arm

Figure 4.8.: Evaluation of different POVs in a teleoperator environment, from Lamb & Owen [100]

A 3D Cockpit Display of Travel Information Finally, Alexander & Wickens [7] [6] proposed a 3D version of a 2D CDTI. The display shows the already mentioned air traffic information for free flight situations. The objective of the survey was to find out which perspective the CDTI should provide in order to achieve the best spatial orientation. 18 flight instructors from the "University of Illinois Institute of Aviation", who flew a predefined flight scenarios, were tested. The independent variables were three different CDTI visualizations (Figure 4.9). A 3D visualization, a 2D co-planar from the top and a 2D co-planar from the side. The dependent variables were: "1) the frequency of maneuvers; 2) safety, in terms of time spent in a state of predicted conflict; 3) the efficiency of avoidance maneuvers defined by the amount of deviation from the target heading, altitude, and airspeed values; and 4) subjective mental workload ratings". On the one side the two 2D variants resulted in lower amount of workload compared to the 3D variant. On the other side, possible conflicts could be detected 4.6 seconds faster in the 3D variant. Alexander et al. concluded that a 3D CDTI is better to detect conflicts (not each crossing line equals a collision - height difference can be assessed better in 3D than in 2D) at the cost of a higher amount of workload.



(a) 3D CDTI (b) 2D co-planar from the top (c) 2D co-planer from the side

Figure 4.9.: Three CDTIs with different POVs from an experiment from Alexander & Wickens [7]

Related Work: Navigational Checking and Mental Transformations Comparing map features with features in the forward field of view (FFOV) in aviation is called navigational checking. Hickox & Wickens [86] did a study to research the influence of the elevation angle and azimuth angle between the electronic map and the FFOV. Results showed that a lower deviation of the elevation and azimuth angle, compared to the real life perspective, resulted in an increased performance in the navigational checking task. Aretz & Wickens [10] proposed that mental rotations are "more than a laboratory phenomenon" and that two mental transformations have to be performed to bring a world referenced 2D map into an egocentric 3D map: one to rotate it into the forward view, and one to bring it into the egocentric perceptive. Aretz & Wickens also conjected that if mental rotations are too difficult, they are not performed.

4.2.3. 3D Visualizations

A related topic to the viewpoint matter is the question, whether a 2D or 3D visualizations should be used. This section discusses the advantages of 2D and 3D visualizations and shows options of how a 3D visualizations can be realized on a 2D monitor.

3D Depth Cues There are different types of 3D visualizations. On one side, there are 3D stereoscopic displays, either with active, passive or without glasses. On the other side, 3D visualizations can be realized on a 2D screen using depth cues. Wickens & Hollands [194] described object orientated cues which can used to implement a 3D visualizations on a 2D monitor. From Wickens & Hollands [194]:

- **Linear perspective**: "When we see two converging lines we assume that they are two parallel lines receding in depth".

- **Interposition**: “When the contours of one object obscures the contours of another, we assume that the obscured object is mire distant”.
- **Height in plane**: “Objects higher in our visual field are farther away”.
- **Light and shadow**: Shadows allow assumptions about the object’s orientation.
- **Relative size**: If objects are known to have the same size, the smaller one is further away.
- **Textural gradients**: The grain of texture grows finer at greater distance.
- **Proximity-luminance covariance**: Closer objects are brighter.
- **Aerial perspective**: More distant objects tend to be hazier and less clearly defined.
- **Parallax**: When the observer moves, closer objects show greater relative movements than further objects.

Apart from these these object orientated cues, there are observer-centered depth cues like **binocular disparity**, which is used for stereoscopic displays, **convergence** and **accommodation**. The cues mentioned above usually are combined and give the same information to the observer. But when cues are not available in a large number, reality can differ from the cues, e.g. when a pilot mistakes bushes for trees, and therefore, thinks he is flying at a much higher altitude than he does in reality [83].

3D Visualizations: Advantages and Disadvantages As driving is a 3D task the congruence between task and visualization already gives a clue on the type of visualization that should be used. The following section will provide an overview on the advantages/disadvantages of a 3D visualizations in the automotive environment.

Advantages of 3D Visualizations As just mentioned, driving is a 3D task and therefore, a 3D visualizations, which matches the number of dimensions from the task, should be considered. In her work Krüger [98] mentions six advantages of 3D visualizations in automotive environments.
These six advantages are:

- **Integration**: Integrating spatial information like width, height and depth supports the user in performing a task. In a 3D visualization this can be done within the visualization itself. If this information is distributed over several 2D visualizations, the user has to perform this integration, which requires a mental effort. Considering several researches, Krüger [98] concluded that a 3D visualization is not automatically the better visualization for tasks that need integration of 3D information; each integration task has to get analyzed before deciding on a visualization.
- **Visualization of relations**: 3D visualizations can also be of use when visualizing complex relations between information. In literature, one can find evidence that it is possible to show more information in a 3D visualization than in a 2D visualization without losing the possibility to recognize and interpret the information correctly (e.g. Hicks et al. [87]) .

- **Spacial compatibility**: Wickens & Hollands [194] and Norman [127] both proposed that reality, control and visualization should be compatible to each other - a concept based on the stimulus control compatibility by Fitts & Seeger [66]. In the driving task, the spacial relation between vehicle and the environment is a continuous analog information. 3D visualizations are able to map this information directly to the visualization. Therefore, fewer mental transformations are needed. A good example is the 3D navigational map that is becoming more and more prominent in today's navigational systems.

- **Attention steering**: The attention of the observer can be lead if the information is distributed over different depth-layers. The shift between two stimuli takes longer when they are in different depth-layers than if they are in the same depth-layer [8]. This shift does take time and effort, and it is easier to shift attention from far to near than from near to far [8]. Objects that are closer are more emphasized than objects further away. This can be used to highlight certain information in a visualization by placing them closer to the observer.

- **Concreteness**: Visualizing information on a 3D visualization allows a concrete visualization of e.g. control elements. No further training or instruction should be necessary in order to understand them intuitively. The principle of pictoral realism by Roscoe [145] also promoted the obvious reference between a visualization and reality. Although this principle refers to spacial arrangement, it can be adapted to concrete visualization. Especially texture, light and shadow can be used to improve the recognizability. This concept does not necessary mean photorealism, as 3D correctness is independent from high visual complexity.

- **Attractiveness**: Especially 3D photo realistic visualizations are being perceived as being attractive [4]. An explanation for that could be that 3D visualizations are closer to the human perception of a real environment. Wickens [190] p.109 stated: "There is little doubt that 3D renderings, if carefully constructed, can provide a natural viewing of a variety of environments, which is aesthetically pleasing". The positive perception of the 3D visualization mainly comes from the photorealism not from the three dimensional presentation. Highly realistic 3D visualizations are perceived very attractive but due to a high visual complexity, the traffic safety aspect can be harmed.

Disadvantages of 3D Visualizations The following paragraph shows an overview of possible disadvantages mentioned in the work by Wickens & Hollands [194] and Krüger [98].

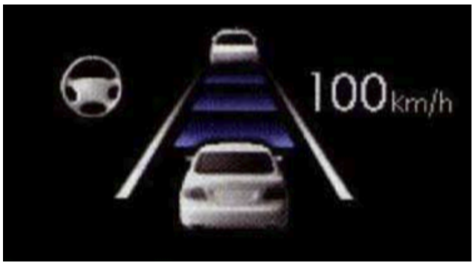
- **Ambiguity**: Representing three dimensions on a 2D display yields to inherent ambiguity (depth, distance, true size of objects) [194]. A good example are the parameters height and depth: an object being located higher in a visualization provides the information that it might be further away, which can lead to possible false assumptions. The ambiguity is a result of the projection from a 3D space onto a 2D image plane: Information does not get lost but 3D information gets shortened and reduced, which yields to perceptional errors (e.g. Wickens & Hollands [194]).

- **False hypotheses**: when no additional information is incorporated into the 3D visualization, ambiguity can lead to false hypotheses. An example is the assumption on the size of a certain object: if the observer sees two vehicles, he assumes that their size is about equal (e.g. Wickens & Hollands [194]).

- Other possible problems associated with 3D visualizations are their **distraction potential**, which can be higher than of a 2D visualizations especially when using visual intense, photorealistic visualizations [111] as well as an animated visualization from an egocentric point of view [128]. **Time for implementation and hardware usage**: This factor gets less and less important with the development of extremely user friendly software and the further distribution of mobile 3D hardware in the mass market.

The disadvantages just mentioned show that it is necessary to carefully implement a 3D visualization in order to use its full potential.

3D Visualization in the Automotive Environment Recently, and with the help of more powerful integrated graphic modules, 3D visualizations in the automotive environment have been established. Contact analogue visualizations for ADAS and 3D visualizations on displays inside the vehicle are the most common areas of application. Contact analogue applications are not of issue in this chapter and will be discussed in Chapter 4.5.1.
Apart from the contact analogue visualizations, other 3D visualization in the automotive environment are possible, for example a 3D visualization of the ACC symbol in a Lexus as one can see in Figure 4.10a or a 3D menu for the on-board entertainment system from Broy [28] (Figure 4.10b).



(a) 3D version of the ACC symbol, showing a 3D model of a vehicle on a 2D screen, found in Krüger [98]

(b) 3D menu for the on-board entertainment system, utilizing five spaces, from Broy [28]

Figure 4.10.: Examples of 3D visualization on 2D screen in the vehicle, ADAS and entertainment

4.2.4. Map Visualization

Visualization of the environment in a virtual map is challenging. Questions like how much detail should be implemented or which purpose, global awareness or local guidance, should be served need to be answered. Problems that can arise, if too much information is presented the wrong way, are:

- **Information Overload**: Information Overload describes a state in which the observer has too much information to make a sensible decision. S/he cannot focus on the actual important piece of information. Sources for information overload can be a low signal-to-noise ratio, new information generated in a rapid frequency or contradicting information [199],[172].

- **Cognitive Capture**: is described by Wickens [192] (p.1) with the following words: "[A]llocation of attention to a particular channel of information, diagnostic hypothesis or task goal, for a duration that is longer than optimal, given the expected cost of neglecting events on other [sensory] channels, failing to consider other hypotheses, or failing to perform other tasks." Reasons can be either the involvement in highly emotional discussion or a visualization that produces too much cognitive capture (the environment is not perceived any longer).

To avoid these problems, a visualization that provides even more information to the driver, has to be carefully designed. In the following, work is presented that shows how maps can be created to avoid phenomenons like information overload and cognitive capture. One possible way is the schematization of concrete maps, as is done in subway maps. In contrast to topographical maps, which try to provide a picture as truthful as possible schematic maps can be seen as a conceptual presentation of the environment. The goal of a schematic map is to find an abstraction of the real world, and therefore, make the map less cluttered while still providing enough features that the observer can acquire spatial knowledge.

Designing a Navigational Map Using a Taxonomy of Basic Branchpoints Casakin et al. [37] provided a deeper insight into how schematic maps can be used as wayfinding aids. In his work, Casakin et al. state that "Due to their abstracting power, schematic maps are ideal means for representing specific information about a physical environment". They depict important information and present this information in a way that is easy accessible. Casakin et al. also provided a taxonomy of schematic branching points and in a case study he let subjects use those basics to draw a map of a certain area. Finally, they showed that using simple schematics it was possible for the subjects to fulfill the task while achieving good results.

Designing Navigation Maps for Automotive Navigation In a work by Schreiber [154], a new approach in designing a map for car navigation was proposed. The work built on the results by Schraagen [153], who showed that for simple navigational situations a turn-by-turn navigation system is favored over cartographic maps, while in difficult intersections, subjects made fewer errors using digital maps than turn-by-turn systems. These results and results from a survey on 3D maps by Dickman [52] were interpreted by Schreiber [154] (p.2) in two results. First, "the decrease of complexity of information eases the information processing" and secondly that "a high level of detail and a congruent visualization of the environment supports the mental imagery of space and the memory of space knowledge". Schreiber provided two different kinds of maps with different complexity. One for way-planning, the other for acquiring detailed spacial knowledge about a location. Both types of maps with different levels of complexity are shown in Figure 4.11.

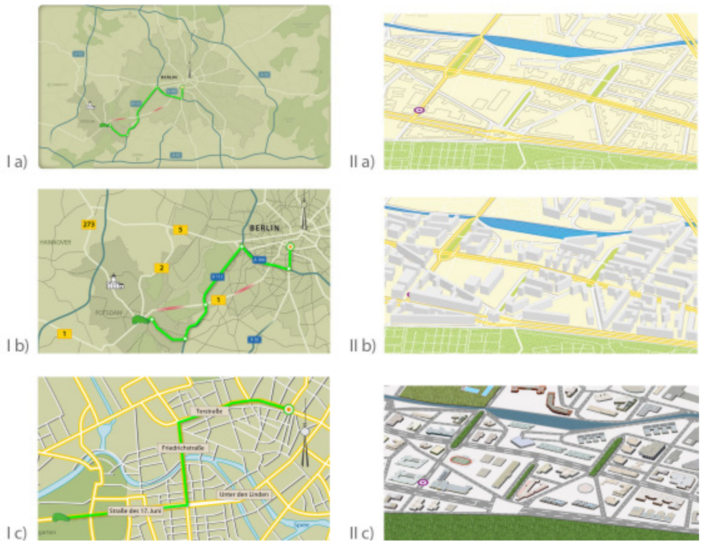


Figure 4.11.: Car navigation maps, type I: for planing a way, type II: for gaining spatial knowledge, with different complexities, from Schreiber [154]

4.3. Conceptional Work

Guidelines, principles, generic and tailored to the automotive environment have been presented. Also, it has been shown that fuel reduction by assisting the driver in early anticipation is a promising and interesting use case for information gathering from the Car2X infrastructure by enlarging the driver's visual horizon to an electric horizon. This chapter presents the conceptional work on a visualization for a deceleration assistance system, a system that uses all possible information, like on-board sensors, Car2X information and digital maps to support the driver in early deceleration. The goal for the system is to inform the driver about a possible deceleration situation as early as possible and to present him an according action ("release the gas" or "step on the brake") in order to use the maximum coasting time from the vehicle's current velocity to the goal velocity.
Topics in this section will be the implemented POV: how a 3D visualization was realized on a 2D screen, how to use the advantages of a 3D display, the colors used in the visualization and the map presentation aspects of the visualization.

4.3.1. The Basic Idea

The basic idea for a visualization in a deceleration assistance system was to provide the driver with a virtual representation of the road ahead from an backward shifted and elevated POV. Figure 4.12 shows an abstract version of the basic idea, which originally was proposed by Nestler et al. [121]. A virtual piece of street represents the range of information from the electric horizon. Also indicated are the position and visualization of the own vehicle as well as other traffic on the virtual road. An originally proposed visualization of the deceleration phase, lane direction and distance marks on the right side of the virtual road were discarded due to information cluttering concerns.

The visualization is located between the speedometer and the revolution meter in the instrument cluster.

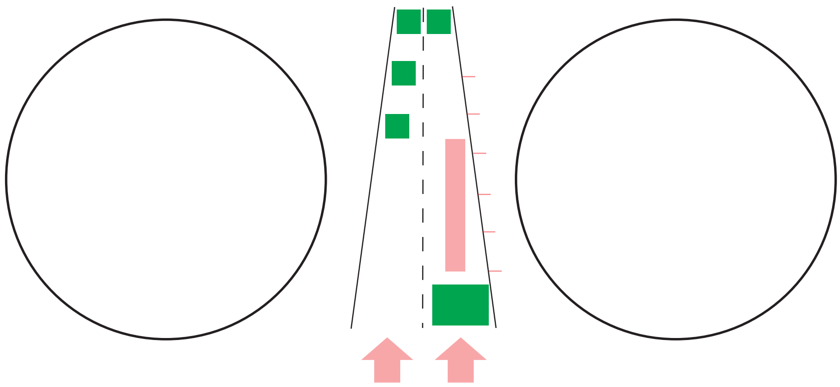


Figure 4.12.: Abstract visualization of the BEV in the instrument cluster, green elements were realized, red elements were discarded

4.3.2. The Implemented Viewpoint

In section 4.2.2 several different viewpoints have been discussed. It was shown that different POVs have different advantages and disadvantages. An exocentric POV predominantly leads to better global awareness and actions that are world referenced are executed better. An egocentric POV provides better local guidance but has the disadvantage that objects can be occluded by other objects. Regarding the task of assisting the driver in early deceleration and the consequential necessity to show information of far ahead objects (e.g. a slower vehicle in front), an exocentric POV is a suitable choice.
During the preparation for the first user evaluation a preliminary study with ten subjects was performed to find the best viewpoint for the visualization. The viewpoint itself can be located on a quadrant around the driver's head, as can be seen in Figure 4.13.The angle α which describes the rotation around the x-axis is the main interesting angle. The larger this angle, the more exocentric and towards a 2D co-planar presentation the viewpoint strives. The distance d describes the radius of the quadrant or in reality the distance between the driver's head and the virtual camera (c = location of virtual camera). If d increases in distance, the observer is able to see a larger portion of the virtual scene, but at the same time each item is reduced in size.

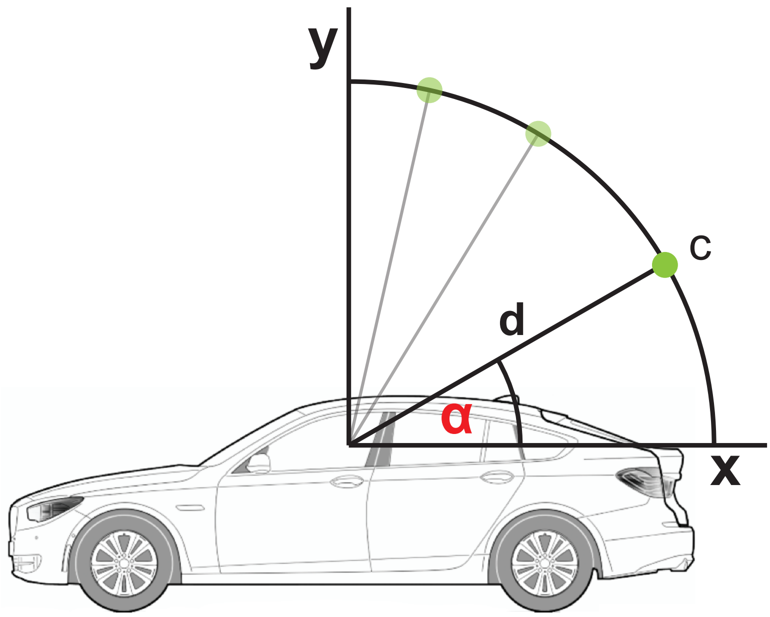
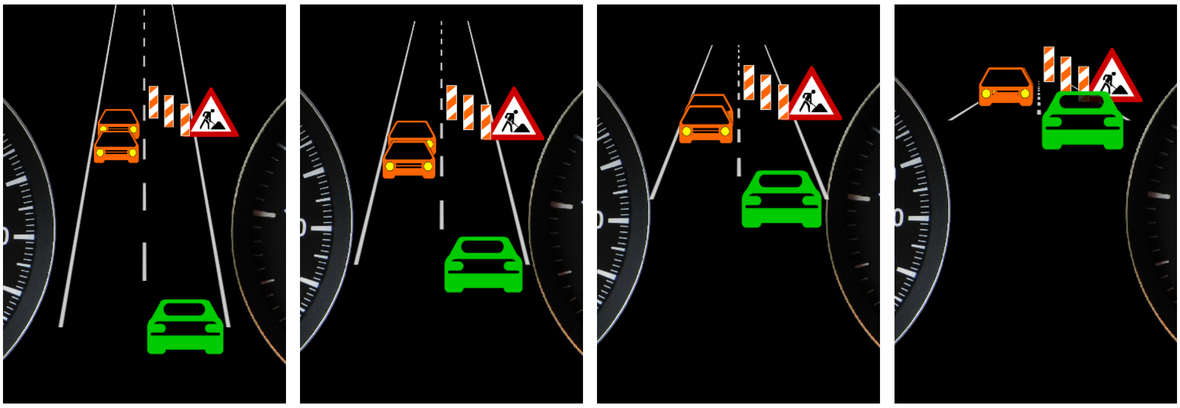


Figure 4.13.: The possible points where the POV can be located on a quadrant around the driver's head, α: the rotation around the x-axis, d: the radius of the quadrant and the distance from the virtual vehicle to the virtual camera (c = location of virtual camera)

Different settings for angle α in Figure 4.14 show the same results that were expected from literature. The smaller the angle α gets the more egocentric is the resulting POV (Figure 4.14d). Consequences that arise with a low angle and an egocentric POV are a loss of information detail on one side, but, on the other side less mental transformation is needed in order to capture the information. If α is large like in Figure 4.14a, the global awareness and the possibility to recognize objects far away improves. The POV moves towards the exocentric side and more mental transformation is necessary to capture the information. The results of a pre-study with ten subjects showed that most subjects prefered an α at around 65°, which can be seen in Figure 4.14b. Using this angle, occlusions are minimal, indication of distances is easily accessible, different depth layers are recognizable and the amount of mental transformation is acceptable. Also using this angle, the curvature of the road is easy to identify for the user (cf. discussion about advantages and disadvantages of different POVs in Chapter 4.2.2).



(a) Steepest α, most exocentric, no occlusion, most mental transformation effort

(b) Medium α, no occlusion occurs, low mental transformation effort

(c) Medium to flat α, some occlusion occurs, few mental transformation effort

(d) Flattest α, most egocentric, occlusion occurs, least mental transformation effort

Figure 4.14.: Different POVs for the Birdeye visualization, tested in pre-study

4.3.3. A 3D Visualization on a 2D Screen

Considering that it was not possible to purchase a 3D stereoscopic display and the fact that a 3D visualization seemed to fit the task, it was necessary to use object oriented depth cues by Wickens & Hollands [194] to visualize a 3D display on a 2D screen. From the eight object oriented depth cues, four cues were chosen to be implemented in the visualization to achieve a 3D display. Figure 4.15 shows that "height in plane", "linear perspective", "interposition" and "relative size" were realized in the visualization while "light", "shadows", "textural gradients", "proximity-luminance", "aerial perspective" and "parallax" were not implemented.

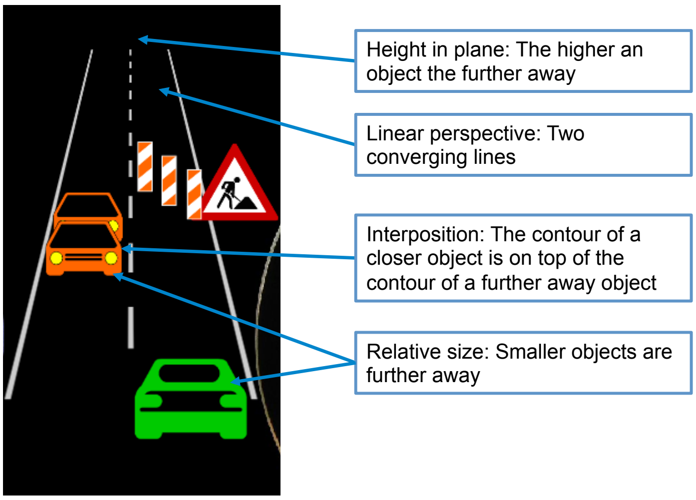


Figure 4.15.: Object oriented depth cues realized in the BEV in order to realize a 3D visualization on a 2D screen

The result is recognizable as a 3D display. This was also backed up by the opinion of experts and subjects during the evaluation.

4.3.4. Using Advantages and Avoiding Disadvantages of a 3D Visualization

Figure 4.16 shows how and in which amount the previously mentioned advantages and disadvantages by Krüger [98] have been taken into account to implement an interface to assist the driver in early deceleration.
Obviously, the BEV, in common sense, is not a photorealistic visualization as well as it is not visually intense. It only shows relevant aspects of the situation lying ahead, and therefore, problems regarding **cognitive capture** and additional mental demands are kept low. At the same time this BEV is **concrete** enough that it is easy for the observer to recognize the situation and possible hazards within the BEV. As already mentioned, the BEV shows all relevant information that is important for the driver in order to decelerate correctly, but all unnecessary information that could yield to **information clutter** was left out. The visualization represents the situation ahead in a **correct spatial relation**; distances, sizes and depth are correctly drawn to scale in order to avoid **false hypotheses**. This also allows **correct attention leading**, meaning that the most relevant objects, in this case the next vehicle or hazard on the street, are presented at the foremost level. Results from two experiments (cf. Chapter 5 and Chapter 6) confirm these statements by calling the BEV clear and understandable. Also the "visualization of the distance" and the "visualization of the oncoming traffic" was received positively by the subjects.

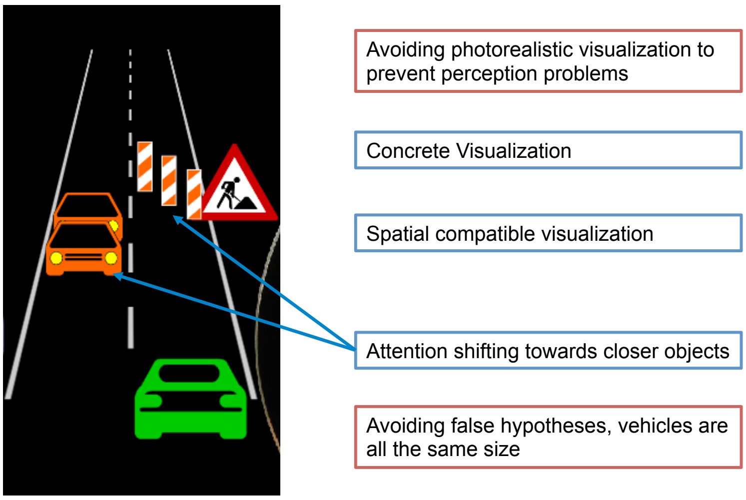


Figure 4.16.: Advantages (blue) and disadvantages (red) that were taken into account in order to achieve the best possible visualization for the BEV

4.3.5. Colors in the BEV

The ego-vehicle, other traffic, the virtual street and the information that supports the driver's action ("release gas","step on brake") were aspects in the visualization for which color coding was used. The color coding of the ego-vehicle, which indicated the requested action, was changed between the second evaluation (Chapter 6) and third evaluation (Chapter 8) due to subjects comments. In the second evaluation the following color progression was chosen: white, green, yellow, for the states “idle”,“release gas” and “‘step on brake” (Figure 4.17a). Due to negative subject statements ("confusing colors") this progression was adjusted before for the third evaluation to: white, pale yellow, dark yellow (Figure 4.17b). By adjusting the colors, the number of different colors was reduced and the green color, which indicated “release gas” was replaced. The green color during the second evaluation did lead to the misinterpretation by the subjects: “go - everything is clear”. The color green was originally chosen due to the corresponding idea of a green (fuel saving) mode. This change is in line with the ISO Norm 2575 [47], which states that green should be used for safe, normal mode of operation. The icon of the ego vehicle was also altered between the second and third evaluation, in order to have a better differentiation between the ego vehicle and other traffic.

(a) Early version of the ego vehicle colors; white: idle state, green: release gas, yellow: step on brake

(b) Later version of the ego vehicle colors; white: idle state, pale yellow: release gas, yellow: step on brake; different icon for better differentiation between ego vehicle and other traffic

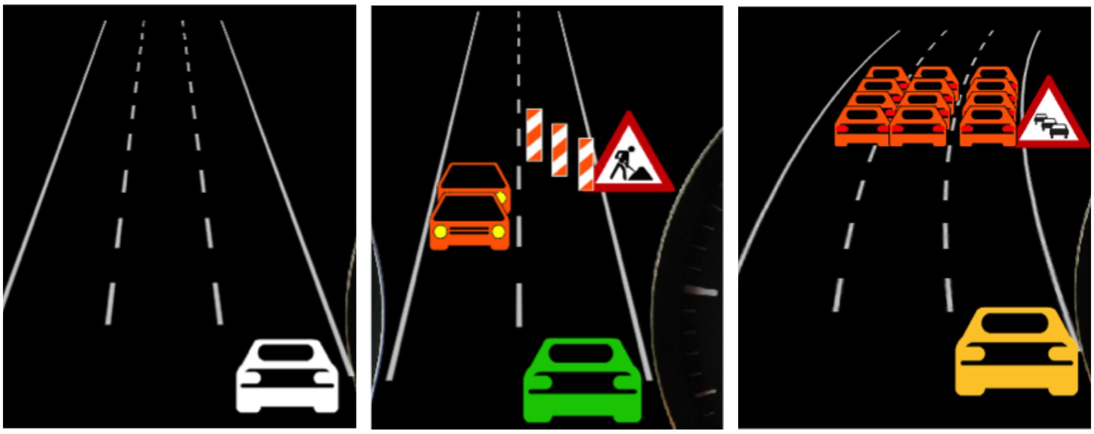
Figure 4.17.: Change in colors and icon of the ego vehicle in the BEV between the second and third evaluation

Other traffic was represented in an orange color, in order to achieve a differentiation to the ego-vehicle. The road markings of the virtual street was realized with a white color, analogue to the real road markings in Germany (cf. Figure 4.18).

4.3.6. Map Visualization in the BEV

Regarding the central use case for the BEV, it was not necessary for the observer to gain perfect spatial knowledge. No wayfinding task should be fulfilled using the BEV. However, it was necessary for the user to identify the situation that was presented to him with his own situation. Furthermore it was necessary to identify certain objects within this visualization as relevant. At the same time, the additional information should not lead to any of the above mentioned problems like information overload or cognitive capture. For the visualization, a degree of abstraction was chosen which allowed good spatial knowledge without increased cognitive load for the observer.

Figure 4.18 shows three different situations visualized using the BEV. In Figure 4.18a the idle state of visualization is shown. This state is visible when no deceleration situation is detected. It shows the ego-vehicle and an empty virtual street, indicating the correct number of lanes but not showing navigational aids, other traffic or environmental details. Figures 4.18b and 4.18c show a deceleration situation. The driver is informed about the action to take, the other traffic, the reason for deceleration and possible obstacles on the road. The curvature of the road was only displayed in case of a deceleration situation, while in the idle state a straight road is presented (cf. Figure 4.18a).



(a) Idle state of BEV, on a three lane highway, no other traffic is visualized

(b) Deceleration situation "release gas", oncoming traffic and reason for deceleration is visualized

(c) Deceleration situation "step on brake", other traffic (traffic jam), course of road (right hand bend) is visualized

Figure 4.18.: Map details visualized in the idle state of the BEV and in deceleration situations

Using this schematic visualization, it was possible to create a visualization that enables the observer to identify the situation and critical elements without creating additional high cognitive load.

4.3.7. Animation in the BEV

As an eye catcher and due to an expert's advice, it was decided to add an "attention catcher" whenever a situation is detected and the visualization is initiated. Figure 4.19 shows the attention catcher, which is the situation symbol (an official traffic sign) popping-up (Figure 4.19a) and fading out (Figure 4.19b) over one second time. The pop-up of the sign increases the probability of detection in the parafovea of the human eye. This decision is supported by work of Hickox & Wickens [86] and Anderson & Kramer [8], who stated that reaction time is worse on visual stimuli which are not in the direct line of sight.

(a) Big traffic sign popping-up when the situation is recognized, sign represents situation

(b) With the use an animation the sign gets smaller and fades out

Figure 4.19.: Big traffic sign pops up at the beginning of each deceleration situations in oder to catch the driver's attention

The second occurrence of animation is the other traffic and the obstacles which are moving towards the ego-vehicle while becoming larger in size as they are getting closer. Finally, the ego-vehicle is visualized on the correct lane, using a discrete animation with no intermediate state. The street itself is not animated. Figure 4.20 gives an overview of the animated and non-animated objects.

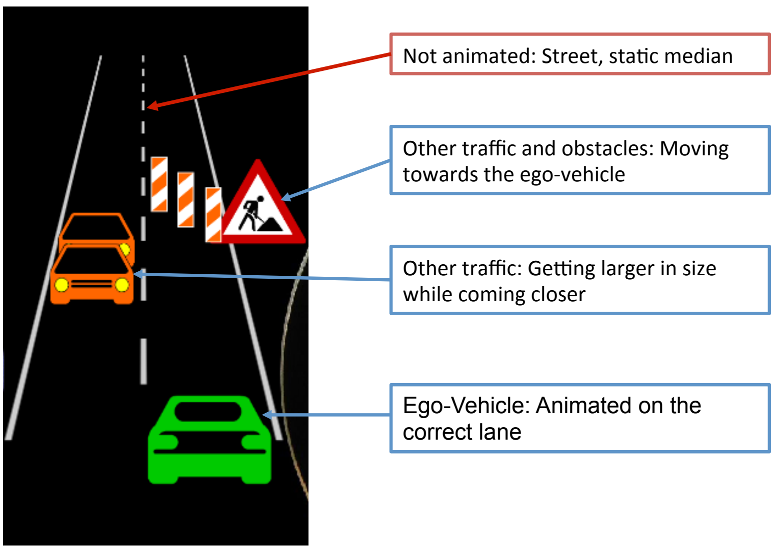
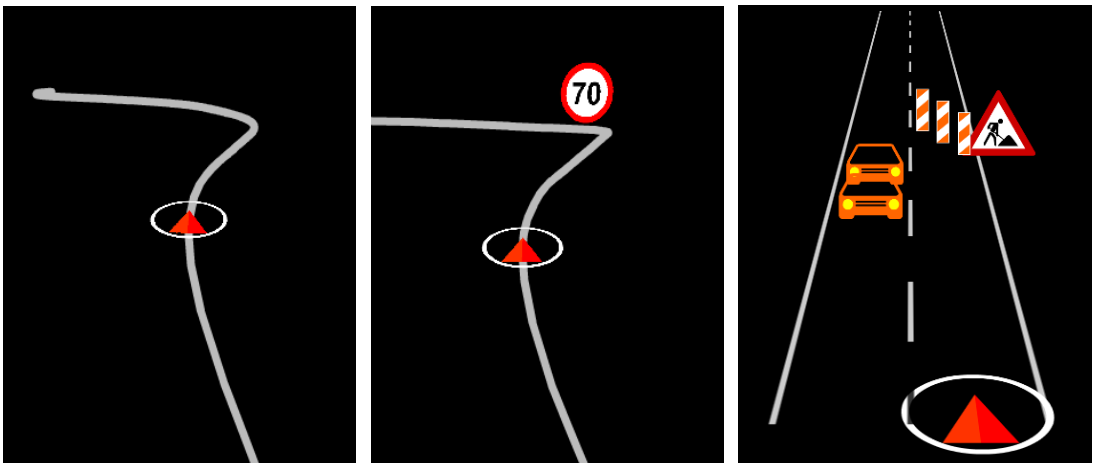


Figure 4.20.: An overview on which elements were animated (blue) and which were static (red) in the BEV during an deceleration situation

During the development of the visualization, a discrete animation of the oncoming traffic was implemented. In this case the other traffic was not continuously animated while getting closer, but in three discrete steps. After implementation the idea was abandoned due to its unworthy looks.

4.4. The Navimap

The BEV is a consistent visualization for presenting information in early deceleration situations. Yet for simple situations like a speed limit sign, the level of detail used in the BEV can be considered inappropriate. Therefore, a second implementation of the display was realized, the so called Navimap. The idea of the Navimap is to combine the BEV with a navigational view. Complex deceleration situations (Figure 4.21c) are displayed in the BEV, while simple situations like speed limits (Figure 4.21b), will be presented in the simpler navigational view, which also is the idle view (Figure 4.21a) when no deceleration situation is detected. A zoom between the two possible views is initialized whenever the other view is needed. This section presents related and conceptional work on the Navimap.



(a) Idle visualization, navigational view, only course of road is visualized, ego vehicle centered

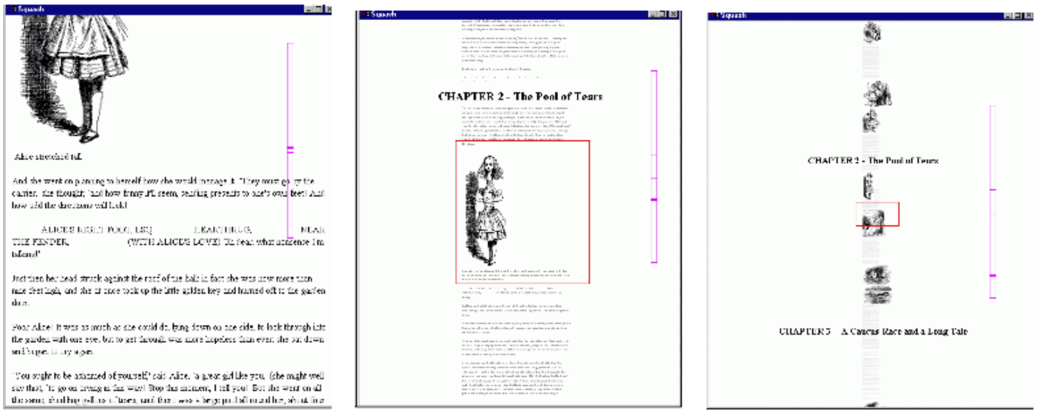
(b) Simple situation, visualized in the navigational view with the help of a official traffic sign

(c) Complex situation, visualized in the BEV, the ego vehicle representation is taken into this view

Figure 4.21.: The navimap visualization concept, idle state and deceleration situations

4.4.1. Related Work

The idea for zooming in and out of a visualization, in regard to the detail that should be displayed, also finds an application in several other domains. For example Igarashi & Hinckley [89] used an automatic zooming technique to browse large documents. Figure 4.22 shows that in the static view, the maximum zoom factor allows to see all details in a small part of the document, while during fast scrolling (Figure 4.22c) details are reduced to a minimum.



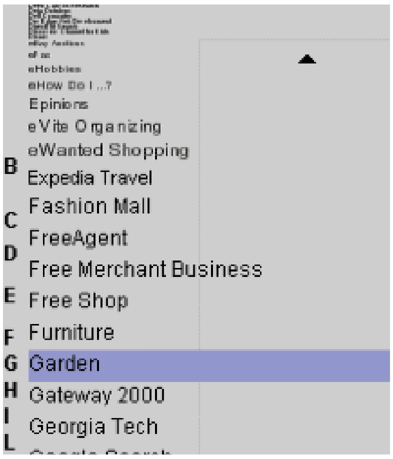
(a) Static view, zoomed in, small portion of the document is visible, detailed information is visible

(b) Normal scrolling, view is zoomed out, a larger portion of the document is visible, details get smaller

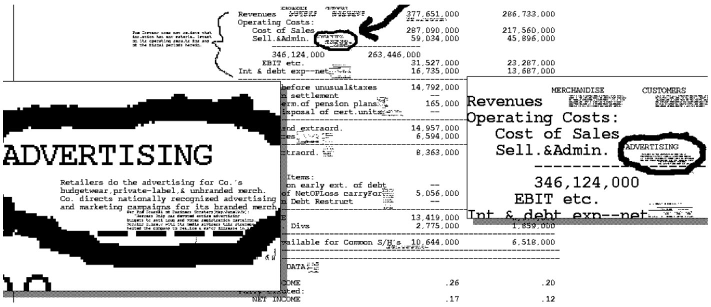
(c) Fast scrolling, view is zoomed out even more, a even larger portion is visible, details are not visualized any more

Figure 4.22.: Speed dependent automatic zooming form Igarashi & Hinckley [89]

The fisheye menu (e.g. Furnas [70] or Bederson [17]) zooms in the area of interest and distorts its surrounding. Figure 4.23a shows a drop-down menu, which uses the fisheye technique in oder to show the currently selected area in higher detail. Another possible application for the zoom effect is a zoomable map like the one Perlin [133] used in his “Pad” project, in which zooming is seen as the best way to navigate in information space. ”Semantic zooming is commonly used with maps, where the same area on the map may be shown with different features and amounts of detail depending on the scale”. Figure 4.23b shows three views on the same document in different zoom and detail factors.



(a) Fisheye zoom in list, the currently highlighted item is well visible as are items next to the highlighted item, items further away are visualized smaller, by Bederson [17]



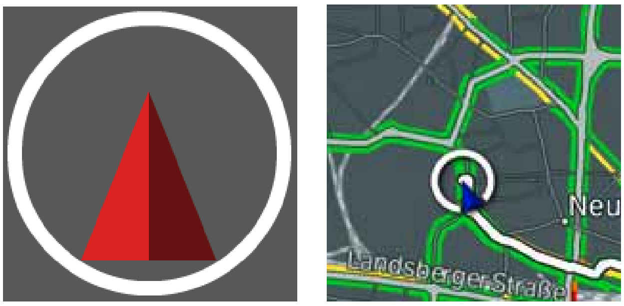
(b) Zoomable map, three views in different zoom and detail, the zoomable interface by Perlin [133]

Figure 4.23.: Zoomable interfaces

Finally, the automated zoom can be found in a navigational system, that changes the zoom factor in regard to the driven speed, the slower a vehicle gets, the higher the zoom factor and the more details are revealed and vice versa. It should be mentioned that these interfaces are interactive, The user directly interacts with them while at looking at them, whereas the Navimap only displays information to the user but does not receive direct input from him.

4.4.2. Conceptional Work

The Ego vehicle The ego vehicle in the BEV was visualized by a small car icon. In the Navimap, this icon was replaced by an arrow/circle combination. This was done due to "cheap" look of the car icon in navigational view. In order to follow the consistency paradigm, it was necessary to incorporate the arrow/circle combination into the complex view. Otherwise the ego vehicle would have been represented by two different visualizations, which could have led to confusion with the driver. The design of the arrow/circle (Figure 4.24a) allows the driver to easily identify one's own position, and due to the arrow the heading is also easily identifiable. The design was taken from the current BMW navigation system (Figure 4.24b). The color red was chosen due to the best visibility; no additional request for action was encoded in the ego vehicle.



(a) Ego vehicle representation via an arrow and cricle

(b) BMW Navigation System view including arrow and circle

Figure 4.24.: The ego vehicle visualization in the Navimap

The Navigational View The visualization of the navigational view and its design rationales are seen in Figure 4.25. The navigation view consists of the ego vehicle visualization using the arrow/circle combination and a visualization of the upcoming route. The route is visualized using a gray line. No environmental or lane visualization is shown in this view. This was done in order to get a contrast to the complex view and to achieve simplicity. The navigational view was presented to the driver at the same viewing angle α as the BEV but the distance (d) was increased, which allows an expanded view on the scenery ahead. In the navigational view, the ego vehicle is stationary and the map turns relatively to the vehicle as necessary.
Simple situations like an upcoming speed limit sign, are presented directly in the navigational view. In order to do so, an official traffic sign is placed at the correct place inside the visualization. The sign is tethered to the map, but rotates itself in a way that the driver is always able to see the information frontally (bill-boarding technique).

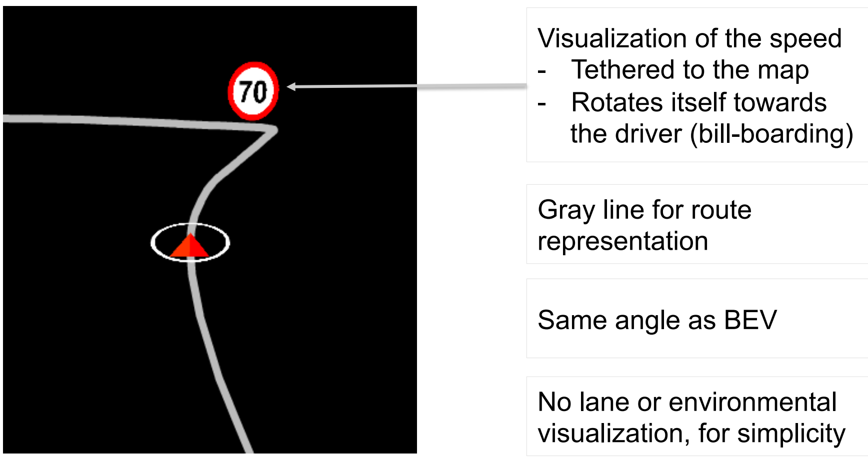
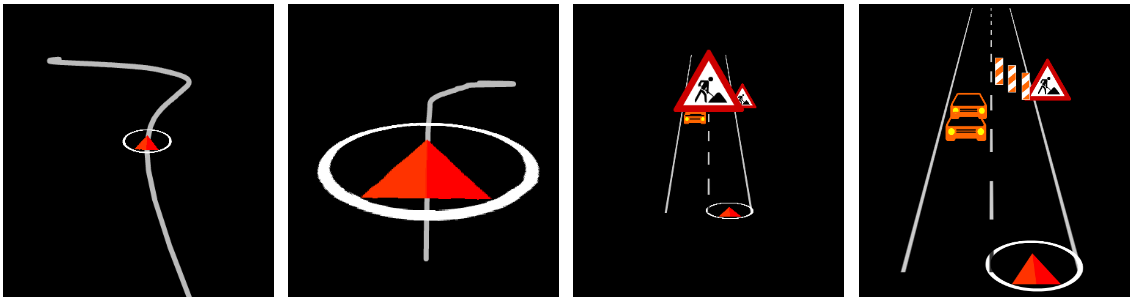


Figure 4.25.: Details of navigational view of the Navimap, simple situations are presented in this view

Zoom Between the Navigational View and the BEV When a complex situation is to be displayed, the zoom is realizing the transition between the navigational view and the BEV. Figure 4.26 shows this transition. Zooming begins from the normal navigational view. When the zoom effect is close enough (Figure 4.26b), the navigational view fades out and the BEV fades in and zooms in further (Figure 4.26c), until the complete BEV is is reached (Figure 4.26d). Figure 4.26d shows that the attention-catcher in the BEV is also used in the Navimap. Statements ("good overview" and "not disturbing") from the evaluation (cf. Chapter 5) indicate that the zoom between the two views does not disturb the user. As this visualization was omitted for the second evaluation no in-depth evaluation regarding the user distraction was conducted.



(a) Navigational view, zoomed out, course of road visible (b) Zooming into the navigational view until ... (c) ... no more zoom is available and zoom into the BEV begins (d) Completely zoomed in BEV

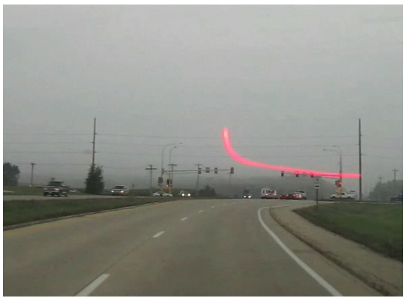
Figure 4.26.: The zoom animation between the navigational view and the BEV in continuously animated stages

4.5. Virtual Racing Line

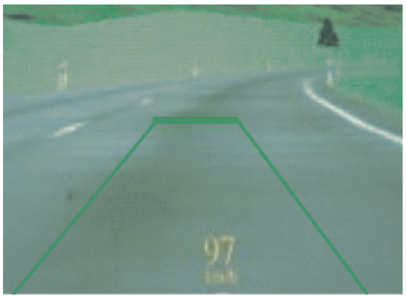
The VRL is a contact analogue visualization concept to support the driver in early anticipation. A contact analogue visualization uses a contact analogue HUD (CAHUD) in order to visualize information in the environment, the visualization thereby is not vehicle- but world referenced. Further information on contact analogue visualizations as well as on the technique behind a CAHUD can be found e.g. in Toennis & Klinker [174]. Although contact analogue visualizations only can directly highlight aspects in the visual horizon of the driver, reactions to and distraction of contact analogue visualizations are superior to conventional visualizations in the CID or instrument cluster. Therefore, a contact analogue concept for assisting prospective driving seemed to be promising.

4.5.1. Related Work

An example for ADASs concepts which use contact analogue visualization is an augmented arrow by Toennis & Klinker [174], which can be seen in Figure 4.27c. It is indicating a source of hazard by showing a 3D arrow pointing at the hazard's direction. A further example is the virtual cable [110], a contact analogue navigation system, which uses a virtual cable in the sky in order to guide the driver (Figure 4.27a). Tönnis et. al [175] did use a contact analogue visualization for a lateral and longitudinal support, which is based on an idea originally proposed by Bubb [32]: the “Braking Bar”. This is a concept that uses a contact analogue bar in front of the vehicle to indicate the minimum stopping distance (Figure 4.27b). Spiessl [165] used a visualization called “Magic Carpet” as a contact analogue visualization for visualizing lateral errors in automatic longitudinal and lateral assistance systems (Figure 4.27d).

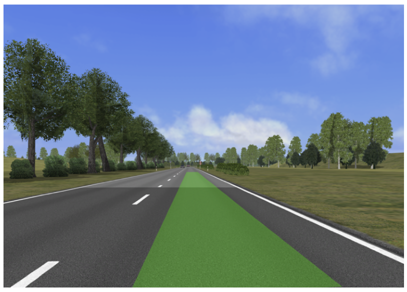


(a) Virtual Cable, for assisting navigation, from [110]



(b) Braking Bar, indicating the stopping distance, from Tönnis et. al [175]

(c) 3D arrow, for indication of hazard source, from Toennis & Klinker [174]



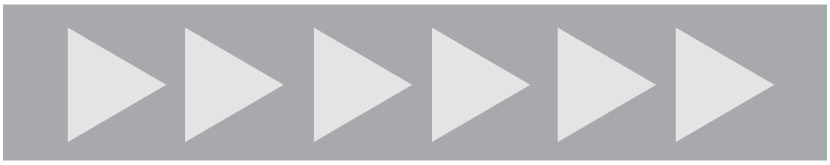
(d) Magic Carpet, indicating a the future path of a vehicle, from Spiessl [165]

Figure 4.27.: Related work: contact analogue automotive visualizations from different

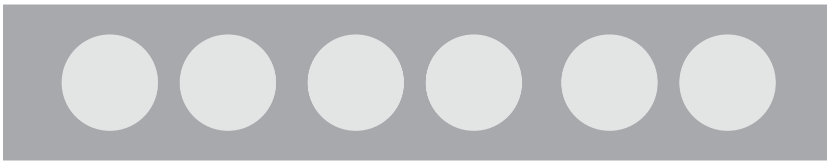
4.5.2. Conceptional Work

The Idea Keeping the visualization simple and not distracting were two of the main design goals. It is not possible to highlight information from beyond the visual horizon directly using a contact analogue visualization, therefore, an indirect message has to be incorporated into the visualization.
A concept similar to the virtual cable, has the advantage of being able to combine navigational information and prospective information. Therefore, the basic idea was a contact analogue navigational line, in combination with three different colors that communicated the information from the deceleration assistance system.

Design Rationalities Several different designs for the VRL were discussed. Figure 4.28 shows different alternatives. Figure 4.28a to 4.28c show different versions of a dashed line. Triangles, circles and a normal dashed line were possible alternatives. All three designs were discarded due to unsteadiness of a dashed line, which gives the eyes of the observer points of references which can, but should not, be fixated. A solid line, as can be seen in Figure 4.28d, was finally chosen, as is does not provide points of reference and hereby, a smooth visualization is achieved.



(a) A dashed line consisting of triangles



(b) A dashed line consisting of circles

(c) A "normal" dashed line

(d) Solid line

Figure 4.28.: Design alternatives for the VRL

Two locations for the VRL are possible: directly on the street or above the head of the observer. Figure 4.29 shows the possible positions. A position directly on the street does have the advantage of being directly at the center of the driver's field of view. Reaction should be faster and information is harder to oversee. The position above the head of the driver does have the advantage that no other vehicle or obstacle can occlude the visualization; especially in heavy traffic this can be a problem. As the deceleration assistance system is not primarily a traffic safety system, the position above the head of the driver was implemented.

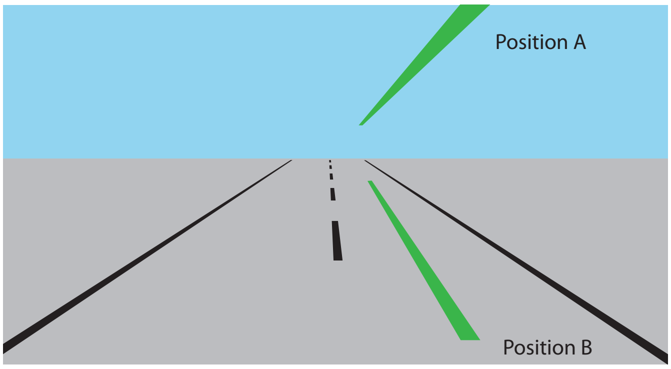
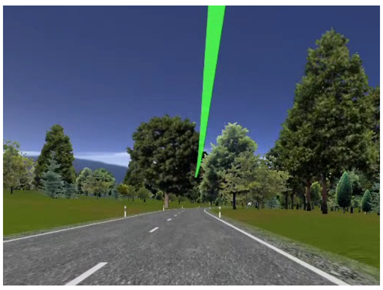


Figure 4.29.: Possible positions of the VRL (green), directly on the street (Position B) or above the head of the observer (Position A)

Implementation Instead of using a head mounted display or CAHUD, it was decided to integrate the VRL directly into the virtual environment of the simulator. This provided several advantages: No need for extra and expensive hardware, fast to realize, perfect matching between the environment and the assistance visualization as well as an unlimited field of view. Regarding the six classes of hybrid display environments defined by Milgram & Kishino [116], this approach best fits class 6: "Completely graphic but partially immersive environments (e.g. large screen displays) in which real physical objects in the user's environment play a role in (or interfere with) the computer generated scene" and can be best called augmented simulated reality [165].

Information Encoding Figure 4.30 shows the three stages of information encoding: the white line with no action requested from the driver, the green line indicating the request for "release gas" and Figure 4.30c show the request for stepping on the brake.

(a) Idle state, no request for action, solid white line



(b) Deceleration situation, request for action: "release gas", solid green line

(c) Deceleration situation, request for action:"step on brake", solid yellow line

Figure 4.30.: Three different states of the VRL

5. Evaluation of Visualization Possibilities, a Video Experiment

Evaluating six graphical possibilities to support early deceleration in a fast to conduct video experiment.

Three different visualizations were introduced in Chapter 4: the BEV, the Navimap and the contact analogue VRL. All concepts support the driver in early deceleration by providing information on the upcoming situation and two of these visualizations (BEV and VRL) advise him with two kind of actions: "release gas" and "step on brake". In order to reduce the number of possible visualizations before conducting an interactive driving simulator experiment, a video experiment was conducted. Three further visualizations called "chevrons", "iconic" and "LED" were evaluated during the experiment but are not described in this work. Further descriptions of these visualizations can be found in Laquai et al. [102] and [101]. The objective, the experimental design, the results and the conclusion of the video experiment are part of this chapter.

5.1. Objective

The objective of this evaluation was to reduce the number of visual concepts in order to conduct an in-depth usability evaluation using an interactive driving simulator.

5.2. Experimental Design

A video experiment with a within subjects design was chosen. The experiment took place in a fixed-based driving simulator with 30 subjects. As independent variables the visualizations were evaluated and the subjective acceptance of each variant was measured. This chapter provides an overview of the experimental design.

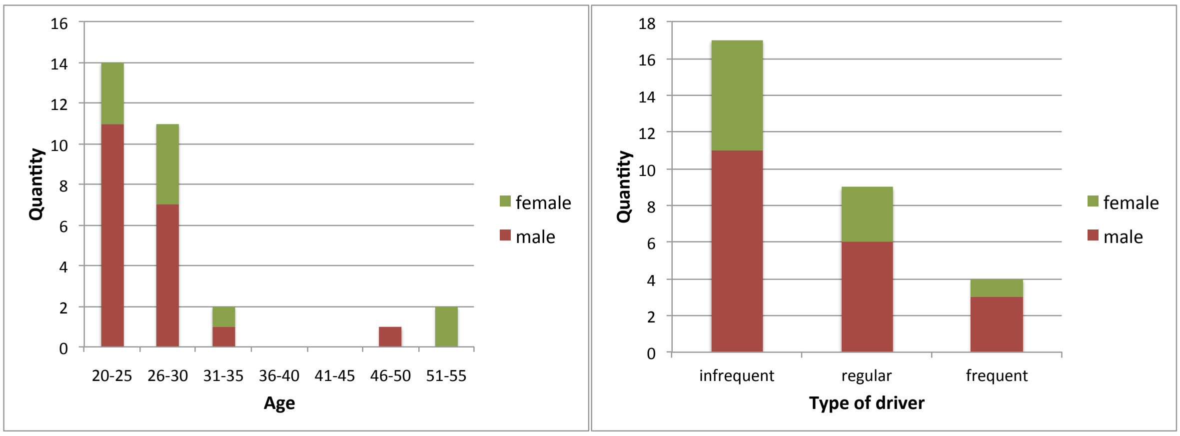
5.2.1. Subjects

30 subjects took part in the experiment, consisting of 20 male and 10 female subjects. The average age of the subjects was 27.9 years with a standard deviation of 8.7 years. All subjects held a valid category B driving license, with at least 4 years of driving experience. Subjects were divided into infrequent, regular and frequent drivers. Drivers were categorized due to the following criteria:

- Infrequent: up to 10,000 km/y

- Regular: between 10,000 km/y and 20,000 km/y
- Frequent: over 20,000 km/y

Figure 5.1 shows the distribution of age, gender and driving experience. Mainly students from the "Technische Universität München" participated in the experiment. This explains the statistic in Figure 5.1a, showing that 46% (14) of the subjects were between 20 and 25 years old. Regarding the driving experience, 43% of the subjects could be considered regular or even frequent drivers with more than 10,000 km per year.



(a) Age distribution of the subjects

(b) Driving experience distribution of the subjects

Figure 5.1.: Subject distribution for the video experiment

5.2.2. Apparatus

To carry out the experiment, a fixed-base driving simulator at the chair for "Mensch Maschine Kommunikation" at the "Technische Universität München" was used, consisting of a BMW 5 series body with complete interior, and a projection screen of 4 x 3m, covering approximately 73° field of view. The analogue instrument cluster was removed and replaced by a freely accessible 11 inch LCD screen. Instead of the production HUD, a full color HUD was used utilizing an acrylic glass construction. Fig. 5.2 shows the driving simulator and the custom HUD. Using this HUD it was possible to project a virtual image size of approximately 30 x 40 cm.

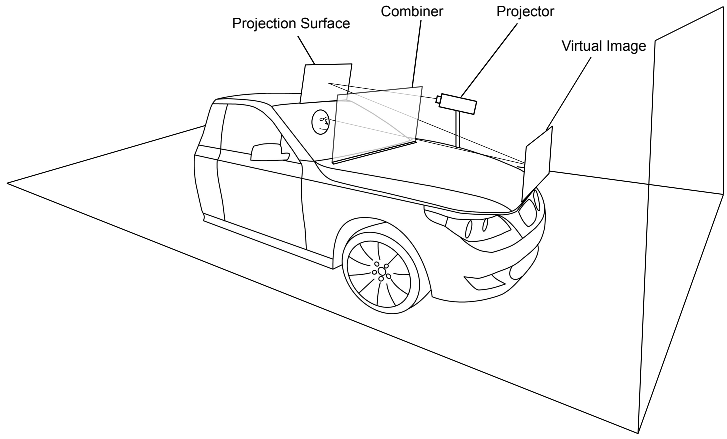


Figure 5.2.: Driving simulator mock-up for the video experiment including the custom HUD construction

Due to the number of variants, a fast to conduct video experiment, instead of an interactive driving simulator evaluation, was chosen. Therefore, a video from the driving simulator software SILAB was recorded alongside the driving data. The driving data and the video were used in a self implemented program to be synchronously played back. The necessary data for the visualization was then transmitted to the visualization. Apart from a paper questionnaire, a touchscreen was installed inside the vehicle, which allowed the subjects to rate the overall acceptance of the current visualization. The user interface which allowed a rating between 0 and 100 can be seen in Figure 5.3.
The BEV was presented to the subjects in the instrument cluster, the Navimap in the custom HUD construction and the VRL, as mentioned before, was integrated into the video (cf. Figure 4.30). Presenting the visualizations in the most appropriate way, was the main reason for this diversification of displays. Also it should be kept in mind that the concepts, not the display, was the focus of the evaluation.

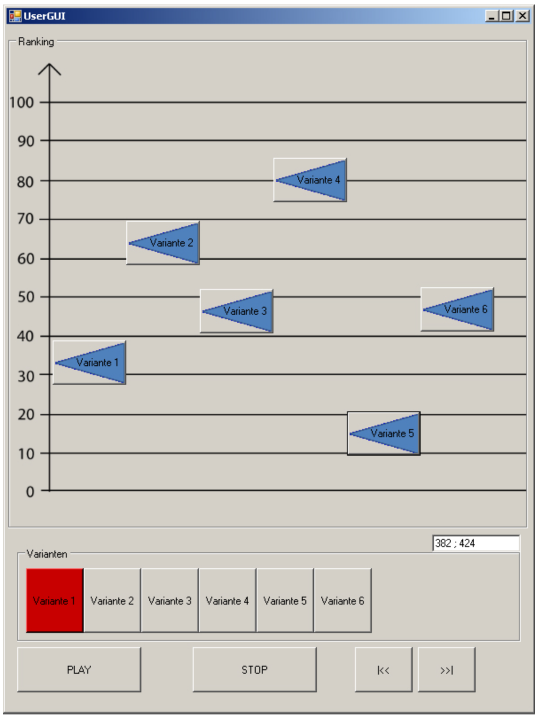


Figure 5.3.: User interface for ranking the six different graphical variants from 0 to 100, shown on a touch screen inside the driving simulator

Situations Three situations were chosen for the video. Table 5.1 shows a short overview of the situations. A complete description of the situations can be found in Appendix B.1.

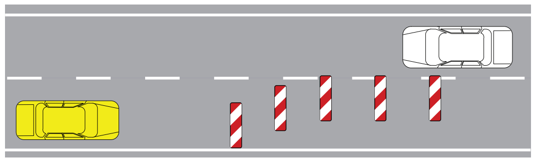
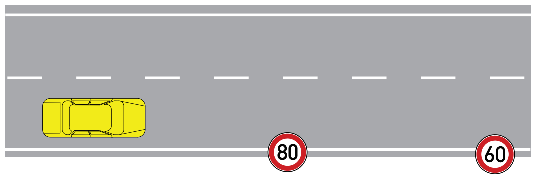
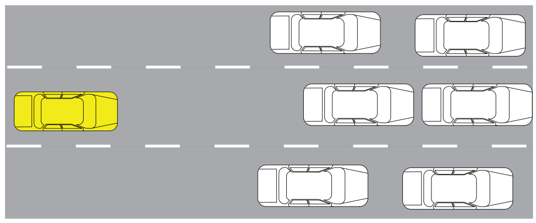
Name	Description	2D Oberview
Construction Site	Rural Road: own lane is blocked by an accident, oncoming traffic is blocking the oncoming lane.	
Speed Limit	Rural environment: two sequential speed limits with subsequently reducing speed limits; Signs are visible late.	
Traffic Jam	Highway environment: a traffic jam (still standing) is blocking all three lanes of a highway; The end of the jam is located in a right hand bend.	

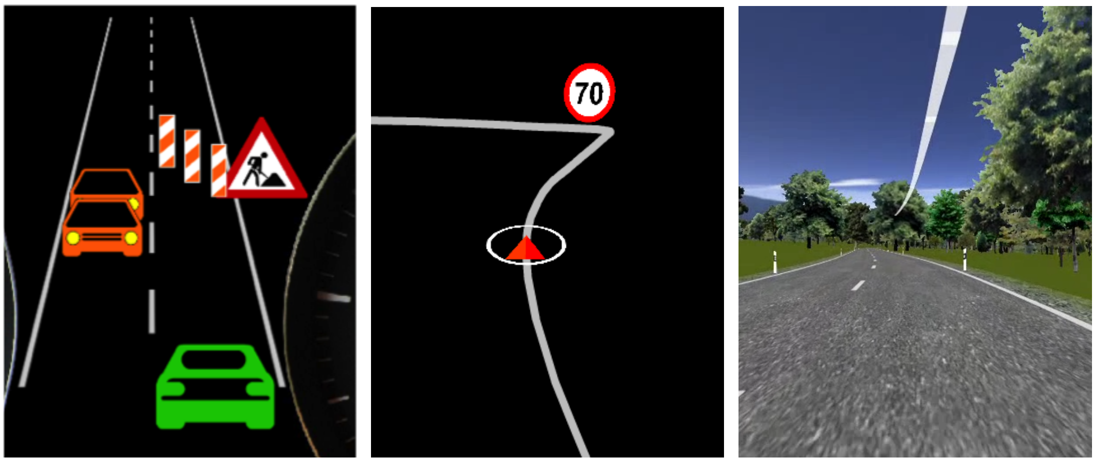
Table 5.1.: Short situations description of the three situations

The situations were chosen due to their good coverage of possible situations. The "Speed Limit" situation is a very common but simple situation. The "Construction Site" situation is very rare, but highly dynamic and complex to visualize. The "Traffic Jam" situation is rather rare, but highly safety critical.

5.2.3. Independent and Dependent Variables

Independent variables in this experiment were the visualizations presented to the subjects. Altogether six different visualizations were used, in this work only three visualizations will be considered. Information about the other three visualizations can be found in Laquai et al. [102]. A detailed explanation of the visualizations evaluated in this chapter can be found in Chapter 4.

Visualizations Figure 5.4 shows the three visualizations presented in this work:
The **BEV** (Figure 5.4a), which was shown in the instrument cluster, the **Navimap**, which was shown in the custom HUD (Figure 5.4b) and the **VRL** (Figure 5.4c), which was directly integrated into the recorded video (augmented simulated reality).



(a) The BEV - in the instrument cluster (b) The Navimap - in the custom HUD (c) The VRL - augmented simulated reality

Figure 5.4.: Three out of six different visualizations that were evaluated in the video experiment

Dependent Variables measured in the experiment were questions about the subjective acceptance of the different visualizations. This included the question, whether the visualization would be used in the subject's vehicle, the visualization was appealing and intuitive and, finally, how much the visualization supported anticipation. Also, desirable system attributes were prompted, which include e.g. helpful, appropriate, predictable, relieving, etc. Finally, open questions were asked, considering aspects liked and disliked for each variant.

5.2.4. Procedure

As the objective of the experiment was a subjective rating of the different visualizations, a within subjects design was chosen. Subjects received an standardized explanation for each concept before the start of the experiment. Each subject then saw each of the six visualizations in three different situations. The order in which the six visualizations were shown was permuted throughout the course of the experiment. The order of the situations was the same in for each visualization. Subjects were able to rate the overall acceptance of each visualization during the experiment with the use of the touchscreen mentioned and explained earlier. After the completion of the experiment, subjects received a questionnaire to rate all visualizations. The questionnaire can be found in Appendix A. The overall experiment took about 30 minutes to complete. No money was paid to the subjects for participation.

5.2.5. Evaluation Procedure

A repeated measures ANOVA was used in order to analyze the subjective data. The post-hoc analysis was performed with the use of the least significantly different test (LSD) by Fisher. The results of the ANOVA can be found at each item, including the F-value, df and p-value.

5.3. Hyptheses

Hypothesis 1: The BEV included more information than the Navimap, while the VLR has the lowest amount of information. Therefore, the BEV will be received as the most complicated visualization with highest cognitive demand, the VRL as the most simple with the lowest demand. The Navimap will be in between the other variants.
Hypothesis 2: Due to the contact analogue visualization in the VRL, it will be perceived as less distracting. The BEV, due to the fact that it is presented in the instrument cluster, will be rated the most distracting visualization.
Hypothesis 3: The BEV, due its detailed visualization, will provide the best anticipatory support.
Hypothesis 4: Due to the lack of information about the oncoming situation, the VRL will receive the lowest rating in all items that concern anticipation support.

5.4. Results

The following section shows the results of the subjective impressions the subjects had during the evaluation. The results include the rating of the variants during the video experiment, as well as the results of the questionnaire after the experiment.

Subjective Acceptance This section covers four questions of the questionnaire. Subjects were able to rate whether or not they would like to "use" the variant in his vehicle, how much the variant was "visually appealing", if the variant was "intuitively understandable" and if the variant did "support anticipation" for prospective driving. Subjects were able to rate each item from 1 (not at all) to 5 (absolutely).
Figure 5.5 shows a comparison of the mean values for each variant over all items. All variants show a similar progression and received the highest rating for the "Intuitive" item. The VRL received the lowest ratings in all four items, with all ratings, apart from the rating for "Intuitive", being below an average of 3.0. The results of the repeated measures ANOVA can be found in Table 5.2. A complete overview of the mean values, the standard deviations, minima, maxima and standard errors regarding the results of the system acceptance can be found in Table A.1 in Appendix A.2.1.
The Navimap as well as the BEV received clearly higher ratings than the VRL. All items of both variants are in the upper half of the scale, with the BEV receiving higher ratings in "Appealing" and "Use", while the Navimap receiving higher rating in "Intuitive" and "Anticipation Support".

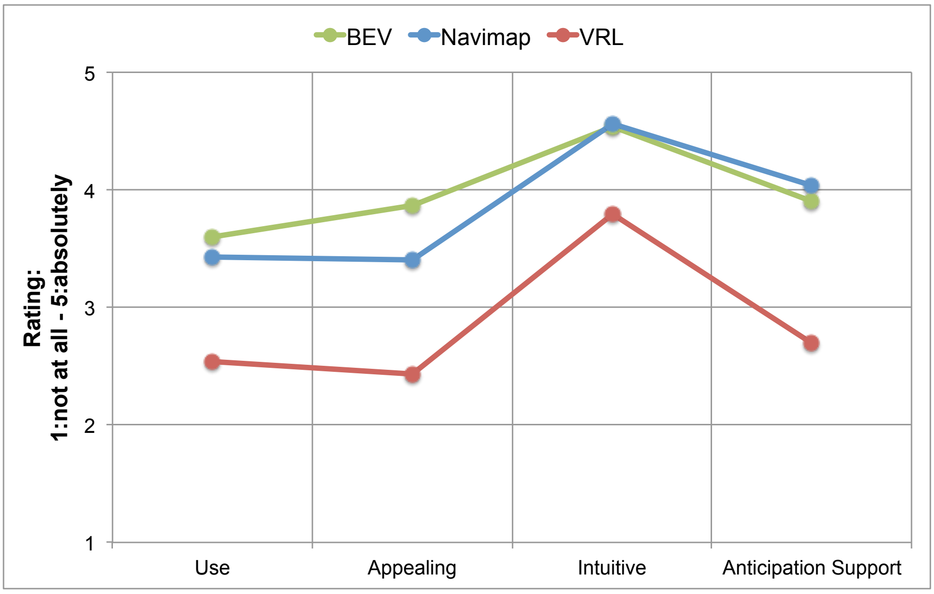


Figure 5.5.: Comparison of the mean values for four different items regarding system acceptance items

- **Use:** The BEV with a mean value of 3.6 received the highest rating. The average rating of 3.4 for the Navimap was lower than the rating for the BEV, but was still in the positive part of the scale. The VRL, with a rating of 2.5 received the lowest rating and was in the negative part of the scale. A significant difference was found with F=7.449, df=2 and p=.001. The post-hoc analysis showed no significant difference between the BEV and the Navimap, but a significant difference between the VRL and the Navimap (p=.011) and a highly significant difference between the VRL and the BEV with p=.000.

- **Appealing:** The BEV received the highest rating with a mean rating of 3.9, which was clearly in the positive part of the scale. The difference to the Navimap, which with a mean value of 3.4 also was in the positive part of the scale, was larger than in any other item. The rating for the VRL with a mean rating of 2.4, again was in the negative part of the scale. A highly significant difference was found with F=11.932, df=2 and p=.000. The post-hoc analysis showed a highly significant difference between the VRL and the BEV as well as between the VRL and the Navimap. The difference between the BEV and the Navimap is larger than in any other item, but not statistically significant with p=.105.

- **Intuitive:** This item received the overall best ratings for all variants. With a mean value of 4.5 respectively 4.6, the BEV and the Navimap received a clearly positive rating, with both ratings just 0.5 units below the perfect score of 5.0. The VRL with a mean rating of 3.8 received a rather positive rating in this item. A significant difference was found with F=8.736, df=1.537 and p=.002. The post-hoc analysis showed a highly significant difference between the VRL and both other variants with p=.003. No significant difference can be found between the BEV and the Navimap.

- **Anticipation Support:** This item was rated the second highest for all variants. The Navimap with a mean rating of 4.0 received the highest rating of all variants. The BEV, with an average of 3.9 received a marginally lower rating. Both ratings were in the clearly positive part of the scale. Only the rating for the VRL, with a rating of 2.7, was clearly lower and in the negative part of the scale. A highly significant difference was found with F= 19.422, df=2 and p=.000. The post-hoc analysis showed a highly significantly difference between the VRL and both other variants. No significant difference was found between the BEV and the Navimap.

All significances and the results of the post-hoc analysis can be found in Table 5.2.

Use			
df = 2, F= 7.449, p=0.001			
	VRL	BEV	Navimap
VRL		0.000	0.011
BEV	0.000		.567
Navimap	0.011	.567	
Appealing			
df = 2, F= 11.932, p=0.000			
	VRL	BEV	Navimap
VRL		0.000	0.007
BEV	0.000		.105
Navimap	0.007	.105	

Intuative			
df = 1.537, F= 8.736, p=.002			
	VRL	BEV	Navimap
VRL		.003	.003
BEV	.003		.813
Navimap	.003	.813	
Supporting Anticipation			
df = 2, F= 19.422, p=0.000			
	VRL	BEV	Navimap
VRL		0.000	0.000
BEV	0.000		.580
Navimap	0.000	.580	

Table 5.2.: Results of the ANOVA and post-hoc analysis for the four items regarding system acceptance

Desirable System Attributes This section covers 18 items presented to the subjects with the use of a semantic differential. For visualization purposes Figure 5.6 and Figure 5.6 present the desirable system attributes on the right side, while on the left side one can find their counterparts. In some cases it is not clear, which side is favorable. Figure 5.6 shows nine adjective-pairs with the highest combined ratings for all three visualizations, followed by Figure 5.7 presenting the adjectives with the lowest combined ratings. Subjects were able to rate on a five point scale.
All results of the repeated measures ANOVA as well the results of the post-hoc analysis can be found in Tabel A.2 and Table A.3 in Appendix A.2.2. A complete overview of the mean values, the standard deviations, minima, maxima and standard errors regarding the results of the system acceptance can be found in Tabel A.4 to Table A.6 in Appendix A.2.2 as well.

Figure 5.6 shows that all ratings for the VRL were located more to the left, and therefore, unwanted side than the ratings for the BEV and Navimap. Only for the items “obvious” and “predictable” all variants were rated similar. The ratings for the VRL were located around the undecided part of the scale with a tendency to the positive part for most items. The tendency of the VRL progression showed a slightly different behavior than the progressions for the BEV and Navimap. Both progressions, for the BEV and the Navimap, were clearly in the positive part of the scale with mean values ranging from 3.5 to 4.1. Moreover, both progressions show the same tendencies, with their ratings being very similar.

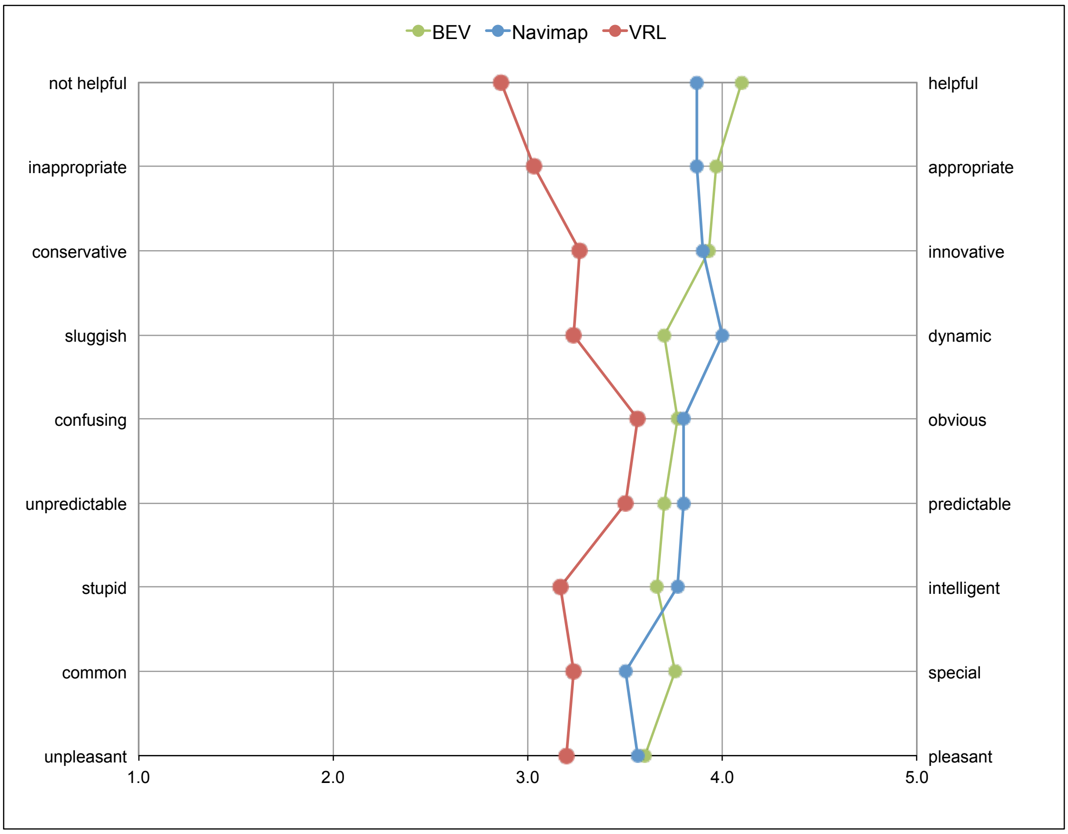


Figure 5.6.: Comparison of the mean values for the three variants regarding desirable system attributes with the highest combined mean value

- **not helpful/helpful:** With a mean value of 4.1 this was the highest rated item for the BEV and with a mean rating of 3.9 it was just marginally lower for the Navimap. Both variants were clearly on the "helpful" side of the scale. The average rating of 2.9 for the VRL was clearly lower than the rating for the other two variants and marginally on the "not helpful" side of the scale. A highly significantly difference was found with F=12.824, df=2 and p=.000. The post-hoc analysis showed a highly significant difference between the VRL and the BEV with p<=.01. Also a highly significant difference between the VRL and the Navimap with p<=.01 was found.

- **inappropriate/appropriate:** With a mean value of 4.0 and 3.9 for the BEV respectively for the Navimap, this item was also rated high for both visualizations. The mean values of both visualizations were clearly on the "appropriate" side of the scale. With a mean rating of 3.0, the VRL was located on the undecided part of the scale and clearly lower than the rating for the BEV and the Navimap. A highly significantly difference was found with F=11.168, df =2 and p=.000. The post-hoc analysis showed a highly significant difference between the VRL and the BEV with p<=.01.Also a highly significant difference between the VRL and the Navimap with p<=.01 was found.

- **conservative/innovative:** All three mean values were located in the "innovative" part of the scale. With a mean rating of 3.9, the BEV and the Navimap did receive a clearly positive rating. The mean rating of 3.3 for the VRL could be described as neutral with a tendency to the positive part of the scale. A significant difference between the variants was found with F=4.268, df=2 and p=.019. The post-hoc analysis showed a significant difference between the VRL and both other visualizations with p <=.05.

- **sluggish/dynamic:** This item did receive the highest rating for the Navimap variant with a mean rating of 4.0 and was therefore in the clearly positive part of the scale. The rating for the BEV followed with a rating of 3.7, which was also located in the positive part of the scale. The rating for the VRL was only marginally in the positive part with a mean value of 3.2. A significant difference between the variants was found with F=6.652, df=2 and p=.003. The post-hoc analysis showed a highly significant difference between the VRL and the Navimap with p <=.01. No other differences were significant.

- **confusing/obvious:** With mean ratings of 3.6, 3.8 and 3.8 for the VRL, BEV and Navimap, all variants did receive similar ratings. All ratings were located in the rather positive part of the scale, with the BEV and the Navimap having received slightly better ratings than the VRL. No significant difference was found with F=0.440, df=2 and p=.646.

- **unpredictable/predictable:** Again, the ratings for the VRL, BEV and Navimap were similar with mean values of 3.5, 3.7 and 3.8. All ratings were located in the rather positive side of the scale. The Navimap was considered the most "predictable" visualization, while the VRL was rated least predictability. No significant difference was found between the variants with F= 1.052, df=1.512 and p=0.356.

- **stupid/intelligent:** Both ratings for the BEV and the Navimap (3.7 and 3.8) could be considered on the clearly "intelligent" side of the scale, with the Navimap having received a marginally better rating. The rating for the VRL with 3.2 had to be considered neutral with a tendency to the "intelligent" side. A significant difference was found between the visualizations with F=4.268, df=2 and p=.019. The post-hoc analysis showed a significant difference between the VRL and both other visualizations with p <=.05. No significant difference between the BEV and the Navimap was found.

- **common/special:** An equal distribution of the variants with mean values of 3.2, 3.5 and 3.8 for the VRL, Navimap and BEV was found. All ratings were located on the special side of the scale. The BEV with a 3.8 rating could be considered "special", while the VRL was only marginally conceived "special". A significant difference was found between the visualizations with F=6.652, df=2 and p=.003. The post-hoc analysis showed a significant difference between the VRL and the BEV with p<.05.

- **unpleasant/pleasant:** With mean ratings of 3.2 for the VRL and 3.6 for the BEV and the Navimap, all visualizations were considered rather "pleasant", with the VRL having received the lowest rating. No significant difference was found with F=0.958, df=2 and p=.380.

Figure 5.7 shows items of the semantic differential with the lowest combined values. Apart from the items "simple" and "reserved" the progressions of the BEV and the Navimap again were located in the more positive part of the scale than the VRL. Both progressions (BEV and Navimap) did have the same tendencies. The BEV was located marginally more to the right than the Navimap, except for the items "makes fun", "clear" and "simple". Apart from the items "not distracting" and "reserved" all ratings of the Navimap and the BEV were located in the positive part of the scale. The progression of the VRL did have a slightly different tendency and also was located in the slightly negative part of the scale at all items, except for the items "simple", "clear" and "reserved".

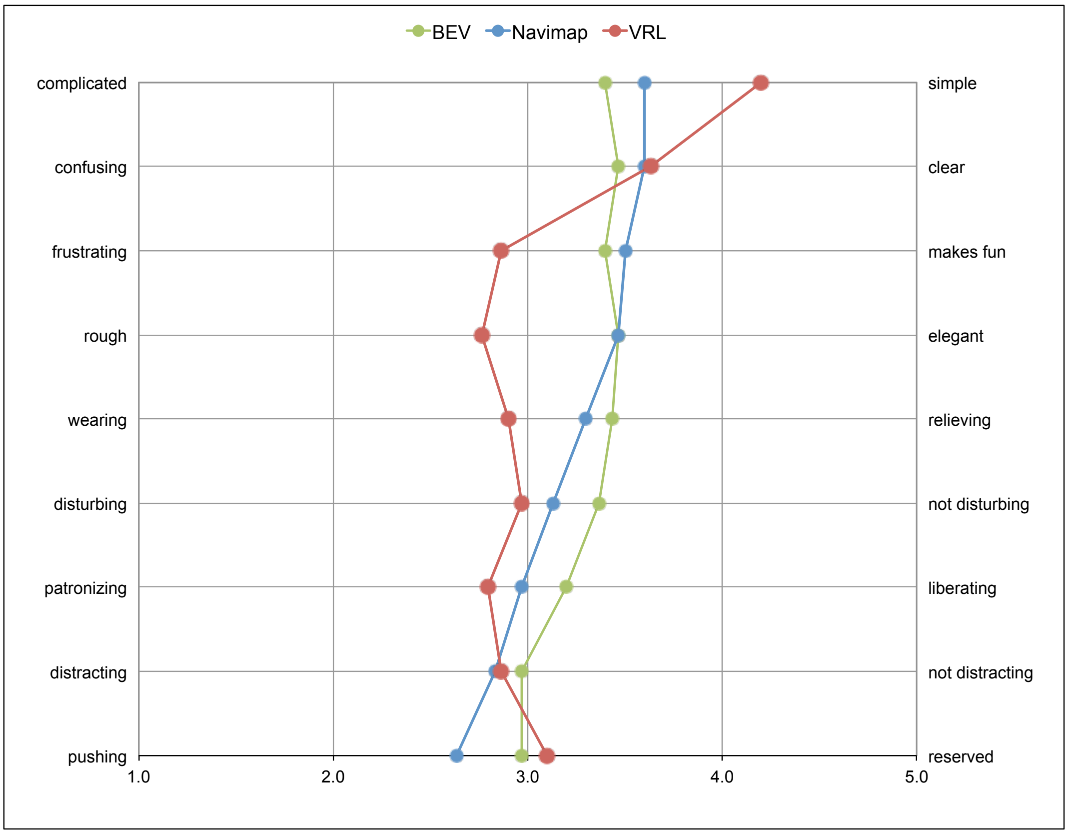


Figure 5.7.: Comparison of the mean values for the three variants regarding desirable system attributes with the lowest combined mean value

- **complicated/simple:** With a rating of 4.2 for the VLR, this variant received the highest rating for all variants and all items. The mean values (3.4 and 3.6) for the BEV and the VRL were also on the rather "simple" side of the scale but clearly lower than the rating for the VRL. A highly significant difference between the variants was found with F=7.616, df=2 and p=.001. The post-hoc analysis showed a highly significant difference between the VRL and the BEV and a significant difference between the VRL and the Navimap.
- **confusing/clear:** The ratings for this item were very similar, with mean values of 3.5 for the VRL and 3.6 for the BEV and the Navimap. All ratings were on the rather "clear" side of the scale. No significant difference was found with F=0.213, df=2 and p=.809.
- **frustrating/makes fun:** The ratings for the BEV and the Navimap with 3.4 and 3.5 were on the far more positive side of the scale than the mean rating of the VRL with

2.9. Both ratings, for the BEV and the Navimap, were located on the rather "makes fun" side of the scale, while the rating for the VRL could be considered neutral with a tendency to the "frustrating" side. A significant difference was found with F=4.228, df=2 and p=.019. The post-hoc analysis showed a significant difference between the VRL and both other variants.

- **rough/elegant:** The BEV and the VRL, both received a mean rating of 3.5 and were located on the rather "elegant" side of the scale. Again, the VRL did receive a lower rating and, with a mean value of 2.8, could be considered marginally "rough". A significant difference was found between the visualizations with F=5.587, df=2 and p=.006. The post-hoc analysis showed a significant difference between the VRL and both other variants with p<.05.

- **wearing/relieving:** With a mean rating of 3.3 and 3.4, for the Navimap and the BEV, both were located on the rather "relieving" side of the scale. The VRL, with a mean rating of 2.9, was located in the neutral part. A significant difference was found between the visualizations with F=3.523, df=2 and p=.036. The post-hoc analysis showed a significant difference between the VRL and the BEV with p=0.024.

- **disturbing/not disturbing:** Both, the Navimap and the VRL with mean ratings of 3.1 and 3.0, did receive a neutral rating for this item. Only the rating for the BEV, with an average of 3.4, can be considered as rather "not disturbing". No significant difference was found with F=0.972, df=2 and p=.384.

- **patronizing/liberating:** With ratings of 2.8, 3.0 and 3.2 for the VRL, the Navimap and the BEV, all variants received a rather neutral rating, with a tendency for the VRL to the "patronizing" side and tendency for the BEV to the "liberating" side of the scale. No significant difference was found with F=2.326, df=2 and p=.107.

- **not distracting/distracting:** All mean ratings, with 2.8, 2.9 and 3.0 for the Navimap, the VRL and the BEV, were either neutral or had a tendency to the distracting part of the scale. The Navimap did receive the most "distracting" rating. No significant difference was found with F=0.130, df=2 and p=.878.

- **pushing/reserved:** With a rating of 2.6, the Navimap received the most "pushing" rating of all variants. Both ratings for the BEV and the VRL, with 3.0 and 3.1, were in the neutral part of the scale. No significant difference was found with F=1.526, df=2 and p=.226.

Rating Figure 5.8 shows the comparison between the three variants during the experiment. The data, as explained before, was collected via a touchscreen inside the driving simulator. Subjects had the possibility to rate the overall acceptance of each visualization between 0 (lowest rating) and 100 (highest rating). The Navimap, with an average of 61.9 did receive the highest rating, followed by the BEV with 53.5 and the VRL with 35.7.

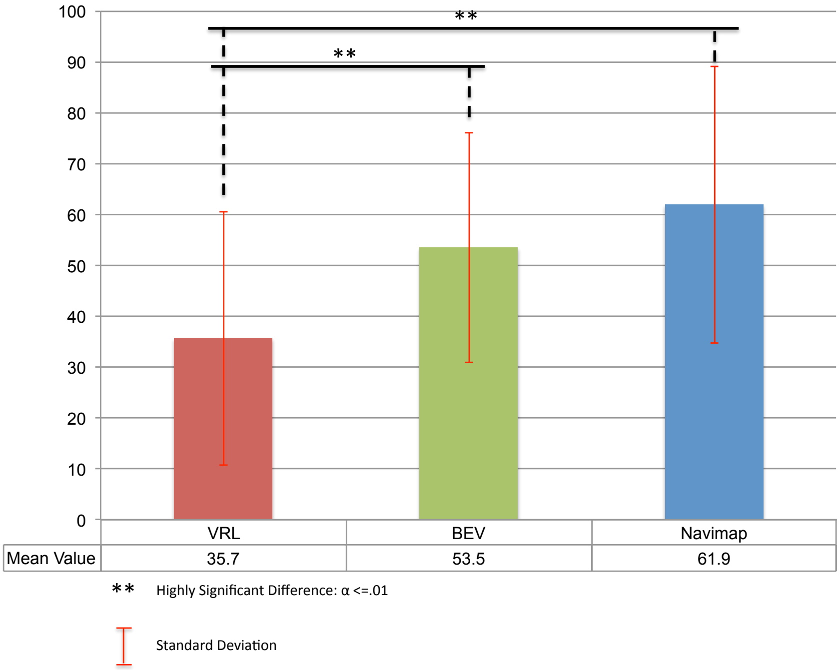


Figure 5.8.: Mean rating for all three variant regarding the overall acceptance, measured via the touchscreen

A highly significant difference was found between the visualizations with F=5.587, df=2 and p=.006. The post-hoc analysis showed a highly significant difference between the VRL and the BEV as well as between the VRL and the Navimap. No significant different was found between the BEV and the Navimap. Results of the repeated measures ANOVA and post-hoc analysis can be found in Table 5.3. A complete overview of the mean values, the standard deviations, minima, maxima and standard errors regarding the results of the system acceptance can be found in Table A.7 in Appendix A.2.3.

ANOVA for the Rating			
F= 5.587, df = 2, p=0.006			
	VRL	BEV	Navimap
VRL		0.008	0.001
BEV	0.008		0.184
Navimap	0.001	0.184	

Table 5.3.: Results of the repeated measures ANOVA and post-hoc analysis

Open Questions Table 5.4 to Table 5.6 show an overview of the open questions, regarding aspects liked and disliked.
For the VRL, a total of 18 statements regarding aspects liked were mentioned by the subjects. With 5 respectively 6 statements, the simple presentation as well as the place of projection was mentioned. A total of 20 statements regarding aspects disliked were mentioned. These statements mainly concerned color and too little information.

VRL			
Aspects liked		Aspects disliked	
Total	18 statements	**Total**	20 statements
Simple presentation	5 statements	Color	5 statements
Place of projection	6 statements	Too little information	4 statements
Supports Lane Keeping	4 statements	Visualization of the course of the road	2 statements

Table 5.4.: Statements on aspects liked and disliked considering the VRL

Regarding aspects liked and disliked for the BEV: A total of 22 statements regarding aspects liked were mentioned by the subjects. These statements mainly mentioned the good visualization of the situation and the intuitive and clear visualization. 11 statements were mentioned regarding aspects disliked; 7 out of these 11 statements mentioned a visual overload as a negative aspect.

BEV			
Aspects liked		Aspects disliked	
Total	22 statements	**Total**	11 statements
Good visualization of the situation	6 statements	Visual overload	7 statements
Intuitive & clear	5 statements		

Table 5.5.: Statements on aspects liked and disliked considering the BEV

Finally, 20 statements regarding aspects liked and 12 statements regarding aspects disliked were mentioned by the subjects when asked about the Navimap. Regarding aspects liked: 7 statements referred to the visualization of the course of the road, 5 referred to the good overview and that the visualization was not disturbing. Concerning aspects disliked: 5 out of 12 statements regarded the constantly large visual presentation and 3 statements the bad graphical visualization.

Navimap			
Aspects liked		Aspects disliked	
Total	20 statements	**Total**	12 statements
Course of road	7 statements	Consistent large visualization	5 statements
Good overview, not disturbing	5 statements	Bad graphics	3 statements
Navigation visualization	3 statements		

Table 5.6.: Statements on aspects liked and disliked considering the Navimap

5.5. Discussion

Regarding the general acceptance of the three variants: Results do not show a clear tendency between the BEV and the Navimap. Both visualizations received high ratings regarding the items "use", "appealing","intuitive" and "anticipation support". Only for the item "appealing" the difference between the BEV and the Navimap is prominent and just missed a tendency with p=0.105. Both variants received a nearly perfect rating for the item "intuitive". The fact that subjects only saw the variants for about one minute each, might explain the difficulty to differentiate between the variants. Also, the number of subjects relative to the number of variants (6 overall) was chosen quite low. Only the rating for the VRL is significantly lower in all items.

Regarding the amount of information presented: The visualization with the fewest amount of information, the VRL, was perceived as the simplest visualization (supporting Hypothesis 1). But results on the items "clear" and "wearing" and "distracting" show that although the visualization was perceived simple, it is not less confusing or distracting and even more wearing than both other visualizations. This partially negates Hypothesis 2, which proposed that the low amount of information would be conceived as less complicated and that fewer cognitive demand would be necessary to capture the presented information. This result might be influenced by the overall low rating for the VRL. Therefore, it should not be concluded that a contact analogue visualization for a deceleration assistance system is more wearing than a visualization in a HUD or the instrument cluster. Improving the VRL with additional information on the upcoming situation could resolve this problem.

The BEV as well as the Navimap seem to equally support anticipation. In the direct question, as well as in the items "helpful", "appropriate" and "predictable" both visualizations received equal ratings. This partially negates the hypothesis (Hypothesis 3) that the BEV provides the best anticipation support due to the most detailed information provided. The visualization of simple situations in a less detailed view, as done in the Navimap, seemed to be accepted by the subjects.
The VRL received worse ratings in all these items, and, therefore, confirms the hypothesis (Hypothesis 4) that the simple visualization is not enough to properly support anticipation beyond the visual horizon. This result confirms the results by Samper & Kuhn [147], which showed that the visualization of the regulation object was considered useful.

5.6. Conclusion

A simple color code for the request of action was not enough. The VRL did not incorporate enough information for supporting prospective action. If such a visualization should be used in a deceleration assistance system, it is necessary to add information about the upcoming situation.
It was possible to visualize complex situations using a large amount of visual elements, if the information was shown in a naturalistic way. A complex visualization did not necessarily mean an increased cognitive load.
For a deeper usability evaluation a reduction in variants is necessary. Also, a video experiment cannot replace an interactive driving simulator evaluation.

In order to reduce variants a video experiment was useful; indications of problems could be detected.

6. Evaluation of the Bird's Eye View as a Visualization for Prospective Driving

A driving simulator user study evaluating the "Bird's Eye View" against an "Iconic" visualization.

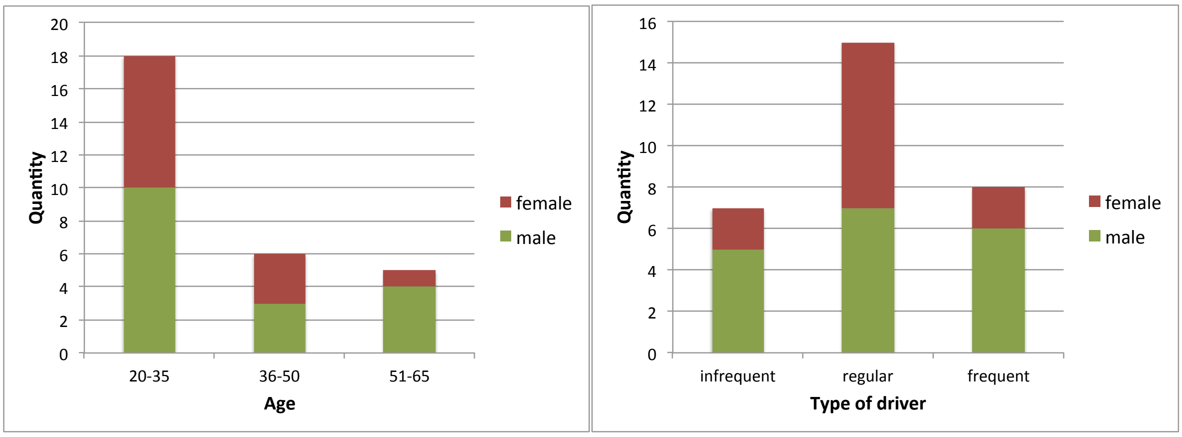
A video experiment was conducted in order to reduce a large variety of visualizations. The BEV and an Iconic variant (Laquai et al. [102] and [101]) were chosen to be further evaluated. Regarding a deceleration assistance system, these variants span a continuum, from the lowest amount of information necessary (Iconic: request for action and symbol to indicate situation) to the maximum amount of information that should be shown to the driver (BEV: number of lanes, other traffic, etc.). In order to evaluate both concepts, a driving simulator experiment was chosen, which allows a qualitative comparison and is an indicator for quantitative conclusions. The experimental design, including an overview of the subjects, the apparatus, dependent and independent variables, the procedure, results and a conclusion are part of this chapter.

6.1. Experimental Design

A fix-based driving simulator experiment was conducted with 29 subjects. Two visualizations, the BEV and an Iconic visualization as well as seven categories of situations were used as independent variables. Acceptance, usability, workload and gaze distraction were measured as dependent variables. This section provides an overview of the experimental design.

6.1.1. Subjects

29 subjects, 18 male and 11 female, participated in the experiment. The average age of the subjects was 35.7 years with a standard deviation of 13.1 years. All subjects held a valid category B driving license, with at least 5 years of driving experience. Figure 6.1 shows the distribution of age, gender and driving experience. 24% (7) can be considered infrequent driver with an average of up to 10,000 km per year. 48.3% (15) of the subjects can be considered regular drivers with a driving amount of 10,000 to 20,000 km per year and 27.7% (8) can be considered frequent drivers with more than 20,000 km per year.



(a) Age distribution of the subjects (b) Driving experience distribution of the subjects

Figure 6.1.: Subject distribution for the driving simulator experiment

6.1.2. Apparatus

A fixed-base driving simulator at the "Lehrstuhl für Ergonomie (LfE)" at the Technical University Munich was used. The simulator consisted of a complete BMW 6 series body and three front facing 3x2 meter projection screens, which resulted in an overall field of view of 180°. The interior of the simulator was left to production standards, only the original analogue instrument cluster was replaced with a freely accessible 11 inch LCD screen in order to present custom visualizations to the driver. The test course was implemented using a driving simulator software called SILAB. The software allowed easy implementation of test course scenarios and recorded the driving data with 60 Hz.
Gaze behavior also was recorded using a head mounted eye tracking system called DIKABLIS [60]. The system recorded the visual data at 25 Hz and allowed real time analysis during the experiment as well an offline analysis after experiment.

6.1.3. Independent and Dependent Variables

Different visualizations and different situations, in which the driver was supported in early deceleration, were the independent variables in this experiment.

Visualization Figure 6.2 shows both visualizations used in the experiment. Figure 6.2a shows an example representation of the BEV; detailed information can be found in Chapter 4.3. Figure 6.2b shows the second visualization, called Iconic from now on. It uses a symbolic visualization for the upcoming situation and a 3D representation of the gas and brake pedal in order to visualize the requested action of the driver (further description follows below). It was decided to evaluate these two visualizations, as a continuum was spanned up by them: From the Iconic visualization, which was the variant with the minimum amount of information possible (reason for deceleration and request for action) and the BEV, having been the visualization, which included the most information that should be to present to the driver. The last variant was a baseline visualization, with just the instrumental cluster and no additional information shown to the driver.

(a) Bird's Eye View visualization (b) Iconic visualization

Figure 6.2.: Exemplary situation (traffic jam) visualization for the two different visualizations used in the experiment

Both visualizations incorporated two essential pieces of information, a situation description and the request for "release gas" or "step on brake". Table 6.1 shows, how the BEV communicated the description of the situation and the two just mentioned requests. The situation and all relevant objects were visualized on a short piece the virtual street, the request for action was communicated by the color and size of the virtual ego-vehicle in the BEV. A green ego-vehicle indicated "release gas", while a yellow ego-vehicle indicated "step on brake". In the Iconic visualization, the upcoming deceleration situation was decoded by an official traffic sign which indicated the upcoming situation. The sign itself had a gray border due to the fact that at the moment it was shown to the driver, it is not already valid. The request for action ("release gas" "step on brake") was visualized by a 3D representation of the gas and the brake pedal. The according pedal (gas or brake) was highlighted by an orange color as well as it was animated (the pedal was moving back and forth). (Table 6.2) In case of no deceleration situation, the BEV showed the driver an empty piece of street (Table 6.1), while the Iconic visualization disappeared completely. It was decided not to completely remove the virtual piece of street in the BEV, due to a too high potential for distraction when a large amount of visual elements fading out and in.

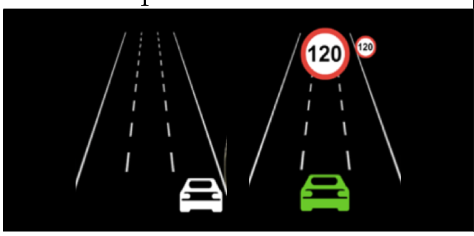
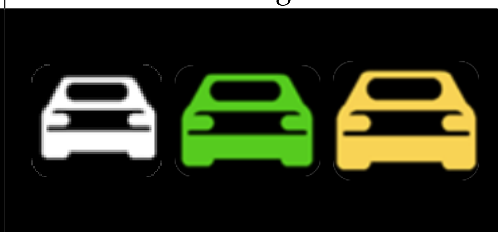
Bird's Eye View	
Representation of the situation	Request for action
Virtual representation of the Road	Color-coded ego-vehicle
	

Table 6.1.: Overview on the situation visualization and request for action encoding in Bird's Eye View Visualization

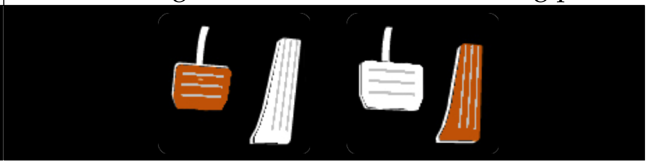
Iconic visualization	
Representation of the Situation	Request for action
official traffic sign	Color coding and animation of according pedal
	

Table 6.2.: Overview on the situation visualization and request for action encoding in Iconic Visualization

In order to evaluate the visualizations, a deceleration assistance system had to be implemented. The deceleration strategy that was used during the experiment was as follows: When the ego-vehicle approached a deceleration situation, the driver was informed to "release the gas" padal at a point in time that allowed the vehicle to coast to the necessary limit without braking. If the driver did not release the gas pedal or the situation was detected too late, the system informed the driver to "step on the brake" pedal. A detailed description of the algorithm and the deceleration strategy can be found in Popiv [135].

Situations Thirteen situations were implemented in the test course; seven categories of situations were used to evaluate the user acceptance and usability. Following, a short description of the seven categories, a complete description of all 13 deceleration situations can be found in Appendix B.1.

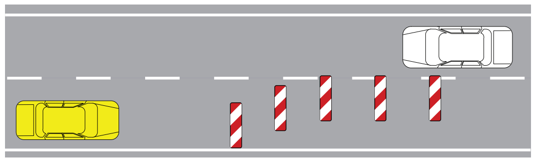
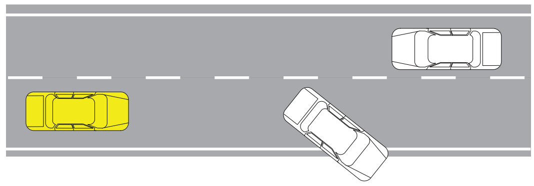
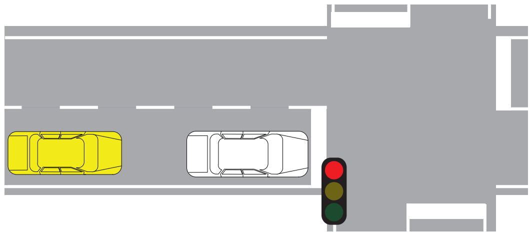
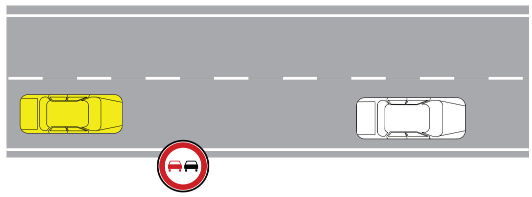
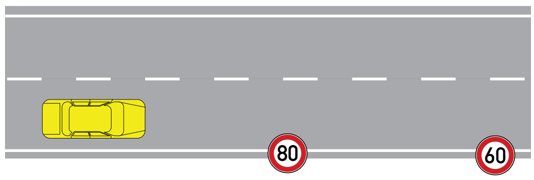
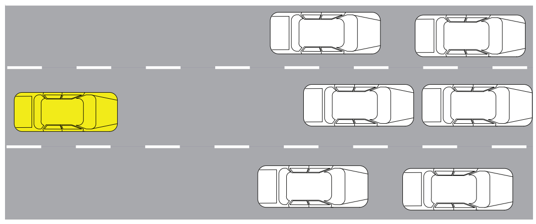
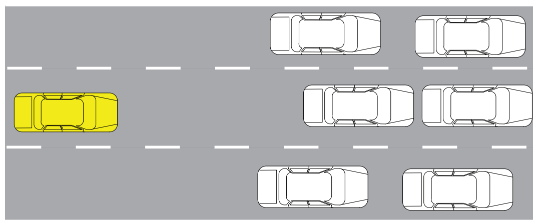
Name	Description	2D Overview
Construction Site	Rural Road: own lane is blocked by an accident (construction site), oncoming traffic is blocking the oncoming lane.	
Parking Vehicle	Urban environment: own lane is blocked by a parked vehicle, oncoming traffic is blocking the oncoming lane.	
Traffic Light	Urban environment: red traffic light ahead, other vehicles are waiting in front of traffic lights.	
Slow Preceding Vehicle	Rural environment: slow vehicle in front, overtaking is prohibited or blocked by oncoming traffic.	
Speed Limit	Rural environment: two sequential speed limits with reducing speed; Signs are visible late.	
Slow Moving Jam	Highway environment: a slow moving jam (60km/h) is blocking all three lanes of a highway.	
JamTraffic	Highway environment: a traffic jam (still standing) is blocking all three lanes of a highway, the end of the jam lies in a right hand bend.	

Table 6.3.: Short situation description of seven situation categories

Dependent Variables Dependent variables that were measured:

- Subjective workload: Measured using the one dimensional SEA scale, which rates the subjective workload with a value from 0 (no workload) to 240 (the maximum amount of workload).
- Gaze distraction due to the visualizations: Measured by the DIKABLIS system and represented in the mean and maximum gaze duration on the instrument cluster during the deceleration situations.
- Desirable system attributes: Measured by the use of a semantic differential questionnaire right after the test drive of each variant. Adjectives that were prompted are e.g.: helpful, appropriate, predictable, relieving, etc.
- Subjective impressions within different situations: Measured by a questionnaire after the completion of all three test drives.
- Overall acceptance of the system, regarding the aspect of likability, understandability and how well the system prepares for the upcoming situation.
- Acceptance of the system activation point.

6.1.4. Procedure

Subjects had the possibility to again themselves with the simulator in an introduction drive, which took about 20 minutes to complete. Afterwards, a so-called first-contact scenario was presented to the subject, in which both visualizations were shown to the subjects in three different deceleration situations. After the first-contact scenario, an oral interview was conducted, in which subjects were asked about the visualization considering aspects like "what the system is about", "which information was seen by the subjects" and "what was the meaning of the information". Accordingly, both visualizations were explained to the subjects using a prepared statement. In the main part of the experiment, three variants (Baseline, Iconic, BEV) were driven by the subjects, 20 minutes each. The test course included 13 deceleration situations. To reduce the learning effect, the order of the three variants was permuted throughout the course of the experiment. During the test drives, drive data was collected and after each drive a questionnaire was presented to the subjects, concerning subjective workload and specific questions about the just seen visualization. After the completion of the three test drives, a final questionnaire was given to the subjects, whose main content was the comparison of the two visualizations. The original questionnaire can be found in Appendix B.2. During the three test drives the gaze behavior was recorded using a gaze detection system ("DIKABLIS"). The whole experiment tool about 90 minutes to conduct.

6.1.5. Evaluation Procedure

A repeated measure ANOVA was used in order to analyze the workload and the gaze behavior. The post-hoc analysis was performed with the use of the least significant different test (LSD) by Fisher. The results of the ANOVA can be found at each item, including the

F-value, df and p-value.
All other subjective data was analyzed with the use of a 2-tailed T-Test for repeated measures. The t-value and p-value can be find at the according item.

6.2. Hypotheses

The following hypotheses should allow a prediction for the comparison between the Iconic, the BEV and the Baseline.
Hypothesis 1: The use of the deceleration assistance system will result in a lower workload, independent of the visualization.
Hypothesis 2: Due to the additional visualization, the gaze distraction (mean and maximum) of both visualizations will be higher than during the baseline.
Hypothesis 3: Due to the large number of visual elements in the BEV, the gaze distraction (mean and maximum) will be higher than for the Iconic visualizations
Hypothesis 4: Due to the better graphical possibilities of the BEV, the visualization allows better recognition of the situation than the Iconic visualization.
Hypothesis 5: The BEV will be perceived as less pushing than the Iconic visualization, due to a less dominant graphical request for action.

6.3. Results

Subjective and objective results are presented.

6.3.1. Subjective Results

This section presents the subjective results, including the subjective workload, the acceptance of the system and the visualizations, situation dependent results as well as free statements of the subjects concerning aspects liked, disliked and missed information.

Workload The subjective workload was measured using the one dimensional SEA scale, which measures the workload on a scale from 0 (no workload) to 220 (more than an extraordinary workload). The workload was measured with the use of a questionnaire that was handed to the subjects after driving each variant. Figure 6.3 shows the results of the workload measurement. With mean values of 77, 67 and 50, all three variants were rated with a low to medium workload. A significant difference was found with F=16.024, df=1 and p=.000. The post-hoc analysis showed a highly significant difference between the **Baseline** and the **BEV** (p=.001) as well as a significant difference between the **Iconic** and the **BEV** with p=.011. No significant difference was found between the **Baseline** and the **Iconic** variant (p=.590).

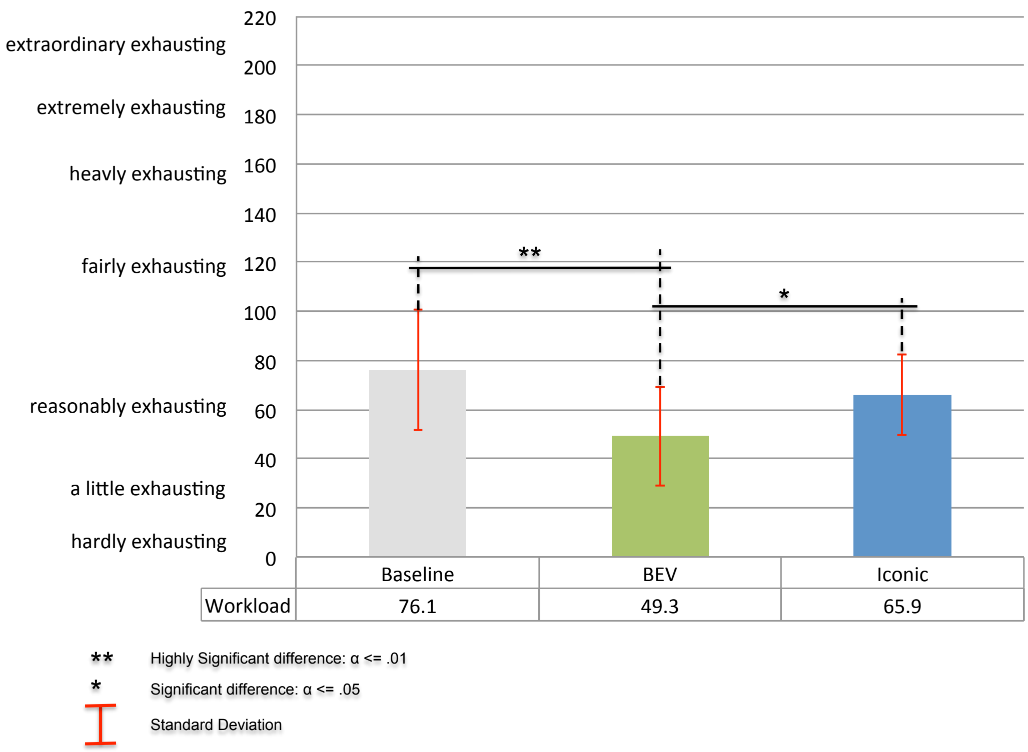


Figure 6.3.: Comparison of subjective workload for the two visualizations and the baseline during the complete drive, measure using the one dimensional SEA scale

Desirable System Attributes Before the experiment, desirable system attributes and their counterparts were defined. These attributes were evaluated with the use of a five point semantic differential, which was given to the subjects after each variant. This paragraph shows the results.
Figure 6.4 shows the attributes, with the bottom combined ratings for the BEV and the Iconic visualization. Figure 6.5 shows the results for the items with the upper combined ratings. Statistical values and the results of the 2-tailed T-Test can be found in Table 6.4 and Table 6.5. Regarding the lower rated items (Figure 6.4), the progression of the Iconic visualization was situated around the neutral rating of 3.0, with ratings between 2.8 and 3.2. Only the rating for the item "predictable" was clearly in the positive part of the scale. The progression for the BEV was located in the positive part of the scale for all items with ratings between 3.3 and 4.0. The BEV received clearly higher ratings for all items, except for the item "predictable", which with a mean ratings of 3.6 and 3.7 were rated similar.

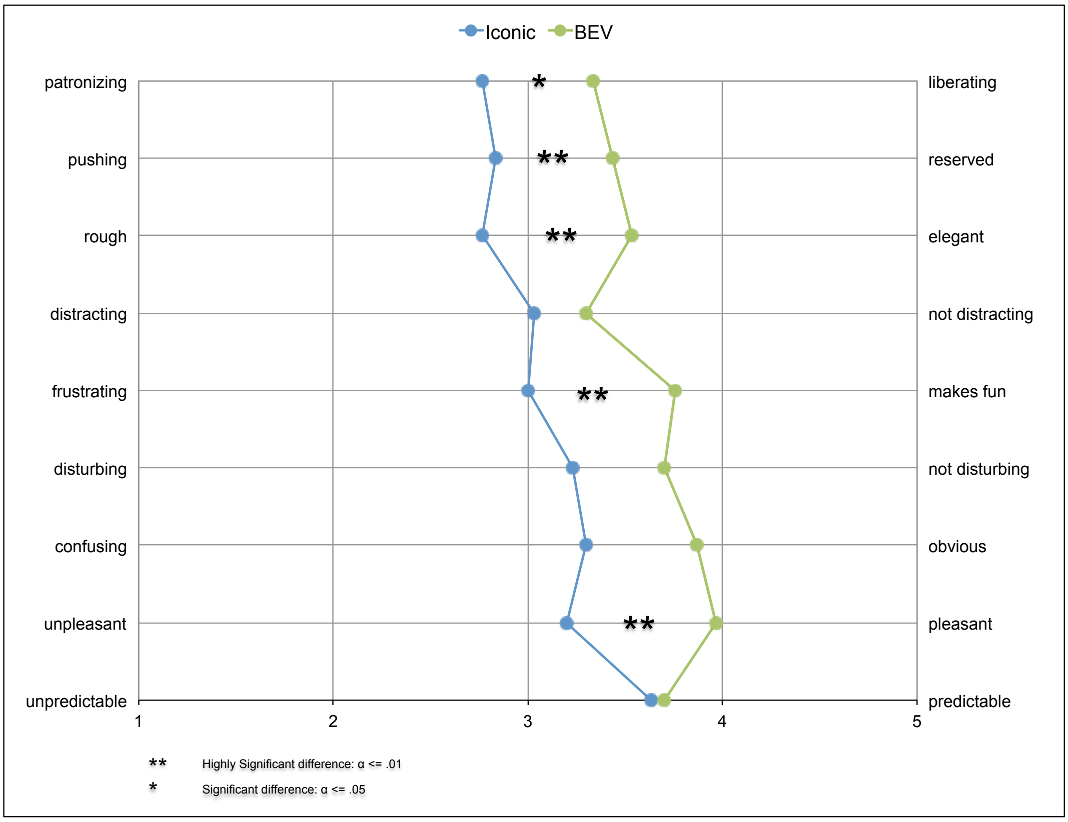


Figure 6.4.: Comparison of the mean values for the two variants regarding desirable system attributes with the lowest combined ratings

Regarding all items:

- **patronizing/liberating:** With a mean rating of 2.77, the Iconic visualization received the lowest overall rating and was in the rather "patronizing" part of the scale. With a mean rating of 3.3 the BEV was in the rather "liberating" part of the scale. The difference between the two variants was **significant** with t=-2.599 and p=.015.

- **pushing/reserved:** With a rating of 2.83 the Iconic visualization was rated rather "pushing", while the BEV, with a rating of 3.43, was on the "reserved" side of scale. The difference between the BEV and the Iconic visualization was **highly significant** with t=-2,827 and p=.008.

- **rough/elegant:** The Iconic visualization did again get the lowest overall rating with an average of 2.77. The difference to the BEV was quite large, and with a mean rating of 3.53 the BEV was on the "elegant" side of the scale. The difference was **highly significant** with t=-3.915 and p=.001.

- **distracting/not distracting:** Both ratings were close to each other and around the neutral part of the scale. With a rating of 3.30 the BEV was conceived less "distracting" than the Iconic visualization, which, with a mean value of 3.03, received a neutral rating. **No significant** difference was found.

- **frustrating/makes fun:** With 3.0, the Iconic visualization received a neutral rating compared to 3.76 for the BEV, which was clearly in the positive part of the scale. The difference was **highly significant** with t=-3.993 and p=.000.
- **disturbing/not disturbing:** Both ratings were in the "not disturbing" part of the scale, with 3.7 as a mean rating for the BEV and 3.23 for the Iconic visualization. The difference was **not statistically significant**.
- **confusing/obvious:** Both ratings were on the "obvious" side of the scale, with 3.3 for the Iconic visualization and 3.87 for the BEV. The result for the BEV could be called clearly "obvious". The difference between the two visualizations was **not significant** with p=.051.
- **unpleasant/pleasant:** With a rating of 3.2, the Iconic visualization was on the marginally "pleasant" side of the scale. With a 3.97 rating, the BEV was rated clearly more "pleasant". The difference was **highly significant** with t= -2.986 and p=.006.
- **unpredictable/predictable:** Both visualization did practically receive the same rating with 3.63 for the Iconic visualization and 3.70 for the BEV. Both visualizations, therefore, were on the "predictable" side of the scale. **No significant** difference was found.

Table 6.4 shows a complete overview of all mean values, standard deviations for both variants, the BEV and the Iconic visualization. It also shows the t-value, the degrees of freedom and the p-value, which was calculated using a 2-tailed T-Test for repeated measures.

	patronizing liberating	pushing reserved	rough elegant	distracting not distracting	frustrating makes fun	disturbing not disturbing	confusing obvious	unpleasant pleasant	unpredictable predictable
Iconic Mean	2.77	2.83	2.77	3.03	3.00	3.23	3.30	3.20	3.63
Iconic Std.	1.040	1.289	1.073	1.402	1.000	1.165	1.393	1.157	.765
BEV Mean	3.33	3.43	3.53	3.30	3.76	3.70	3.87	3.97	3.70
BEV Std.	.884	.935	.860	1.088	.739	.915	1.106	1.098	.837
t	-2.599	-2.827	-3.915	-.915	-3.993	-1.919	-2.036	-2.986	-.421
df	29								
Sig. (2-tailed)	.015	.008	.001	.368	.000	.065	.051	.006	.677

Table 6.4.: Statistical values and results of the 2-tailed T-Test regarding the desirable system attributes with the highest combined ratings

Regarding the better rated items (Figure 6.5), both progressions were in the positive side of the scale. The progression of the Iconic visualization was located below the progression of the BEV in each item. With ratings between 3.37 and 3.83, the Iconic visualization did receive rather to clearly positive results. The progression of the BEV, with ratings between 3.77 and 4.50, was in the clearly positive part of the scale. Both progressions showed similar tendencies.

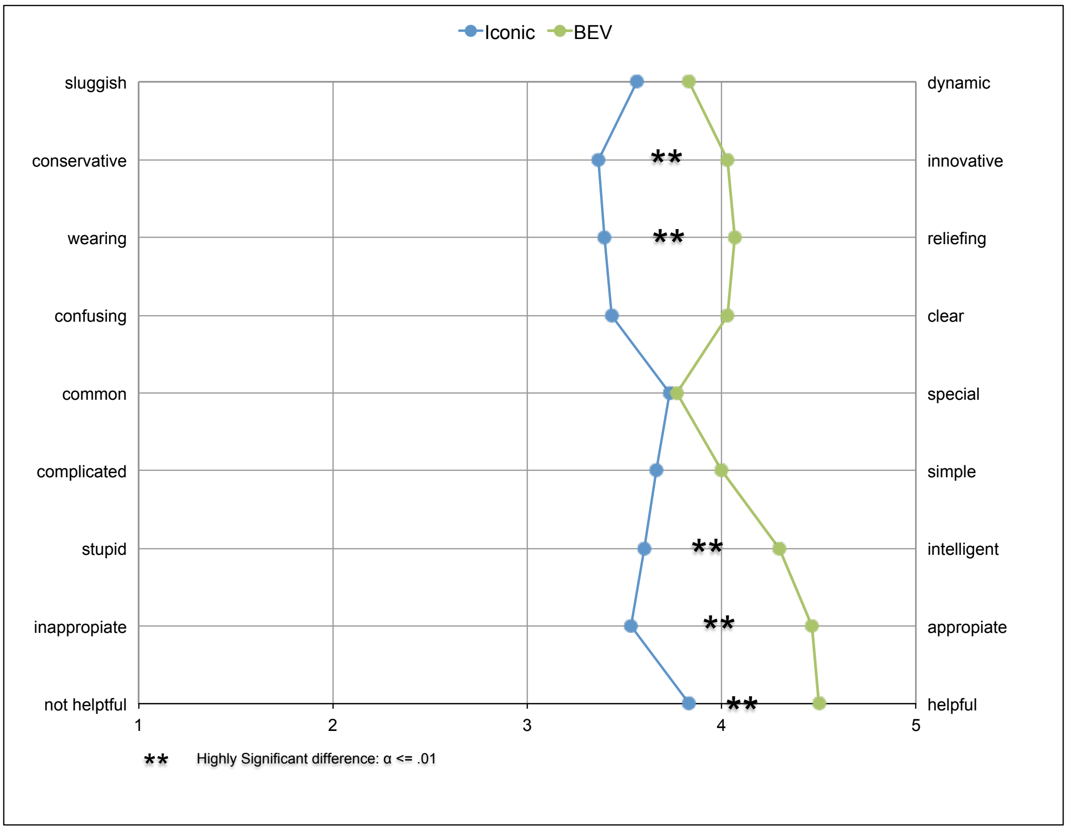


Figure 6.5.: Comparison of the mean values for the two variants regarding desirable system attributes with the highest combined ratings

- **sluggish/dynamic:** Both ratings, with 3.57 for the Iconic visualization and 3.83 for the BEV, were in the "dynamic" part of the scale, with the BEV has been rated slightly more dynamic than the Iconic visualization. The difference was **not significant**.

- **conservative/innovative:** A larger difference could be found in this item, with a rating of 3.37 for the Iconic visualization and 4.03 for the BEV. The BEV is clearly rated more "innovative" than the Iconic visualization. The difference is **highly significant** with t=-3.673 and p=.001.

- **wearing/relieving:** With a rating of 3.4 and 4.07 for the Iconic respectively the BEV, the Iconic visualizations lies on the "relieving" side, while the BEV was rated clearly relieving. The difference was **highly significant** with t=-2.763 and p=.010.

- **confusing/clear:** With a rating of 3.43 for the Iconic visualization and a rating of 4.03 for the BEV, the BEV was rated to be more "clear" and less "confusing" than the Iconic visualization. **No significant** difference was found with p=.053.

- **common/special:** Both visualizations did receive similar ratings. With 3.73 for the Iconic visualization and 3.77 for the BEV, both ratings were on the "special" side of the scale. **No significant** difference was found.

- **complicated/simple:** Both variants were rated “simple”, with a mean rating of 3.67 for the Iconic visualization and 4.00 for the BEV. **No significant** difference between the variants was found.
- **stupid/intelligent:** The Iconic visualization with a rating of 3.6 was conceived “intelligent” by the subjects. The BEV with a rating of 4.3 was conceived “clearly intelligent” and did receive the third highest rating of all items. The difference was **highly significant** with t=-3.336 and p=.002.
- **inappropriate/appropriate:** The second highest rating for the BEV was received in this item with a rating of 4.47. Therefore, the BEV was conceived clearly “appropriate” by the subjects. The Iconic visualization with a mean value of 3.53 still was conceived “appropriate”. The difference was **highly significant** with t=-4.731 and p=.000.
- **not helpful/helpful:** The highest rating of all items and visualizations was received by the BEV in this item. With a mean rating of 4.5 the BEV was considered “really helpful”. The Iconic visualization with a mean rating of 3.83 still was considered “helpful”. The difference was **highly significant** with t=-3673 and p=.001.

Table 6.5 shows a complete overview of all mean values, standard deviations for both variants, the BEV and the Iconic visualization. It also shows the t-value, the degrees of freedom and the p-value which was calculated using a 2-tailed T-Test for repeated measures.

	sluggish dynamic	conservative innovative	wearing relieving	confusing clear	common special	complicated simple	stupid intelligent	inappropriate appropriate	not helpful helpful
Iconic Mean	3.57	3.37	3.40	3.43	3.73	3.67	3.60	3.53	3.83
Iconic Std.	.679	1.033	1.102	1.305	.868	1.184	1.070	.973	1.053
BEV Mean	3.83	4.03	4.07	4.03	3.77	4.00	4.30	4.47	4.50
BEV Std.	.791	.809	.691	.964	.898	.947	.702	.730	.572
t	-1.861	-3.673	-2.763	-2.014	-.197	-1.355	-3.336	-4.731	-3.673
df	29								
Sig. (2-tailed)	.073	.001	.010	.053	.845	.186	.002	.000	.001

Table 6.5.: Statistical values and results of the 2-tailed T-Test regarding the desirable system attributes with the highest combined ratings

Subjective Acceptance Following, the results of the subjective acceptance is presented. Results cover four aspects: How much the variants were liked by the subjects (“Likability”); How secure the subjects felt about the requested action from the system (“Requested Action”); How understandable the visualization was (“Understandability”) and how well the subjects did feel “prepared for the situation”. These items were collected via a questionnaire directly after each drive.

Figure 6.6 shows the results of these questions on a scale from 1 to 5, with 5 being the most positive rating for all items. In order to combine these items in one diagram, the original item labels were not included in the diagram. Statistical values and the results of the 2-tailed T-Test can be found in Table 6.6.

Both progressions, of the Iconic visualization and the BEV, were located in the positive part of the scale, with the ratings for the BEV being higher in each item than the ratings for the Iconic visualization. With mean values between 3.22 and 3.87 the results for the Iconic visualization ranged from rather positive to positive. The rating for the BEV, with mean values from 4.10 to 4.37, showed a clear positive result on all items.

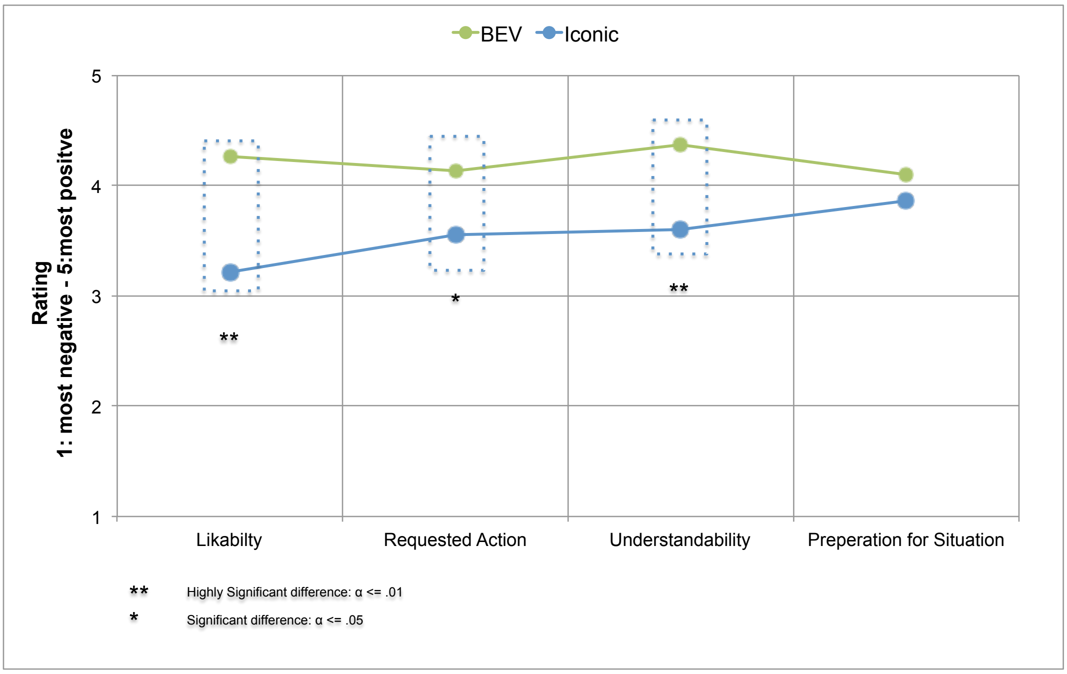


Figure 6.6.: Comparison of the mean values for four different items regarding system acceptance items in the LfE driving simulator experiment

Regarding the four just mentioned items:

- **Likability:** With mean values of 3.22 for the Iconic visualization and 4.27 for the BEV a clear difference could be stated. While the rating for the BEV showed a clear statement, the rating for the Iconic visualization was only marginally in the positive part of the scale. The difference was **highly significant** with t=-4.462 and p=.000.

- **Requested action:** Regarding the question on how secure the subjects were about the requested action, both visualizations did receive positive ratings. With 4.13, the mean rating for the BEV was located in the clearly positive part, while a rating of 3.55 for the Iconic visualization still could be considered a positive result. The difference between the two variants was **significant** with t=-2,319 and p=.028.

- **Understandability:** With 4.37, the BEV received the highest mean rating of all items and could be considered clearly "easy to understand". With 3.6, the Iconic visualization still received a positive rating. The difference was statistically **highly significant** with t=-4173 and p=.000.

- **Preparation for Situation:** Both ratings were similar, with 3.87 for the Iconic visualizations and 4.10 for the BEV. Both visualization did receive clearly positive ratings. **No significant** difference was found.

Subjects also were asked on a five point scale, if the request for action was shown too early or too late ("Timing"). Figure 6.7 shows the results of this question. With mean values of 2.54 for the Iconic visualization and 2.76 for the BEV, both ratings showed that subjects did conceive the request as being a little bit too early. **No significant** difference was found between the BEV and the Iconic visualization.

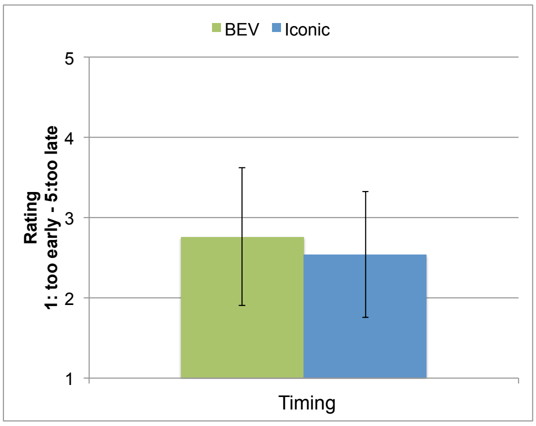


Figure 6.7.: Comparison of mean values regarding the timing aspect of the visualizations

Table 6.6 shows statistical values for all acceptance items as well as for the "Timing" aspects. It includes the mean values, the standard deviation, the t-value and the p-value. All values were calculated using a 2-tailed T-Test for repeated measures.

	Likeability	Requested Action	Understand-ability	Preparation for Situation	Timing
Iconic Mean	3.22	3.55	3.60	3.87	2.54
Iconic Std.	1.142	1.147	1.133	1.008	.862
BEV Mean	4.27	4.13	4.37	4.10	2.76
BEV Std.	.828	1.074	.890	1.125	.787
t	-4.462	-2.319	-4.173	-.925	-1.620
df			29		
Sig. (2-tailed)	.000	.028	.000	.363	.116

Table 6.6.: Statistical values and results of the 2-tailed T-Test regarding the system acceptance and the timing aspect of the visualization

Situation Dependence Results At the end of the experiment, in a final questionnaire, subjects were asked about how helpful, on a five point scale, each visualization was in seven categories of situations. These categories were: "Construction Site", "Parking Vehicle", "Traffic Light", "Slow preceding vehicle", "Speed Limit", "Slow moving traffic" and "Highway Jam".
Figure 6.8 shows a comparison between the mean value for the BEV and the Iconic visualizations in the "Construction site", the "Parking Vehicle" and the "Traffic Light" situation. In all situations the BEV received a higher rating than the Iconic visualization and was received "rather helpful" to "very helpful". Statistical values and the results of the 2-tailed T-Test can be found in Table 6.7.

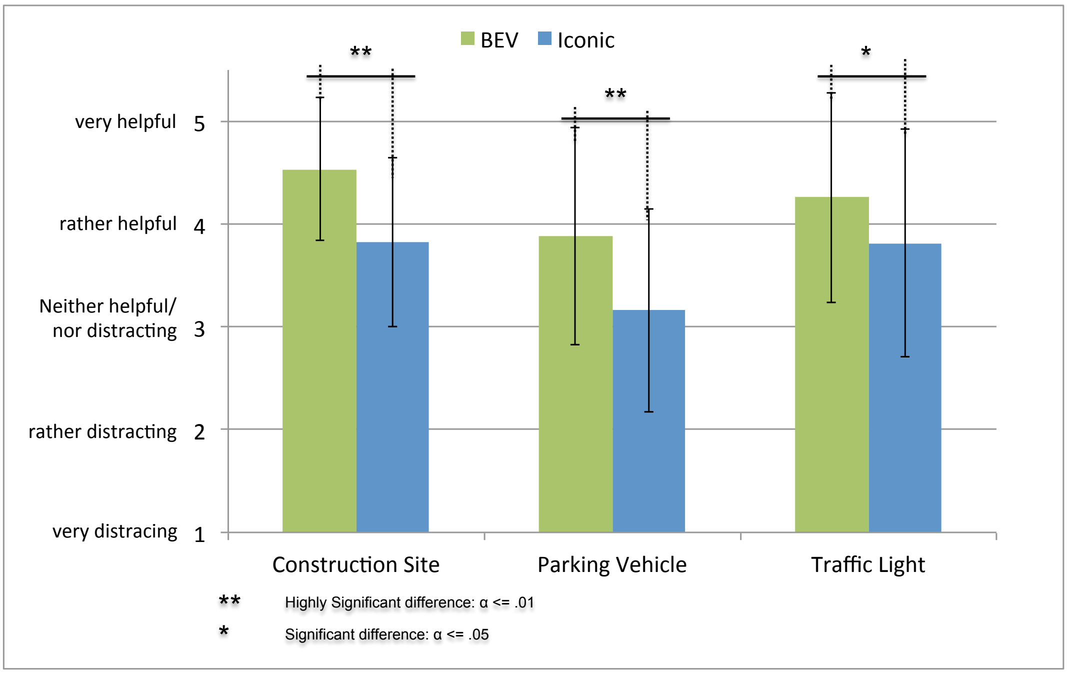


Figure 6.8.: Comparison of mean values regarding of the helpfulness within three category of situations ("Construction site", "Parking Vehicle" and "Traffic Light")

- **Construction Site:** With 4.54, the BEV received the second highest rating and was considered "very helpful". The Iconic visualization still was considered "rather helpful", with an average rating of 3.82. The difference of 0.72 was the largest difference in ratings between the BEV and the Iconic visualization and **highly significant** with t=-3.603 and p=.001.

- **Parking Vehicle:** With a mean rating of 3.16, the Iconic visualization received the lowest rating of all situations and was conceived as "partly helpful". The BEV with a rating of 3.88 did receive a "rather helpful" verdict. The difference was **highly significant** with t=-3.524 and p=.002.

- **Traffic Light:** Both visualizations received a "rather helpful" rating. With 4.26, the BEV was rated **significantly** more helpful than the Iconic visualization with a mean rating of 3.81, with t=-2.726 and p=.011.

Table 6.7 shows statistical values for the three just mentioned categories of situations. It includes the mean values, the standard deviation, the t-value and the p-value. All values were calculated using a 2-tailed T-Test for repeated measures.

	Construction Site	Parking Vehicle	Traffic Light
Iconic Mean	3.82	3.16	3.81
Iconic Std.	.819	.987	1.111
BEV Mean	4.54	3.88	4.26
BEV Std.	.693	1.054	1.023
t	-3.603	-3.524	-2.726
df		29	
Sig. (2-tailed)	.001	.002	.011

Table 6.7.: Statistical values and results of the 2-tailed T-Test considering three categories of situations ("Construction site", "Parking Vehicle" and "Traffic Light")

Figure 6.9 shows a comparison between the mean ratings for the BEV and the Iconic visualization in the situations "Slow preceding vehicle", "Speed Limit", "Slow Moving Traffic" and "Traffic Jam". All ratings were in the positive part of the scale. Apart from the rating for the Iconic visualization in the "Slow preceding vehicle" situation, all ratings could be categorized as "rather helpful" or "very helpful". Statistical values and the results of the 2-tailed T-Test can be found in Table 6.8.

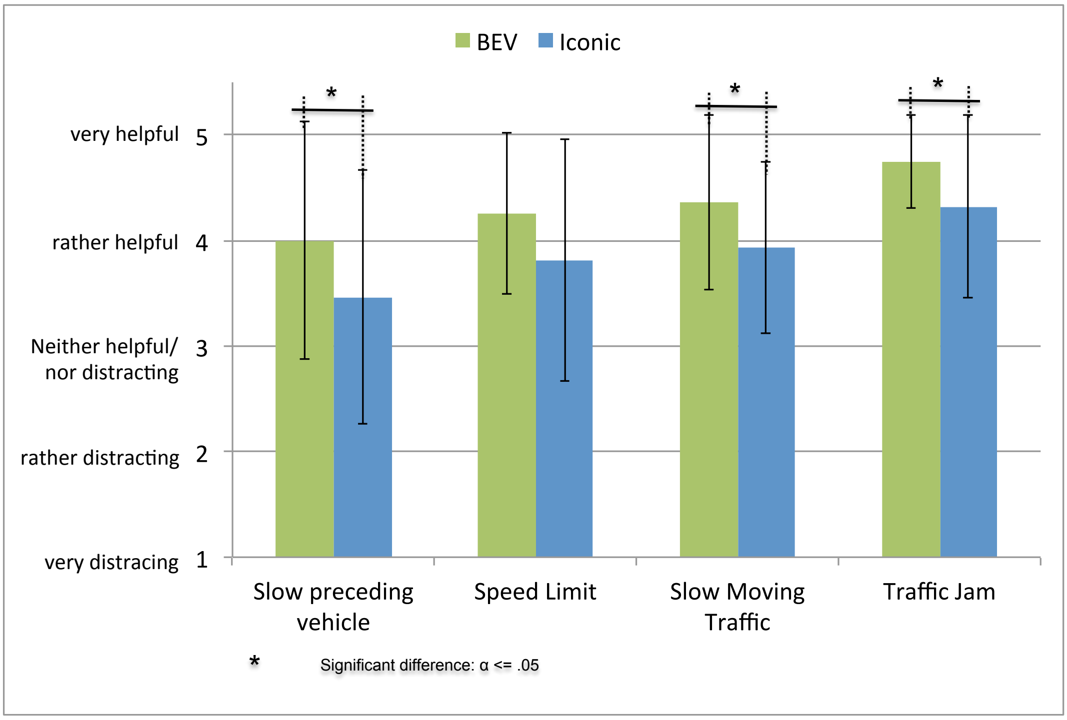


Figure 6.9.: Comparison of mean values regarding of the helpfulness within four category of situations ("Slow preceding vehicle", "Speed Limit", "Slow Moving Traffic" and "Traffic Jam")

- **Slow preceding vehicle:** With an average rating of 3.46 the Iconic visualization did receive the second worst rating of all situations and can only be considered "partly helpful". The BEV also did receive the second lowest rating for all situations but with an average of 4.00 still was considered "rather helpful". The difference was **significant** with t=-2.197 and p=.037.

- **Speed Limit:** Both visualizations were conceived “rather helpful”. With an average of 4.26, the BEV was rated higher than the Iconic visualization, which had an average rating of 3.81. The difference was **not statistically significant**.
- **Slow moving Traffic:** Both visualizations were conceived “rather helpful” with an average of 4.36, the BEV was rated higher than the Iconic visualization, with an average rating of 3.93. The difference was statistically **significant** with t=-2194 and p=.037.
- **Traffic Jam:** The highest rated situation, with an average of 4.32 for the Iconic visualization and 4.75 for the BEV. The BEV did receive a “very helpful” rating. A statistical **significance** was found with t=-2.465 and p=.020.

Table 6.8 shows statistical values for the four just mentioned categories of situations. It includes the mean values, the standard deviation, the t-value and the p-value. All values were calculated using a 2-tailed T-Test for repeated measures.

	Slow preceding vehicle	Speed Limit	Slow Moving Traffic	Traffic Jam
Iconic Mean	3.46	3.81	3.93	4.32
Iconic Std.	1.201	1.145	.813	.863
BEV Mean	4.00	4.26	4.36	4.75
BEV Std.	1.122	.764	.826	.441
t	-2.197	-1.724	-2.194	-2.465
df	29			
Sig. (2-tailed)	.037	.097	.037	.020

Table 6.8.: Statistical values and results of the 2-tailed T-Test considering four categories of situations (“Slow preceding vehicle”, “Speed Limit”, “Slow Moving Traffic” and “Traffic Jam”)

Overall Comparison As a final comparison, the question was raised, which of the visualizations would be preferred if the subject’s vehicle was to be equipped with a deceleration assistance system and whether generally a deceleration assistant was wanted by the subjects. Figure 6.10 shows the results of the decision between the Iconic visualization and the BEV. The difference between the BEV and the Iconic visualization was highly significant with t= -5.578 and p=.000. The mean rating of 4.0 for the BEV showed that subjects would “gladly” have this visualization in their vehicle, while the mean rating of 2.48 indicated a “partly” interest in the Iconic visualization.

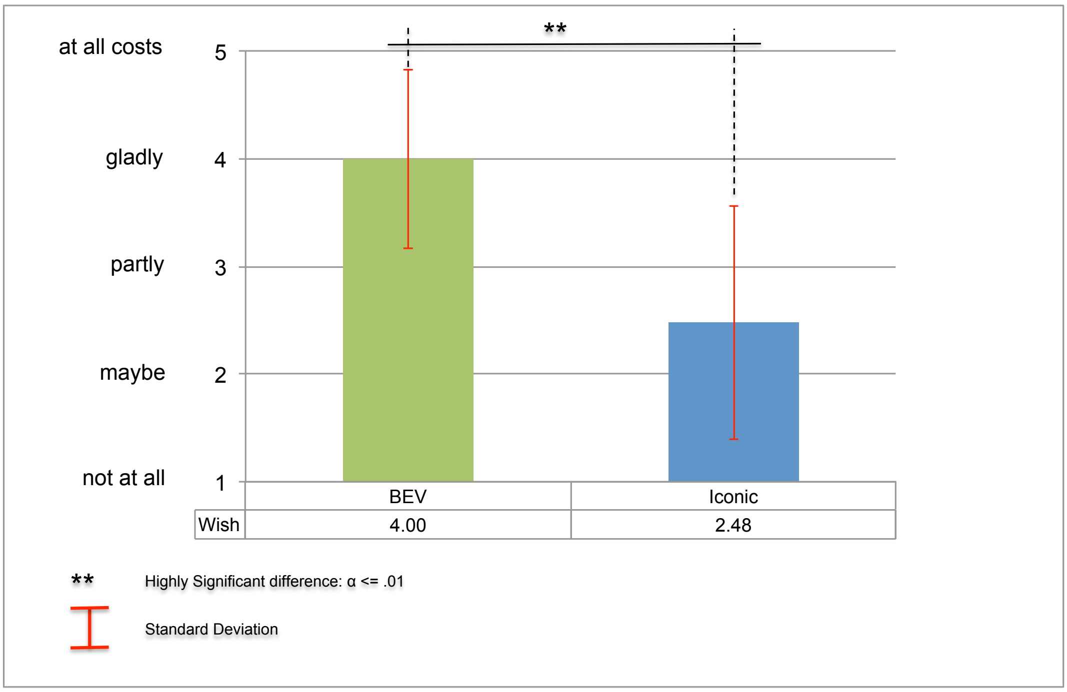


Figure 6.10.: Comparison of the mean value regarding the wish for the Iconic and BEV visualization in a vehicle that is equipped with a deceleration assistance system

Also, the subjects were asked, whether they had a non-specific wish for a deceleration assistance system in a possible future vehicle. With a mean value of 4.04 out of a 5 point scale, the overall tenor was in favor of a deceleration assistance system.
When forced to decide between the two visualizations, 22 against 3 votes favored the BEV.

Free Statements After the completion of all three drives, subjects had the possibility for free statements, with the main focus on elements liked and disliked. In Table 6.9 an overview on the received statements can be seen. In order to provide a better overview, statements were categorized. The number behind each answer is the quantity in which the answer occurred. Single statements were left out due to low relevance.
The BEV received a total of 38 statements about aspects liked, 20 more than the 18 statements for the Iconic visualization. Simplicity was the favorite aspect regarding the Iconic visualization. Understandability and the visualization itself were the favored aspects in the BEV. The BEV also received 23 statements on aspects disliked, 5 less than the 28 statements for the Iconic visualization. Mainly the question for additional information and the irritating colors were named in respect to the BEV. The pedal visualization and the traffic sign visualization were mentioned referring to the Iconic visualization.

	Aspects liked	Aspects disliked
Iconic	Total: 18 statements - Simple design - 5 - Color - 3 - Exact description what to do -3	Total: 28 statements - Pedal-presentation and animation -10 - Signs not understandable -5 - Too early - 3
BEV	Total: 38 statements - Understandable, clear - 11 - Visualization of distance - 7 - Visualization oncoming traffic - 5 - Exact lane visualization- 5	Total: 23 statements - Additional information wanted - 6 - Color irritating - 3 - Too early - 3

Table 6.9.: Free statements on “Aspects liked” and “Aspects disliked” regarding the BEV and the Iconic visualization

Apart from aspects liked and disliked, free statements were also collected regarding “Information missing”, “Unnecessary Information ” and “Information not understood”. Table 6.10 again shows a clustering of the statements. Regarding the Iconic visualization: 12 statements on “missed information” were made, mainly concerning information on clearance, distance and course of road. 14 statements concerned the “unnecessary” pedal visualization and it’s animation and 18 statements mentioned that subjects did “not understand” the pedal visualization and the changed traffic sign. As for the BEV: 3 statements wished for an additional distance information, while in the “Information unnecessary category” only single statements were made. In “Information not understood” the color and situations with a preceding vehicle were mentioned.

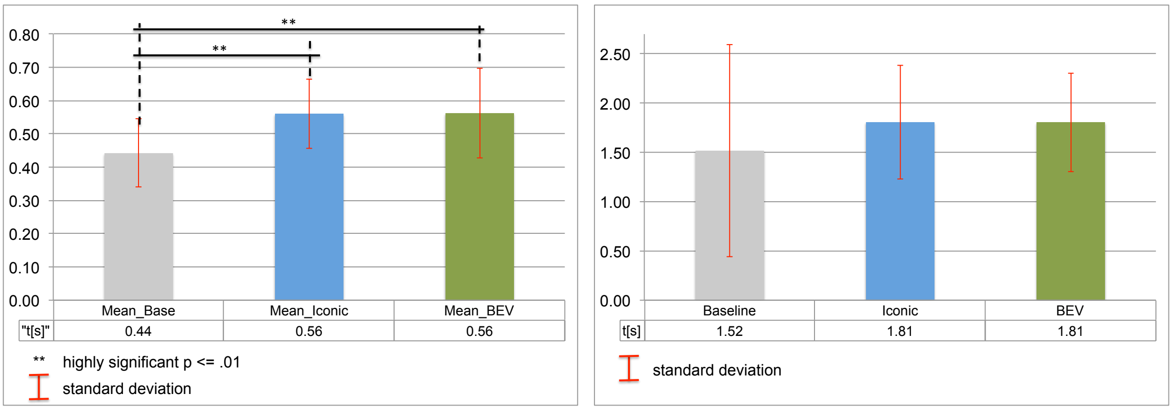
	Information missed	Unnecessary Information	Information not understood
Iconic	Total: 12 statements - Clearance and distance information - 6 - Situation and course visualization - 4	Total: 14 statements - Pedal visualization - 7 - Pedal animation -5	Total: 18 statements - Pedals visualization - 13 - Changed traffic signs - 3
BEV	Total: 6 statements - Additional distance information - 3	Total: 9 statements - Only single statements	Total: 9 statements - Color - 4 - Situations with a vehicle ahead - 3

Table 6.10.: Free statements on “Information missing”, “Information unnecessary” and “Information not understood” regarding the BEV and the Iconic visualization

6.3.2. Objective Results - Gaze Behavior

Objective results on the gaze duration will be presented in this paragraph. More objective results on the gaze behavior can be found in Sommer [162] and Popiv [135].
A comparison between the baseline, the BEV and the Iconic visualization in regard of the mean and maximum gaze duration at the instrumental cluster throughout all deceleration situations can be seen the Figure 6.11. Regarding the mean gaze duration (Figure 6.11a): the Baseline condition, with a mean gaze duration of 0.44 s, had the lowest result. Both visual-

izations, with a mean gaze duration of 0.56 s, did produce an equally longer distraction. A highly significant difference was found with F=13.00, df=2 and p=.000). The post-hoc analysis showed a highly significant difference between the Baseline and the Iconic visualization with p=.000 as well as a highly significant difference between the Baseline and the BEV with p=.000. No significant difference was found between the Iconic visualization and the BEV. For the maximum gaze duration at the instrument cluster (Figure 6.11b), a similar tendency occurred. The Baseline, with a maximum distraction of 1.52 s produced a lower distraction than both visualizations (1.81 s maximum gaze duration). No significant difference was found with F=1.028, df=1.455 and p=.347.



(a) Comparison between the mean gaze duration at the instrumental cluster throughout the complete drive regarding the Baseline, the Iconic visualization and the BEV

(b) Comparison between the maximum gaze duration at the instrumental cluster throughout the complete drive regarding the Baseline, the Iconic visualization and the BEV

Figure 6.11.: Objective results on the gaze behavior

6.4. Discussion

Results showed a clear preference of the BEV over the Iconic visualization. Several reasons influenced this decision. First of all, the BEV seemed to be of a higher visual quality than the Iconic visualization; A result from the semantic differential called the Iconic visualization “rough”. This could have a rather large impact on the subjective acceptance. The visualization and animation of the pedals in the Iconic visualization seemed to be specially affected; several statements did mention the not-worthy, distracting and unintuitive visualization of the pedal visualization. The pedal animation could be considered a command display (cf. Wickens & Hollands [194]), especially the constant animation of the brake/acceleration pedal were received as “patronizing” by the subjects. The BEV on the other side, was conceived more as a status display with its not dominant request for action, which resulted in a rather “liberating” verdict by the subjects (supporting Hypothesis 5). Another factor regarding negative aspects of the Iconic visualization was the limitation to present different kinds of situations with an official traffic sign. Especially the significant differences in favor of the BEV in complex situations like the “construction site” did support this hypothesis (Hypothesis 4). In combination with an “innovative”, “relieving”, “clear” and “intelligent” rating for the BEV, results substantiated the preference of the BEV over the Iconic visualization.

An improvement of the Iconic visualization, especially the visualization of the pedals, could improve the subjective acceptance of this visualization. All above mentioned aspects did contribute to an overall better acceptance as well as reduced workload of the BEV compared to the Iconic visualization (supporting Hypothesis 1).
The main point of critique for the BEV was the great number of colors that were used in the visualization and confused at least some subjects. Therefore, a reduction of the four colors (white, green, yellow, orange) is suggested. Especially the use of the color green in the BEV, which indicated to "release the gas" paddle, did receive the most critique. Also a problem considering the BEV was mentioned in situations with preceding vehicles (Slow vehicle ahead, Traffic light), in which it seemed to be unclear, which of the vehicles was the ego vehicle and which the preceding vehicle.
Although a majority of the subjects liked the idea behind a deceleration assistance system, the rather long coasting time in some situations seems to be an issue. Adjusting the coasting time, maybe in combination with additional braking, could resolve this issue.
Gaze duration at the instrument cluster did increase with the use of both visualizations (supporting Hypothesis 2). Although the BEV provided a higher degree of information density than the Iconic visualization, the gaze duration in average as well as at the maximum did not differ between the BEV and the Iconic visualization (confuting Hypothesis 3). Presenting the multitude of information in a naturalistic way might be an explanation for that. The unfortunate animation of the pedal in the Iconic visualization might also have contributed to this result. The maximum value for gaze duration at the instrument cluster did lie under two seconds for all visualizations, and therefore, can be considered safe to be used in traffic (cf. Zwahlen et al. [206]).

6.5. Conclusion

Two visualizations were successfully developed and evaluated in the course of this evaluation. Regarding the amount of information and the possibility to visualize a wide variety of situations, the BEV has a higher potential than the Iconic visualization in the context of a deceleration system.
By presenting information beyond the visual horizon, the workload of the driver is reduced, although more information is presented to him.
The driver wants to be informed, not commanded. A status display, like the colors of the BEV's ego-vehicle is more appropriate than a command display like the pedals in the Iconic visualization.
The more complex the situation, the worse the helpfulness of the Iconic visualization which used a limited amount of icons for the situation visualization.

7. Automation and Consequences of Automation Failure, System Boundaries of the BEV

Level of automations. The BEV as a low level automated system. Consequences of automation failures. Concepts and related work from the aviation industry.

During the first part of this work, a visualization to assist early deceleration and to enlarg the anticipation horizon, the BEV was introduced. It was evaluated in a fix-based driving simulator against an Iconic visualization. The BEV is a rather complex visualization with detailed information of the upcoming situation. The first evaluation showed an improvement in traffic safety and on fuel efficiency. In order to get an extended insight in the possibilities and the potential problems of the BEV, an extended survey has to be performed. This chapter will show that the BEV, as information visualization system, is a low level automated system. Therefore, the consequences of automation failure, which are well researched for high level automated systems, need to be researched for the BEV as well. Apart form the definition and a description of the different levels of automation, the possible consequences of automation failure and the ironies of automation will be of the topics in this chapter. Finally, related work on automation failure is presented.

7.1. Definition and Background of Automation

In literature one can find many definitions of automation. One by Parasuraman & Riley [131] (p.231) is as follows, “We define automation as the execution by a machine agent (usually a computer) of a function that was previously carried out by a human. What is considered automation will therefore change with time. When the reallocation of a function from human to machine is complete and permanent, then the function will tend to be seen simply as a machine operation, not as automation”. In the Oxford English Dictionary automation is defined as ”automatic control of the manufacture of a product through a number of successive stages” and by ”extension, the use of electronic or mechanical devices to replace human labor”. Other sources stress that automation has ”freed humans from time consuming labor intensive work” or that in automation creativity or decision-making remains rare.
It has to be mentioned that automation is not a binary state, meaning either a process is automated or not, but rather a continuum from the “human does all” to “the machine does all”. This continuum can be categorized into a hierarchy, which states different levels of automation. Typical hierarchies of automation are those from Sheridan [157] and Parasuraman et al. [132]. Both hierarchies try to define different levels of automation, were the task load is distributed between the human and the machine in differing amount. These hierarchies

show that a deceleration assistance system, respectively the BEV, is an automated system. Therefore consequences of automation failure need to be researched.

In the Sheridan hierarchy ten levels of automation are defined, starting with level one: the computer offers no assistance and the human operator has to do all the work. In the second level, ”the computer offers a complete set of action alternatives”, the machine already relieves the human from thinking about action alternatives. During the following levels the degree of automation increases up to the point at which the machine decides and executes all tasks while ignoring the human operator. The ten levels in the Sheridan hierarchy (found in Parasuraman et al. [132]) are:

I. The computer offers no assistance, human must do it all

II. The computer offers a complete set of action alternatives, and

III. narrows the selection down to a few, or

IV. suggests one, and

V. executes that suggestion if the human approves, or

VI. allows the human a restricted time to veto before automatic execution, or

VII. executes automatically, then necessarily informs the human, or

VIII. informs him after execution only if he asks, or

IX. informs him after execution if it, the computer, decides to.

X. The computer decides everything and acts autonomously, ignoring the human.

The hierarchy mainly is based on the distribution of decision and action between man and machine. Parasuraman et al. [132] extended this model by adopting the simple four-stage model of information processing, which includes **Sensory processing, Perception, Decision Making and Response selection**. Parasuraman et al. [132] (p.288) stated that “[t]he four-stage model of human information processing has its equivalent in system functions that can be automated” and proposes a hierarchy of automation with four classes of function, which are:

I. **Information Acquisition**: This stage “applies to the sensing and registration of input data”. Different complexities of automation are included in this stage, from “strategies for mechanically moving sensors” to filtering input information and providing selected information to the user.

II. **Information Analysis**: This stages “involves cognitive functions such as working memory and inferential processes”. “At a low level, algorithms can be applied to incoming data to allow for their extrapolation over time, or prediction”. Typical examples are predictor or trend displays. At a higher level, the integration of multiple variables into a single value is possible.

III. **Decision and Action Selection**: At this stage automation includes selection from decision alternatives. At a low level, this includes systems that provide the best actions but the operator is still able to ignore the recommendation. At high level, this can include systems that automatically take over if the operator does not.

IV. **Action Implementation**: This stage involves "actual execution of the action choice". Again, different degrees of automation, from partial to full, are conceivable.

This introduction showed that there are different options to define and categorize automation. This insight was necessary to provide a foundation for the next sections and allow the reader to understand why the system implemented in this work can be considered an automated system.

7.2. Consequences of Automation

Automating a task has a lot of consequences on the performance of the entire system, the task of the human, the abilities of the operator, the development of the system etc. This section shows the consequences of automation.

7.2.1. Consequences on Human Performance

Due to automation, the task of the operator shifts from an active task, to a monitoring task. This shift has effects on the operator and his performance.

Mental Workload: As mentioned in Chapter 2.3.4, the demand of a task needs to be at an optimal level. Automation often reduces an active task to a monitoring task. If the demand is too low, negative effects on the performance of the operator will be the consequence. Systems that are well designed have the ability to maintain the mental workload of the operator at an optimal level. Vincente & Rasmussen [180] postulates that the transformation of raw data into a graphical representation, which is in line with the operator's representation, is a good design principle. Automation does not necessarily reduce mental workload but can increase it as well, especially in cases were automation is "difficult to initiate and engage" [131].

Situation Awareness: Continuous decision making automation, can reduce the operator's awareness of the system and his environment. As Endsley [59] mentioned, the operator is more aware of a system change when he controls the system himself. This lost of SA can lead to the out-of-the-loop unfamiliarity, a phenomenon that will be explained in Chapter 7.2.2.

Complacency can occur in a system with nearly perfect automation. Consequently, the user might not be monitoring the system in the case of a failure [130]. Complacency is also high, when the operator is occupied with multiple tasks and does not have the possibility to monitor one system aspect [130]. A possible solution is cueing or guidance, which in case of a problem guides the user to the respective area of the display. However, this inherits the problem that uncued areas of a display receive even less attention [204].

Skill Degradation can be a result of decision making automation. With the disuse of the system the operator's ability to perform the task will decrease over time [146].

Further Problems Mentioned by Parasuraman & Riley [131]: **Misuse:** Overtrust in an automated system may lead to an uncritical use of automation, "without recognizing its limitations". **Disuse:** When new technology does not gain instant acceptance, it will not be used and trusted. **Abuse:** "Automation abuse is the automation of functions by designers and implementation by managers without due regard for the consequences for human (and hence system) performance".

Consequences for the Automated System: More sensory data has to be available to analyze the current situation and to perform an according action. Also, the question of liability becomes relevant, when more and more steps are performed by an automated system [30].

7.2.2. Controlling and Monitoring - The Loop

When a human operates a machine, a so-called control loop is initiated, the structure of which is comparable to the information processing models, introduced in Chapter 2.3.2. Figure 7.1 represents a schematic control loop, which is supported by a automated machine part (computer). It shows that when the human uses some kind of input mechanism, the machine executes the input demands of the operator and displays a feedback or result state to the operator, who then again can use the input to adjust the state to his wishes. Such a simple control-loop is initiated for example when driving a vehicle.

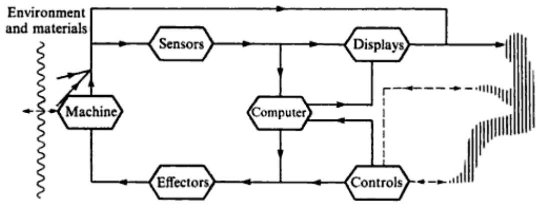


Figure 7.1.: The control loop with computer assistance: operator can use the controls in order to alter the machine state and can control his actions via a display output. Controls and display output are supported by a computer, from Singelton [160]

Out of the Loop Consequences As Kaber & Endsley [91] (p.127) stated: "When an operator is removed from a control loop due to allocation of system functions to an automated/computer controller, the level of human system interaction is limited and, consequently, operator awareness of system states may be reduced". This awareness reduction of system parameters results in a poor mental model of the system and makes it difficult for the operator to detect system failures. Therefore, it takes longer for the operator to manually override the system: a phenomenon that is called "Out of the loop" [58].
For the automated automotive environment an out-of-the-loop consequence would consequently mean a slower manual take-over in case of automation failure.

7.2.3. Ironies of Automation

Bainbridge [11] in her work pointed out the ironies of automation. These are:

- On one side the designer of an automated system has the view that the human operator is unreliable and inefficient, but on the other side "the designer who tries to eliminate the operator still leaves the operator to do the tasks which the designer cannot think how to automate".
- "Designer errors can be a major source of operating problems".
- Due to skill degeneration, the human supervisors will have problems when an error occurs.
- The human supervisor also looses the ability to completely understand the processes within the system (his mental model is worse than under manual control), therefore, problems are harder to come by.
- The monitoring task could be done by an unskilled worker, who in a failure case would have to call a supervisor. If a skilled worker is used for the monitoring task, monitoring becomes even more boring and the attitude towards automation decreases even more.

Bainbridge also discussed possible solutions to the automation problem: For the **monitoring** task for example she proposed that "[d]isplays can help the operator to monitor automatic control performance, by showing the target values". For **short term skill degeneration** a possible solution can be a low cost automatic shut-down, and for **long term skill degeneration** training in a simulator environment can be a solution, which involved the irony that "no one can be taught about unknown properties of the system" (Bainbridge [11] p.5).
Bainbrigde presented guidelines on the interaction between human and automated machine:

- **Instruction and advice:** Using automation to instruct or give advice to the human is considered to negatively influence the human user. His reaction becomes slower and he loses the ability to act intelligently.
- **Mitigating human errors:** Adequate feedback on human errors should be provided with so-called "checks" after an action by the human has taken place. Such a measurement does not evaluate how a state was reached. When humans get enough feedback they are able to adapt their behavior to correct their mistakes.
- **Software generated displays:** This point refers to dynamically adapting displays that show only information connected to the task currently executed.
- **Relieving human workload:** Bainbridge proposed that in situations with high workload, the automated system should take over decision making in order to reduce human workload.

7.3. Imperfect Automation

As we talk about the automotive environment - a highly dynamical environment in which changes can happen from one second to the next - it is important to consider the consequences of imperfect automation. This section provides an insight into the consequences of

an imperfect automation, and what this means for the system designers.
Interesting aspects of imperfect automation are the consequences on the overall performance of such a system, the differentiation between failures as well as the differentiation between compliance and reliance, an expression introduced by Mayer [113].

7.3.1. Types of Imperfect Diagnostic Automation: False Alarms and Misses

In a diagnostic system, the system receives input and uses an implicit detection algorithm in order to detect predefined situations. It decides whether or not certain criteria are met and shows data to the human operator accordingly. When operating reliably, diagnostic systems have many benefits, but in a highly dynamic environment, like the automotive environment, automation can fail [53]. Figure 7.2 shows all possible scenarios that can occur in a diagnostic system. A signal can either be present or absent. When the system detects a present signal, it is a hit; when the system detects a signal which is absent, it is called a false alarm (FA). When a signal is present and the system does not detect it, it is called a miss; and finally, when the signal is absent and the system does not detect anything it is correct rejection.

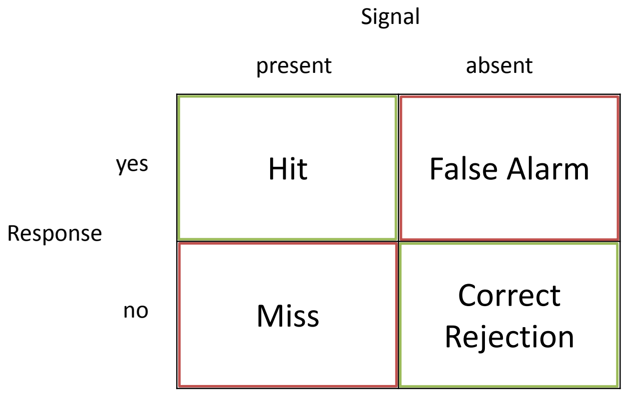


Figure 7.2.: Correct and False reaction of a diagnostic system, "Hit", "Miss", "False Alarm" and "Correct Rection" as possible states

7.3.2. Consequences of False Alarms and Misses

FA and Misses do have consequences in the development and the human perception of a diagnostic system.

Consequences During Development During development imperfect automation often leads to a "Fail-Safe Approach" [169], which should prevent the miss of a critical state. The consequence is an increasing number of FAs (FA-prone systems). Considering human perception of FAs and misses Mayer [113] introduced the terms compliance and reliance.

Consequences on Perception Compliance and reliance (Mayer [113][114]) describe the trust of a user in an automated system in case of a hit or a correct rejection. Compliance describes the attitude of a user to react on a signal in a diagnostic system. Reliance describes the reaction to an absent signal, meaning the trust that a user puts into a system when it shows no response. Compliance and reliance can be described as cognitive states that are influenced differently by FA and Misses. In case of a FA-prone system the compliance of a user is reduced. This is in congruence with the cry-wolf phenomenon from Breznitz [26]. A typical example would be a smoke alarm in the house which gets ignored after a certain number of false alarms. In the case of a miss-prone system, the reliance of the user is reduced, which can lead to a user response although the system did not detect a signal.

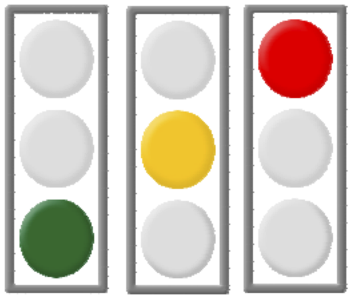
7.4. Related Work: Imperfect Automation

Wickens & Dixon [193] demonstrated that in a diagnostic system, the overall system performance drops rapidly when the reliability of the automated part drops below 70%, in which case the overall performance is lower than the performance of a system with no automated aid. They "suggest[ed] that operators chose to depend on the imperfect automation, knowing that it is far from perfect, in order to preserve available processing resources for other tasks" ([193] p.9). In case of a low level automation, the human operator could still depend on his own diagnostic knowledge.

Lee & Moray [103] conducted a research on the interaction with a semi-automatic pasteurization plant. They mentioned that reliability has great influence on human trust on and use in automated systems. The same statement and critical potential saw Parasuraman et al.[132] (p.291). They concluded that "[u]nreliability lowers operator trust and can therefore undermine potential system performance benefits of the automation" Dixon et al. [53] conducted a survey with 32 subjects, who needed to complete a simultaneous tracking and system monitoring task. The system monitoring task was aided by an audio alert, which was reliable with either 100% or 60% misses or 60% FA. Results of the experiment showed that in the miss-prone automation, performance in the tracking task was reduced. Dixon et al. concluded that this was due to the operator having shifted attention away from the tracking task to catch potential automation misses. A FA-prone automation resulted in a decreased performance in the system monitoring task by reducing operator compliance; also the response times suffered relative to the perfectly reliable automation condition and even dropped below the baseline. Dixon et al. concluded that FA-prone systems do harm the overall performance more than miss-prone systems, due to its negative effect on compliance and reliance, while a miss-prone system only reduces reliance.

Work in the automotive context by Niederee & Vollrath [124] raised the question if worse systems might be the better systems. In an evaluation, she tested to two different levels of automation (waring vs. active speed regulation) with two different stages of reliability (70% vs. 95%). In the active speed regulation variant, an ACC system completely automated the speed regulation, i.e. the vehicle accelerated and decelerated on its own to the appropriate speed. In the warning variant, ACC did not actively control the speed of the vehicle, but the deviation to the allowed speed was indicated to the driver using a traffic light metaphor (Figure 7.3). A between subjects design with four groups of subjects was used. 36 subjects participated in the experiment. Results showed that the worst reaction time was achieved with a highly automated and very reliable (95%) system. Measured in seconds, this means that in case of a failure of a highly automated and highly reliable system, reaction time was up to 20 seconds delayed compared to low automation or baseline (manuel drive). Also reaction time in a failure case in the warning condition (low level automation), was slower than the baseline, Niederee & Vollrath concluded that “in pure warning systems [...] a system failure seems to have little negative effects”. She also concluded that the problems that arise with automated systems in aviation also occur in the automotive context, and that a failure is the more critical the more reliable the system and the higher the automation level is.

(a) Warning variant realized inside driving simulator environment, a traffic light metaphor indicates the driver to adjust the speed



(b) A three stage traffic light metaphor use in the experiment in order to communicate the necessary speed adjustment

Figure 7.3.: Visualization of the warning variant, from Niederee & Vollrath [124]

7.5. Summary

Automation has a strong influence on the human, the task, cognitive demand and mental workload. Automation failure can influence the overall performance, the attitude towards automation and the trust in an automated system. In literature one can find indication that automation failure in a low level automated system might lead to worse reaction. Therefore, the BEV, as a low level automated system, needs further investigation of the possible consequences of automation failure in an additional driving simulator experiment.

8. Evaluation of the System Borders - False Alarms and Misses in the BEV

A driving simulator user study to evaluate the consequences of an automation failure. Results show an effect on the driver's behavior.

As mentioned in Chapter 7.4, the out-of-the-loop phenomenon has primarily been researched for systems with a high level of automation. Little work researched this effect for low level automated systems. Niederee & Vollrath [124] in her work e.g. mentioned a delayed reaction in case of an automation failure in a warning system. Nevertheless, she concluded that the effect had few negative effects. As presented in Chapter 9.4, information sources in the automotive context (e.g. RADAR, Car2X infrastructure) inherit a certain amount of uncertainty. Therefore, it is necessary to research the consequences of automation failure in a low level automated system like a deceleration assistance system, even though, the effect might not be as dramatic as in a highly automated system.
The BEV, as a detailed visualization for assisting early deceleration, was chosen to be evaluated in case of a partial and a complete miss. This chapter provides an overview of the driving simulator experiment that was carried out in order to evaluate the consequences on the driver behavior. This includes a presentation of the apparatus, the independent and dependent variables, the procedure, the results, discussion and finally the conclusion of the experiment.

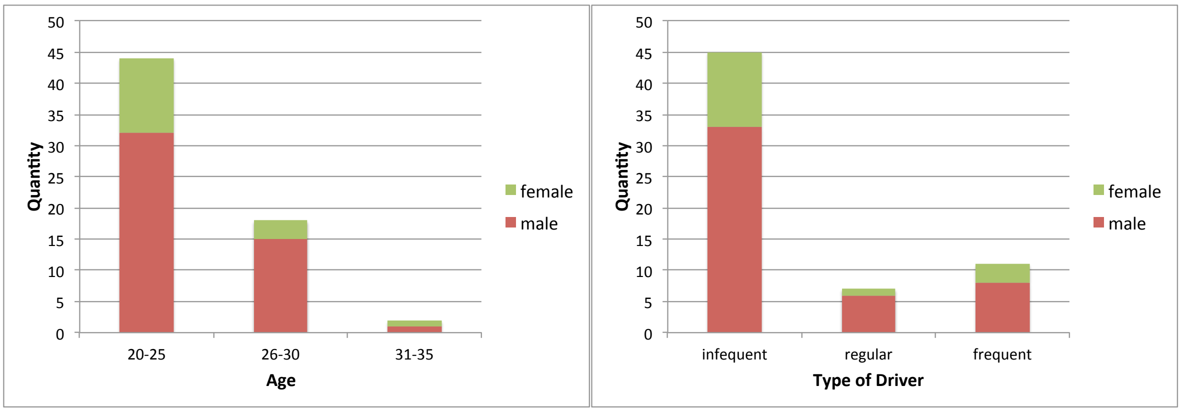
8.1. Experimental Design

As an experimental design, a between subjects design was chosen. This was necessary due to the high learning effect in case of a near crash scenario. As Sommer [162] proposed in her work, age and gender are the two main factors, which primarily influence anticipation ability. Therefore, an equal distribution of male and female subjects as well an equal distribution of age between the two groups was taken care of for the experiment.

8.1.1. Subjects

63 subjects (47 male and 16 female) participated in the experiment, with an average age of 23.8 years and a standard deviation of 2.5 years. All participants held a valid Category B driving license. Subjects were paid 10 € for their participation in the experiment. Mainly students from the "Technische Universität München" participated in the experiment. Figure 8.1 shows the distribution of age, gender and driving experience. 71.4 % (45) of the subjects can be considered infrequent drivers with an average of up to 10,000 km per year. 11.1 % (7)

can be considered regular drivers with a driving amount of 10,000 to 20,000 km per year and 17.5 % (11) can be considered frequent drivers with more than 20,000 km per year.



(a) Age distribution of the subjects

(b) Driving experience distribution of the subjects

Figure 8.1.: Subject distribution for the automation failure experiment

8.1.2. Apparatus

For the experiment, a fixed-base driving simulator at the chair for "Mensch Maschine Kommunikation (MMK)" at the "Technische Universität München" was used, which consisted of a BMW 5 series body with complete interior, and a projection screen of 4 x 3m covering approximately 73° field of view. The analogue instrument cluster was removed and replaced by a freely accessible 11 inch LCD screen. The test course was implemented using the driving simulator software SILAB from the WIVW. The software allowed easy implementation of test course scenarios and recorded the driving data with 60 Hz.

8.1.3. Independent and Dependent Variables

Two independent variables were chosen for the experiment: The first independent variable was the degree of deceleration assistance. In one group no assistance for early deceleration was given, while in the second group, the BEV was shown in the instrument cluster in order to assist the driver. A detailed information on the BEV can be found in Chapter 4.3.
The second independent variable was the degree of failure. Two situations in the test course were not displayed correctly in the group, which was supported by the BEV. One situation (called Partial Miss) was displayed partially correctly, while the second situation (called Complete Miss) was completely missed by the system.
In the "Partial Miss" situation (Figure 8.2), the driver was on a rural road with a speed limit of 100 km/h. In a right hand bend with poor visibility, an accident was blocking the driver's lane. Vehicles were blocking the view on the oncoming traffic. When the driver was about to pass the situation by turning towards the oncoming lane, oncoming traffic appeared and blocked this lane as well (approximately at 8 s TTC). Figure 8.2a is showing the situation from the driver's point of view. Figure 8.2b shows the BEV as it was presented to the subjects during the test drive. It indicated the blocked lane but missed the oncoming traffic. In

Figure 8.2c the theoretically correct visualization can be seen, which would have included the two relevant oncoming vehicles.

(a) Simulator view as seen by the subjects: a truck is blocking the own lane, oncoming traffic is blocking the oncoming lane

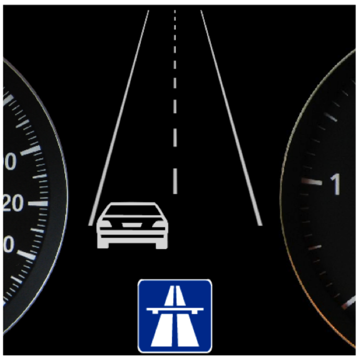
(b) Visualization presented to the subjects, the blockage of the own lane is visualized, the oncoming traffic not

(c) Correct visualization, the blockage of the own lane plus two oncoming vehicles - not presented to the subjects

Figure 8.2.: Situation Partial Miss - Rural Road right hand bend

The "Complete Miss" situation can be seen in Figure 8.3. The driver was on a two lane highway, with a speed limit of 130km/h. No other traffic was on the highway at that specific moment. The end of a traffic jam was in a narrow right hand bend. Figure 8.3b shows the BEV as it was presented to the subjects during the test drive. It reveals that the driver did not get any warning about the oncoming situation. The only visible element was the system idle state, with the type of road and ego-vehicle visible. In Figure 8.3c the theoretically correct visualization can be seen, with the end of the traffic jam moving towards the ego vehicle and blocking the complete highway.

(a) Simulator view as seen by the subjects: a two lane highway with the end of a traffic jam in a right hand bend



(b) Visualization presented to the subjects: the idle state of the BEV, only the type of road and the ego vehicle are shown

(c) Correct visualization: the end of the traffic jam blocking both lanes - not presented to the subjetcs

Figure 8.3.: Situation Total Miss - traffic jam in a right-hand bend, on a two lane highway

The group without visual assistance saw the "normal" instrument cluster including the speedometer and the revolution meter.

Dependent variables measured during the experiment include velocity, TCC, the gas and brake pedal position and the point at brake activation. The gas and brake pedal position both were measured with a value from 0 to 1, with 1 being a maximum pushed pedal. All driving data was recorded using the simulation software. Also recorded were the number of incidents in both situations.

8.1.4. Procedure

Subjects were welcomed and filled out a demographic questionnaire. The group with the visual assistance received a standardized explanation of the BEV, which included a full explanation of the functionality, all possible system states and example situations. Both groups drove through a test course divided up into two parts. The first part consisted of 11 deceleration situations, which did not include either of the two "Miss" situations. In the second part of the test drive, subjects were confronted with 30 deceleration situations. The second part of the test course included the two "Miss" situations, which were permuted throughout the course of the experiment. Both sections combined took a total of about 35 minutes to complete depending on the driving style of the subject. The test course consisted of urban, rural and highway sections.

8.1.5. Evaluation Procedure

A 2-tailed T-Test for independent samples was used for analyzing the TTC at brake activation. Results including the t-value, df and p can be found at both items. Regarding the number of incidents at each situation, the Fisher-Yates-Test (exact chi-squared test) was used.

8.2. Hypotheses

Hypothesis 1: Due to the out-of the loop effect known in highly automated systems, a delayed reaction of the driver is expected in the case of a complete miss for the group with visual assistance.
Hypothesis 2: A partially correct visualization will be enough to alert the driver. Therefore, the driver will be able to better anticipate with the partially incorrect visualization than with no visualization.
Hypothesis 3: The "Complete Miss" situation is highly safety critical. Therefore, the driver does not have the possibility to compensate the worse anticipation, which will result in a higher number of accidents.

8.3. Results

This section presents the results of the driving simulator study (by situation). For both situations the progression of the gas pedal position, the progression of brake pedal position and the point of brake activation are presented.

Construction Site - Partial Miss Situation: Figure 8.4 shows the position of the gas pedal position throughout the partial miss situation. On the y-axis the gas pedal position, from 0 (a released pedal) to 1 (a fully pushed pedal) is plotted. On the x-axis the TTC is plotted.
A clear difference of the progression between the group with visualization and the group without visualization can be seen. While the group with visualization had a lower gas pedal position throughout the whole situation, pending between 0.0 and 0.05, the group without the visualization had a relative higher gas pedal position pending between 0.0 and 0.25. Especially a rather sudden drop for the group without visualization, at about 9.1 s TTC, differentiates the two progressions. The group with visualization had a rather smooth progression throughout the whole situation. Between 7.5 s TTC and 6 s TTC the group without visualization had a higher gas pedal activation than the group with visualization. This is explainable due to a more careful approach to the situation in the 7.5 - 15 s TTC timeframe, and the consequential lower gas activation before 7.5 s TTC. The little sink in the progression for the group

with visualization at 6.5 s TTC might be explained by the appearance of the second vehicle. Drivers thought they could accelerate after the first vehicle had passed, but had to step off the gas pedal again when the second vehicle appeared. It has to be mentioned though, that no corresponding reaction in break pedal progression is detectable (c.f. Figure 8.5).

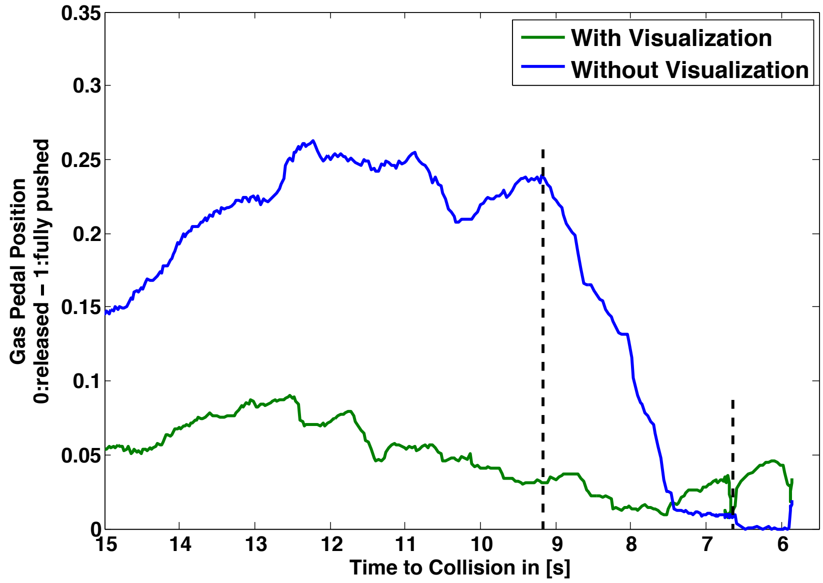


Figure 8.4.: "Partial Miss" situation, comparison of the gas pedal position over TTC

Figure 8.5 shows the position of the brake pedal position throughout the "Partial Miss" situation for the groups with and without visualization. On the y-axis the brake pedal position, from 0 (a released brake pedal) to 1 (a fully pushed brake pedal) is plotted. On the x-axis the TTC is plotted.
The plot indicates a similar behavior between the two groups until 9 s TTC. At this point the group with visualization began to activate the brake pedal, the group without visualization started to activate the brake pedal at 8.2 s TTC. In the further progression, between 7 - 6 s TTC, the group with visualization pushed the brake pedal much less, around 0.3, compared to 0.8 for the group without visualization. This behavior is explainable with the earlier brake activation and by the less activated gas pedal position in the group with visualization.

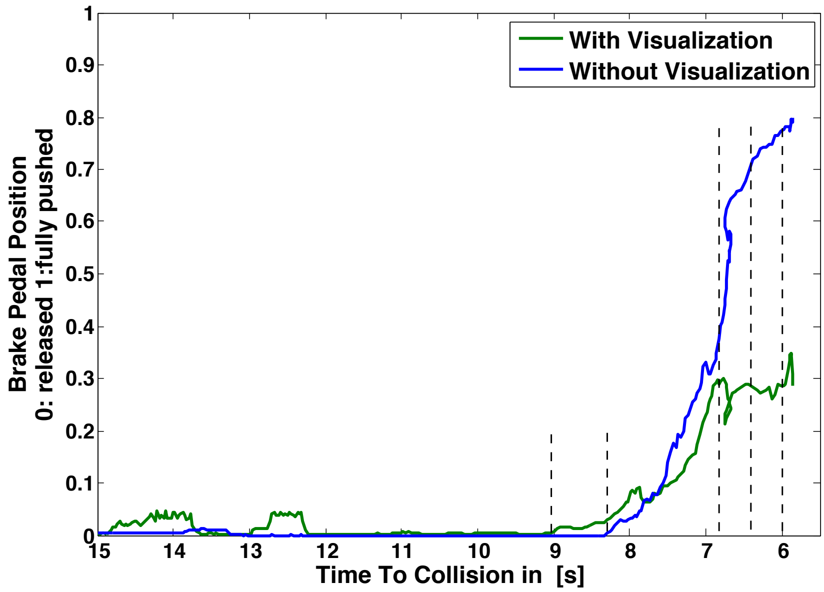


Figure 8.5.: “Partial Miss” situation, comparison of the brake pedal position over the TTC

Figure 8.6 shows the TTC at brake activation for the group with and without visualization. The point of brake activation was calculated as the first value higher than 0.00 within the situation. With a mean value of 7.31 s TTC and a median of 6.64 the group with visualization activated the brake earlier than the group without visualization (mean = 5.86 and median = 5.83). Using a 2-tailed T-Test for independent samples the difference is significant with t=2.472, df=33.92 and p= .019.

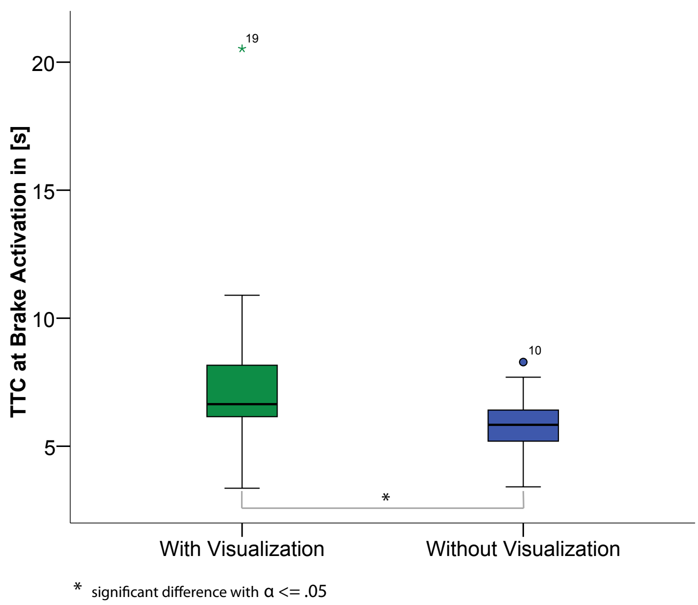


Figure 8.6.: “Partial Miss” situation, comparison of the TTC at brake activation

Apart from the reaction of the driver, also the amount of incidents in the situation was counted. The decision, if an incident occurred was decided by the conductor of the experiment and could have ranged from colliding with a side post to crashing into another vehicle. Figure 8.7 shows that the group with visualization was involved in five incidents - the same amount of incidents the group without visualization was involved in. Using the Fisher-Yates-Test (exact chi-squared test) no significant difference was found with p=1.000.

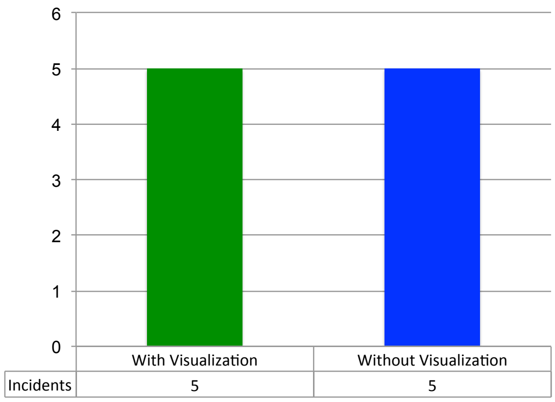


Figure 8.7.: Comparison regarding the number of incidents in the "Partial Miss" situation

Highway Jam - Complete Miss Situation: Figure 8.8 shows the position of the gas pedal position throughout the "Complete Miss" situation. On the y-axis the gas pedal position, from 0 (a released pedal) to 1 (a fully pushed pedal) is plotted. On the x-axis the TTC is plotted.
A similar progression of the group with and without visualization can be observed, with the progression for the group without visualization slightly below the group with visualization. At 6.4 s TTC the group without visualization had a sudden drop in the progression. This drop was also performed in the progression for the group with visualization at about 5.9 s TTC. Both progressions reach a fully released gas pedal position at about the same time, 3.8 s TTC.

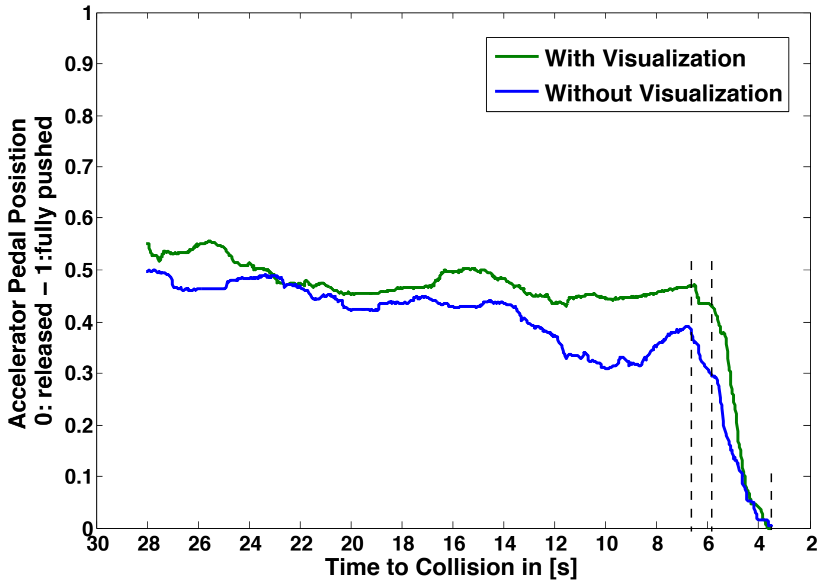


Figure 8.8.: "Complete Miss", comparison of the gas pedal position over TTC

Figure 8.9 shows the position of the brake pedal position throughout the "Complete Miss" situation. On the y-axis the brake pedal position, from 0 (a released brake pedal) to 1 (a fully pushed brake pedal) is plotted. On the x-axis the TTC is plotted.
Again a similar progression between the group with and without visualization can be observed. For both groups no brake activities can be observed until about 6.5 s TTC. The low brake activation points for the group without visualization before that point are the result of a single subject who stepped on the brake in intervals during the approach of the situation. When the situation approached, the group without visualization started to activate the brake at 6.5 s TTC, while the group with visualization did the same at about 6.0 s TTC. Both groups reacted the same and hit the brake with maximum force.

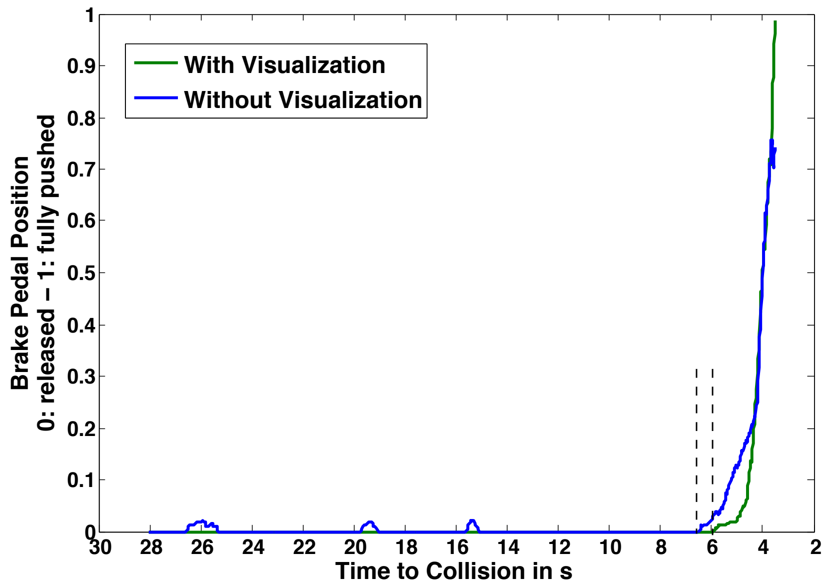


Figure 8.9.: "Complete Miss", comparison of the brake pedal position over TTC

Figure 8.10 shows the TTC at brake activation for the group with and without visualization. With a mean value of 4.68 s TTC and a median of 4.45 the group without visualization activated the brake earlier than the group with visualization (mean = 4.04 and median = 4.05). Using a 2-tailed T-Test for independent samples, the difference is **highly significant** with t=-2.764, df=55 and p= .008.

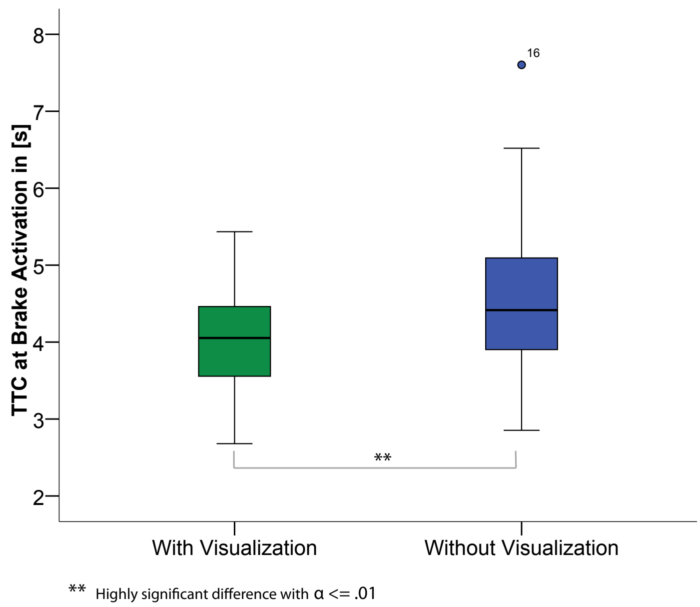


Figure 8.10.: "Complete Miss" situation, comparison of the TTC at brake activation

Apart from the reaction of the driver, also the amount of accidents in the situation were counted. The decision if an accident occurred was decided by the conductor of the experiment and could have ranged from colliding with a side post to crashing into another vehicle. Figure 8.11 shows that the group with visualization was involved in twelve incidents, while the group without visualization was involved in seven incidents. Using the Fisher-Yates-Test (exact chi-squared test) no significant difference was found with p=0.169.

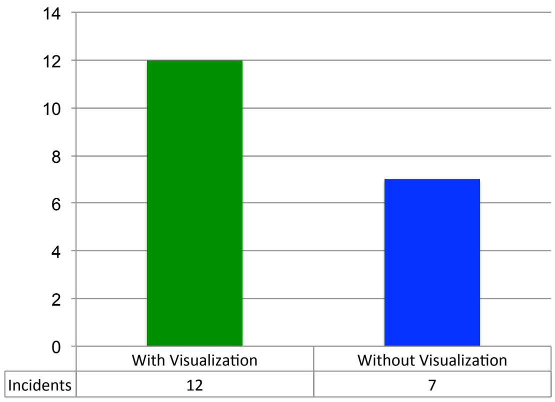


Figure 8.11.: Comparison regarding the amount of accidents in the "Complete Miss" situation

8.4. Discussion

Two different situations were investigated in detail in this experiment, a "Partial Miss" situation and a "Complete Miss" situation. In the "Partial Miss" situation the group with (a partially incorrect) visualization showed an earlier anticipation and reaction to the situation than the group without a visualization. The visualization, although only partially correct, resulted in early deceleration by stepping of the gas pedal and in an advanced activation off the brake pedal. In both conditions five accidents happened, which indicates that early anticipation and a proper reaction was not enough to prevent the accidents from happening. The main obstacles (two oncoming vehicles) were missing in the visualization, therefore, the group with visualization did not have an advantage at the time of the critical maneuver (turning into the oncoming lane). No negative effect was observed as well, meaning, the group with the visualization was not involved in more accidents than the group without visualization. It can be interpreted that in the critical moment, the drivers did not look at the visualization any more, but only concentrated on the real-life traffic scenario. Therefore, no group had an advantage over the other regarding the critical moment.
In the "Complete Miss" situation, subjects with (completely missing) visualization reacted later and were involved in more incidents than the group without visualization. In this situation the group without visualization showed an anticipating behavior that can be considered better than the group with visualization. This might be explained by the course of the situation: In a highway scenario with a narrow right hand bend, the group without visualization did a natural thing: they approached the situation with care, which can be seen by looking at the gas pedal position. Although only slightly lower than for the group with visualization, the gas pedal position for the group without visualization led to slower and therefore, more careful approach of the situation. This is the result of a correct situation anticipation, in which a narrow right hand bend can be seen as a possibly safety critical situation. The

group with (completely missing) visualization, trusted in the visualization to inform them correctly, which resulted in a faster and therefore, less careful approach of the situation. The delayed reaction can be either explained by the subjects waiting for the visualization or by not being mentally fully alert due to the overtrust in the system. The fact that twelve subjects with visualization were involved in an incident, while only seven subjects without a visualization were involved in an incident show that in a highly safety critical situation, with few or even no safety reserves, the negative effects of a complete miss could not be compensated by the subjects.
The results have to be considered with care. For one, the evaluation was conducted in a driving simulator with untrained subjects. A ten minute introduction drive is not enough for the subjects to perform at their real-life level. Also, the brake pedal in the driving simulator used reacts differently from a real-life brake pedal, therefore, a longer simulator training, especially regarding the braking behavior, would be necessary. Finally, the "Complete Miss" situation (traffic jam) was designed to be a highly safety critical situation, in which an incident was only preventable by a good anticipation and according reaction by the driver. The fact that 7 out of 31 subjects with no visualization were involved in an accident show that this situation was highly safety critical.
This experiment confirms the results by Niederee & Vollrath [124], which stated a delayed reaction in case of an automation failure in a low level automated system. A transfer to a real-life traffic scenario cannot be concluded due to the reasons mentioned above. Therefore, a transfer to a real-life experimental vehicle is necessary in order to verify the findings.

8.5. Conclusion

A difference between a partial miss and a complete miss regarding the anticipation of the driver was shown. In the "Partial Miss" situation, anticipation and reaction of the group with (partially incorrect) visualization was improved over the group without visualization. In a "Complete miss" situation on the other side, negative effects on the anticipation and reaction were observable.
If no safety reserves are available, the negative effect on the anticipation leads to a negative effect on traffic safety.
This leads to the conclusion that in a driving simulator environment, an information system like the anticipation support system (BEV), although only of low automation level, can lead to negative effects in the case of a "Complete Miss". How much this effect is transferable into reality can only be speculated about.

9. Uncertain Data - Consequences and Visualization

Information visualization including uncertain information. Sources of uncertainty in the automotive content. Ways to handle uncertain data. Visualizing uncertain data, related and conceptional work.

As shown in the Chapter 8, problems arise when automation is less than perfect. In this chapter uncertainty in information is the topic. Uncertain information is common in today's lives, it also is common in various fields of research (e.g. a geographic information system GIS) to include and visualize information about uncertainty. In automotive information visualization though, visualizing uncertainty is less than common. In this chapter, information visualization including uncertain information will be presented as well as possible sources of uncertainty in the automotive environment. Different ways to handle uncertainty, related work as well as conceptional work for presenting uncertain information on upcoming speed limits will be of topic.

9.1. Uncertainty - a Definition

In an automated diagnostic system, information is received, filtered and diagnosed by a computer. The information source can include uncertainty, which can have various reasons. For the deceleration assistance system, mentioned in chapter 4.3, information sources include long range sensors, digital maps, video cameras and Car2X communication. These sources can include uncertainty: digital maps may a have low resolution or simply be out of date, Car2X communication which uses short and long range sensors does include sensory uncertainty, etc.

There are numerous definitions for uncertainty, for example Hunter & Goodchild [88] (p.55) described it as "degree to which the lack of knowledge about the amount of error is responsible for hesitancy in accepting results and observations without caution". Other definitions summarized in a work by Griethe & Schuhmann [79] (p.2) include:

- **error:** "outlier or deviation from true value"
- **imprecision:** "resolution of a value compared to the needed resolution (e.g. values are highly accurately given for countries but are needed for states)"
- **accuracy:** "size of the interval a value lies in"
- **lineage:** "source of the data (e.g. at first hand or at second hand)"
- **subjectivity:** "degree of subjective influence in the data"

- **non-specificity:** "lack of distinctions for objects (e.g. an attribute value is known to be one of several alternatives but not which one)"
- **noise:** "undesired background influence"

For this work, uncertainty can be best described as noise or error.

9.2. Information Visualization

This chapter is not about general information visualization, but visualization of uncertainty. Just a short introduction is given on the goals of information visualization. For more information on information visualization please refer to e.g. [163], [119].
A definition from Keim et al. [92] (p.2) stated that information visualization is "the communication of abstract data through the use of interactive visual interfaces" or from Card et al. [34] (p.6): "the use of computer-su orted, interactive, visual representations of abstract data to amplify cognition". Spence [163] stressed the formation of a mental model or mental image. Figure 9.1 shows this process, in which data gets visualized and the observer gains an insight by looking at the picture. This process is called information visualization.

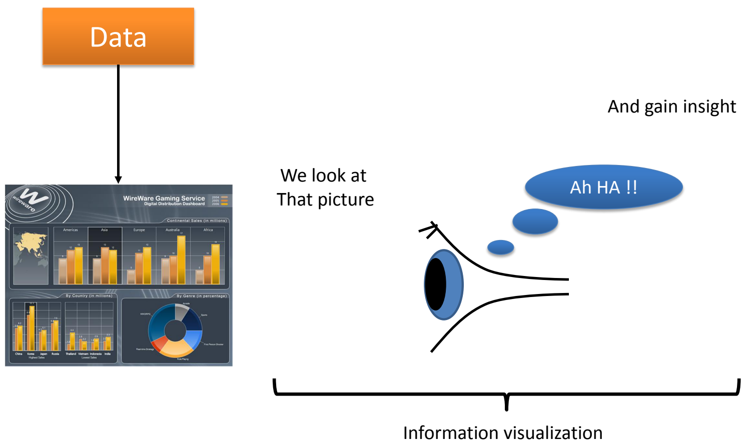
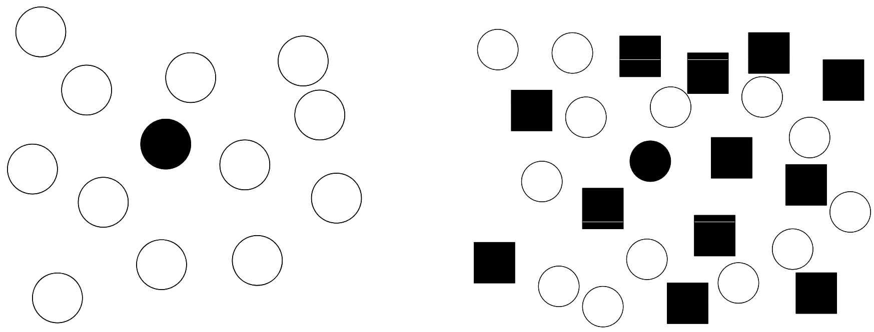


Figure 9.1.: Information visualization, data is transformed into a virtual representation, the observer gains an insight by looking at it, adapted from Spence [163]

Regarding guidelines for good information processing, Mullet & Sano [119] (p. 39) stated that "[g]ood design [...] ensures that significant design elements will be noticed by removing insignificant elements".

Preattentive Processing An interesting concept in information visualization is preattentive processing (PP). PP considers visual information that can be processed without cognitive effort. Treisman [176] in her work mentioned that PP is performed automatically on the entire field of view and detecting basic features. Tasks that can be performed in less than 200-250 ms are considered preattentive, due to the fact that initiation of eye movement takes at least 200 milliseconds (Healy et al.[85]). Typical PP features are color, shape, length, width, curvature, etc. Figure 9.2 shows a typical example of the two target detection tasks: in Figure 9.2a the shape (black circle) can be detected preattentively due to its filling, in Figure 9.2b the shape (black circle) cannot be detected preattentively because "it has no visual feature that is unique from its distractors" (Healey et al. [85] (p.4)).



(a) Target can be detected preattentively because it possess the unique feature "filled";

(b) Target cannot be detected preattentively because it has no visual feature that is unique from its distractors

Figure 9.2.: Examples of two target detection tasks, from Healey et al. [85]

PP can detect simple features from visual displays quickly and effortlessly and in parallel, without any attention being focused on the display (Healey et al. [85]), a characteristic which makes PP especially interesting for automotive information visualization.

9.3. Visualizing the Uncertainty of Data

Uncertain data can lead to imperfect automation. Visualization the uncertainty of data can help overcome this problem. This section will provide an overview of possibilities to visualize the uncertainty of data. To understand the problems associated with visualizing uncertain data, first of all a look at the visualization pipeline is provided, afterwards the visualization pipeline is extended with uncertainty information.

9.3.1. The Visualization Pipeline

The visualization pipeline (VP), is a model originally proposed by Haber & McNabb [82] (p.74) in order to "transform raw data into a geometric abstraction of the scientific information content, which then can be rendered to a displayable image using [...] image processing". Data enrichment & enhancement, visualization mapping and rendering were the three steps originally included in the VP. Santos & Brodlie [148] extended the VP by replacing the data enrichment process with two processes, data analysis and filtering. A VP can be seen in Figure 9.3. Raw data has to surpass four main stages in order to be transformed into image data, these are:

I. **Data Analysis**: The input is raw data which then is prepared for visualization. Smoothing filters are applied, missing values are interpolated. At this point no user interaction is present. The results of this stage is the prepared data.

II. **Filtering**: In the next stage, the prepared data is filtered. Parts of the data are selected for further processing in the VP. This is usually done by the user, who selects the necessary data. The result of this step is the focused data.

III. **Mapping**: Numeric data is transformed into geometrical data like points, lines, color, position and size. In the VP, this process can be considered the most critical one, as it majorly influences interpretability. Results of this process are abstract visualization objects.

IV. **Rendering**: Finally, the abstract visualization objects are transformed into image data using the rendering process. The result is the final image data.

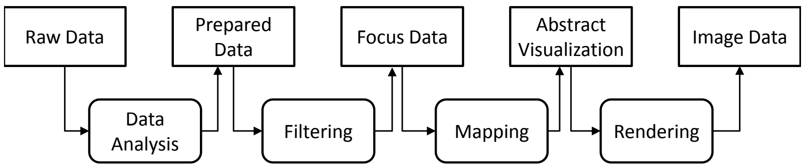


Figure 9.3.: The visualization pipeline, raw data enters the pipeline and with the help of four transformations image data is produced, adapted from Santos & Brodlie [148]

This introduction on the VP provides a short overview on the process of getting raw data to an image. It is the basis for the next step, visualizing uncertain information and what consequences uncertain information can have for the VP.

9.3.2. The Visualization Pipeline - with Uncertainty

In this section the visualization pipeline is extended with an additional piece of information, uncertainty. Based on the VP by Santos & Brodlie [148], Boukhelifa [24] described uncertainty visualization in three stages: the data provision stage, the depiction stage and the usage. In each stage it is necessary to have special skills and knowledge in order to be able to adequately visualize uncertainty. In the **data provision stage** (including raw data), it is necessary to have domain knowledge in order to be able to determine possible sources of uncertainty. In the **data depiction stage** (including filter, mapping and rendering), it is necessary to have visualization skills in order to decide on the best methods to visualize uncertainty. And finally, in the **usage stage** (including image data), it is necessary to have the ability to interpret the visualized information within the context.
Griethe & Schuhmann[79] provided an overview of the influence of uncertain information on the VP. Figure 9.4 shows a partition of the VP into three main categories: **Aquisition**, **Visualization** and **View**, similar to the three stages of Boukhelifa [24] just mentioned. At the data acquisition stage, apart from raw data, raw uncertainty is generated, which e.g. can be produced by sensors that provide information on the quality of the data they are sending. In the visualization stage, this uncertainty can have two influences on the visualization. It either can be filtered and be used to parameterize the correct data or, it can be filtered and be

handled as normal data by visualizing additional information (e.g. error bars). In the second case, mapping and rendering of the uncertainty is necessary. Finally, in the view stage the picture needs to be interpreted by the observer.

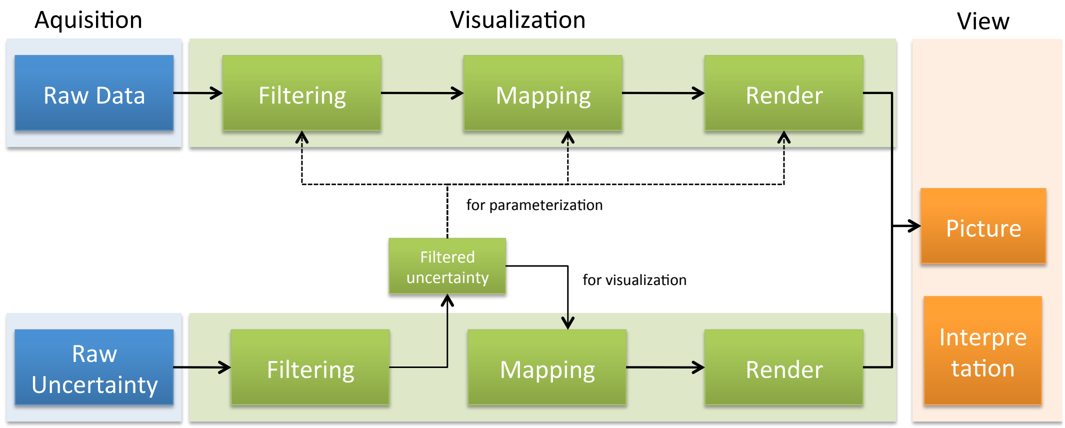


Figure 9.4.: The Visualization Pipeline including uncertainty: uncertainty can either be used to parameterize the raw data or it can be used for an additional visualization, adapted from Boukhelifa [24] and Griethe & Schuhmann[79]

Less than perfect data acquisition is not the only reason for uncertainty. Each stage of the VP can also be the source for an imperfect visualization:

- At **data acquisition:** due to imperfect hardware.
- At **filtering data:** due to imperfect knowledge.
- At **mapping:** due to insufficient representation.
- At **rendering:** due to insufficient hardware .
- At **view:** due to insufficient knowledge by the user.

9.4. Sources of Uncertainty in the Automotive Environment

As Boukhelifa [24] mentioned: in order to deal with uncertainty it is necessary to have domain knowledge to determine possible sources of uncertainty. Considering the deceleration assistance system, an overview on the information sources is provided in this chapter, with special regard to their pros, cons and reliability. Digital maps, long and short range sensors, mechanical vision and the Car2X infrastructure will be of topic.

Uncertainties in Digital Maps Digital maps in combination with a GPS can be a very powerful way to determine a vehicle's position. Today, inaccuracy in GPS can be quantified with 10 m and a latency of 300 ms for non-military applications. Due to different reception in rural and urban areas, Al Nahab et al. [5] in their work proposed that GPS accuracy is 5 to 10 m in 95 % of the time. The European alternative to GPS, Galileo, with 10 m horizontally for the

mass market and 4 m for safety critical applications [18], shows a similar performance.
A possibility to improve GPS accuracy is called differential GPS (DGPS), which uses multiple fixed, ground-based reference stations to enhance the GPS signal by "broadcasting difference between the positions indicated by the satellite systems and the known fixed positions" ([198]). This technique e.g. is used by SOPOS, the satellite positioning service of the german land surveying, to achieve a GPS accuracy in the centimeter range (e.g. Westenberg & Wegner [189]).

Uncertainties in In-Vehicle Sensors Although not all sensors have the ability to transmit the quality of their measurements, it still is possible to include reliability in their readings. This can be done either by comparing readings from different sensors or by taking the accuracy of sensors into account. RADAR is a widely used technology. With the use of RADAR it is possible measure distance, relative speed and azimuth angle. Frequencies that are in use today, are the 24,0–24,25 GHz as well as 76–77 GHz. The 76.5 GHz frequency typically is used for long range RADAR (LRR). LRR has a damper free range of about 200 m and and maximum range of 1000 m. The azimuth angle is about +- 8° [152] [201]. Typical usage for LRR in the automotive context is ACC. Its accuracy lies at 1 m in distance, +- 1 km/h and 0.3°. In a simulation with multiple traffic, Gambi et al. [71] simulated a detection probability between 0.73 and 0.99. The 24,0–24,25 GHz frequency is typically used for Short Range RADAR (SRR). SSR covers a distance between 0.5-70 m [152] [201]. The opening angle of SSR is +-50° with a precision of +-3 cm in distance. Typical usage for SSR in the automotive context are ACC stop-and-go and pre-crash scenarios, blind spot surveillance and parking assistance. The inaccuracy of SRR is as follows: detection probability 0.82-0.99 depending on which object is to be detected, with a worst case of 82% for pedestrian detection.
A further sensor in the automotive context is the ultrasonic sensor at a 40-50 kHz frequency. It typically gets used for the park assistance system. The typical range for an ultrasonic sensor lies between 0-150 cm [125].
An alternative sensor for the range from 1 to 180 m is light detection and ranging (LIDAR) - an alternative to the RADAR, which uses light transmitting diodes instead of radio waves, with a typical wave length of 905 nm [73]. LIDAR has a typical azimuth angle of +-15° and an accuracy of about +-1 km/h in speed and +-1 m in distance. Further information on automotive sensors and uncertainties in sensors can e.g. be found in Walchshäusl [181] and Bauer [16].

Computer Vision Due to rapidly improving technology and a corresponding drop in prices, camera systems at and inside the vehicle are becoming a common feature. Camera based assistance can include traffic sign recognition, lane or obstacle detection, etc.
In order to be able to extract information from a camera image, several approaches are used. One possibility is that a camera is recording an environment; the image then is further processed and information is drawn from image processing and the detection of certain features. Another possibility is the 3D reconstruction of the environment using stereoscopic cameras. Other possibilities are the detection of objects and the distance to objects.
Advantages of visual systems are:

- Passive measurement (therefore no regulation).

- The automotive infrastructure is dedicated to visual impact, which makes it easy to use cameras.
- High technical transparency due to the close relationship to the human perception.

Concerning accuracy, Shneier [159] conducted a survey in 2005, in which 72 out of 92 traffic signs were correctly detected, resulting in 78% correct detection probability. Soendoro & Supriana [161], in 2011, proposed an algorithm for traffic sign recognition with an average of 97% accuracy. Still, camera based systems and their performance is influenced by the environment. Typical problems for camera bases systems are:

- Heavy fog, rain or snowfall.
- Signs concealed by other objects (trees, other vehicles, etc.)
- Driving towards bright light.
- Dirt on the camera lens
- Trucks or buses with speed stickers

Readers with further interest in computer vision in an automotive context are referred to Stiller et al. [166].

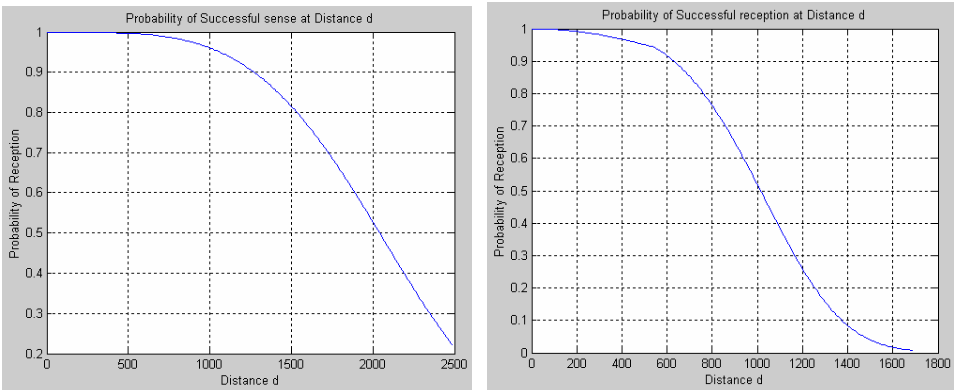
Summery Table 9.1 depicts characteristics and potential of different sensor technology.

	Vision	Lidar	Radar
Weather dependent	yes	yes	no
Primary measurement			
Position	-	+	+
Speed	-	-	+
Brightness pattern	+	+	-
Function			
Detection of Objects	+	+	+
Recognition of Objects	+	+	+/-
Lane Detection	+	+/-	-
Traffic Sign Detection	+	-	-

Table 9.1.: Characteristics and potential of different sensor technology, from Stiller et al. [166]

Inaccuracies Within the C2X Infrastructure As mentioned in Chapter 2.2, the Car2X infrastructure is based on the 5.9 GHz spectrum, and is a wireless LAN IEEE standard 802.11p, with a bandwidth of 27 MBits/s. Within this structure uncertainties can arise, which can affect the reliability of information from this structure. Signals within the Car2X Infrastructure can be transferred via single-hop in a distance of around 1000 m. Internal sensor data, from vehicles and the infrastructure, are transmitted by the Car2X infrastructure. Xu et al. [203]

in his work, evaluated the possibility that a vehicle is correctly receiving information from another vehicle. First, the vehicle has to sense the communication partner, then the information has to be transmitted correctly. Figure 9.5, shows the probability for correctly sensing a vehicle (Figure 9.5a) and receiving an information chunk (Figure 9.5b). Accordingly, at a distance of 500 m, the probability of correctly receiving a piece of information from another vehicle lies at about 93%.



(a) Probability of correctly sensing a vehicle (b) Probability of correctly receiving an information chunk

Figure 9.5.: Reception probability of an information chunk over distance, from Xu et al. [203]

9.5. Handling Uncertainty

The influence of uncertainty in the VP as well as sources of uncertainty in the automotive context were of topic so far. One way to approach the uncertainty problem is technical by improving the sensors themselves and therefore reducing uncertainty. This approach is necessary to pursue in the future. One problem will remain though: information will not be 100% certain. Therefore, it is necessary to utilize other possibilities in order to cope with uncertainty. This section shows ways to deal with uncertainty, including mathematical approaches as well as an insight in the effect of uncertainty on human perception. Also, four general ways of dealing with uncertainty by Chalmers et al. [39] will be presented.

9.5.1. Mathematical Approaches to Improve Certainty

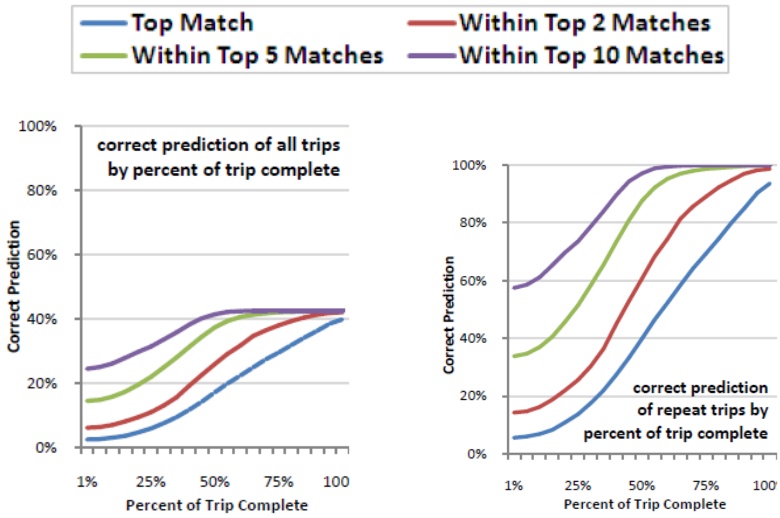
The Dempster-Shafer theory (DST) for sensor fusion and Bayesian networks are two widely used mathematical approaches in the automotive context in order to handle uncertainty.

The Dempster-Shafer Theory The DST originally developed by Dempster [44] and further explored by Shafer [156] is a theory that allows the fusion of multiple sources, including their uncertainty, to calculate the most possible result. In the automotive environment, the DST can for example be applied for sensor fusion for on-vehicle sensors. The DST is a mathematical theory which combines information from different sources, including their reliability and forms a cumulated result, which is better than any single information. In order to use the DST, it is necessary to be able to quantify the reliability of an information source.

Examples of the use of the DST in the automotive context can be found in a work by Savi & Limbourg [150], who used the DST to get improved data of the vehicle's environment in order to recognize and classify those objects. Considering the fact that more and more information sources will be available in the future, mathematical approaches like the DST are necessary to provide the most probable result.

Bayesian Network Also used in the automotive context when dealing with uncertain information is a Bayesian Network BN. A BN is a directed acyclic graph, with nodes and edges. The nodes represent a state with a probability, while the edges represent dependencies between the states. Each node also has a probability function which indicates the possibility that a child node, in dependency of the state of its parents, takes a certain state. In the automotive context BN are used for example to determine the wish to take a turn at the next intersection [95]. In contrast to decision trees, which have yes/no decisions, a BN does not lose any knowledge, therefore, uncertain knowledge does not get lost.

Related Work: Route Prediction A mathematical approach for dealing with uncertainty in the automotive context was presented by Fröhlich & Krumm [69] in their work on route prediction. A lot of driver assistance ideas include the necessity of knowing where the driver is going. This works properly as long as the driver uses a navigation system. But what happens when the navigation system is inactive? With the use of a route predictor it is possible to predict one's route without knowing the goal of a trip. Information about previous routes and GPS data are necessary for a route predictor. The basis for this approach is the fact that large portions of a driver's trips are repeated over and over again. Fröhlich & Krumm in their work took the first part of the trip and, in contrast to other algorithms, did not predict the next section, but rather focused on the long-term prediction of the route. Results showed that over a 40 day period, 60% of the trips were duplicated. With the use of 240 subjects and 14,468 trips, Figure 9.6b shows that, considering all trips, within 50% trip completion the correct trip can be predicted in 20%. Considering repeat trips, Figure 9.6c shows that this percentage improves to 40%.



(b) Correct prediction of all trips over percentage of trip completion

(c) Correct prediction of all repeat trips over percentage of trip completion

Figure 9.6.: Probability to predict correct trip after percent of trip completion, from Fröhlich & Krumm [69]

9.5.2. Humans Dealing With Uncertainty

Apart from technical or mathematical approaches, it is also important to take a look at the receiver of uncertain information, the human, and recognize the problems and possibilities a human has when being confronted with uncertainties. This section will provide an overview of the effects uncertainty can have on human abilities, as well as a general categorization of dealing with uncertainties.

9.5.3. Developing a System Including Uncertainties

Categorization of Possible Ways to Handle Uncertain Information Regarding the developer of a system that included uncertainties, Chalmers et al. [39] summarized a mental approach to deal with uncertainty. They proposed four different ways to handle uncertainty data, which were:

- **Pessimistic:** Only show information that is known to be correct.
- **Optimistic:** Show everything as if it were correct.
- **Cautious:** Explicitly present uncertainty.
- **Opportunistic:** Exploit uncertainty (cf. Gaver et al. [72]).

Pessimistic and optimistic can be considered engineering-led, e.g. a small dot to represent one's location on a map. An example for a cautious visualization is the signal strength bars on mobile phones. Therefore, the user has the possibility to decide if s/he can make a call. In today's automotive information systems, uncertainty is usually handled either optimistic or pessimistic, by either showing information as it is being correct or not at all. An example would be the current position of a vehicle in the navigation system, or speed limit signs detected by a camera.

Seamless or Seamful System Designs The idea of Chalmers et al. that there are other ways to handle uncertainty can also be found in the field of ubiquitous computing. In contrast to the beginning, in which a seamless system design was propagated (meaning a heterogeneous computer environment pretended to be homogeneous) nowadays an initiative can be found that is propagating the opposite, the so called seamful system. In a seamful system the seam of the heterogeneous environment should no longer be hidden (badly), but should be made visible and useable to the user [13].
Flintham et al. [67] described a game by the name "Can You See Me Now", in which real life players, the so called runners, are being chased by online players through a real/virtual city. Over the two days of gaming, the runners developed tactics to exploit GPS uncertainty in order to improve their gameplay. Due to this experience, Flintham et al. proposed to extend the user interface by including GPS inaccuracies.
The idea of a seamful design is not meant for every system; it rather can be seen as an opportunity to be honest to the user and to use the inevitable problems to one's advantage.

9.5.4. Effects of Uncertainty on the User

The term mode awareness is closely related to the terms mental model and situation awareness. It describes the ability of the user to track and anticipate the behavior of the automated systems (Sarter & Woods [149]).
Uncertainty and especially the way it is presented will influence the mode awareness, mental model and situation awareness of the user. By adding information of data reliability, the developer allows the user to gain a better knowledge of how the systems works.

9.6. Visualizing/Mapping Uncertainty

After presenting sources of uncertainty and possibilities to handle uncertain data, the mapping of the data to a representation is necessary. During the design process this step is crucial. As mentioned in Chapter 9.3.2, uncertainty can either parameterize the original data or it can be mapped to an external visual representation. Several techniques and possibilities to map uncertain data are presented in this section.

9.6.1. Visual Variables

Visual variables are one way to map uncertainty. Jaques Bertin in his his book "Semiology of Graphics" [20] described visual variables as a "vocabulary for making visual statements". Bertin first of all defined marks, which include geometrical shapes like points, lines, areas, surfaces and volume. These marks then can be transformed and by that a meaningful difference can be embedded into the marks. These transformations can be seen in Figure 9.7, which includes seven visual variables: texture, color value, color hue, size, shape and position.

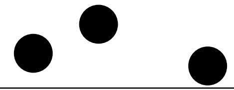
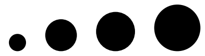
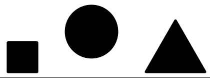
Bertin's Original Visual Variables		Selektive	Associative	Quantitative	Order	Length
Position Changes in the x, y location		X	X	X	X	X
Size Changes in the length, area or repetition		X	X	X	X	X
Shape Infinite number of shapes		?	?			X
Value Changes from light to dark		X	X		X	X
Color Changes in hue in a given value		X	X			X
Orientation Changes in allignment		X	X			X
Texture Changes in grain		X	X			X

Figure 9.7.: Seven visual variables, a "vocabulary for making visual statements", adopted from Bertin [20]

After Bertin (found in Carpendale [35]), visual variables can have different characteristics, which can enhance the performance of a task. These characteristics are:

- **Selective:** A visual variable is selective if a mark is changed in this characteristic, it is easier to select that mark over all other marks. Visual variables that are selective are: position, size, value, color, orientation, texture, pattern; Whether shape is selective cannot be clarified.
- **Associative:** A visual variable is associative, if marks changed in this characteristic can be grouped (e.g. all yellow dots belong to each other). Visual variables that are associative are: position, size, value, color, orientation, texture; "Shape" again cannot be clearly declared associative.
- **Quantitative:** A visual variable is quantitative, if the relationship between two marks differing in this characteristic can be seen numerical (e.g.: one line is four times as long as another line). The only visual variables that are clearly quantitative are "size" and "position".
- **Order:** A visual variable is of order, if changes in it support ordered reading (e.g. more or less dark). Visual variables that can be said to be ordered are "value", "size" and "position".
- **Length:** The length of a visual variable is the number of changes that can be performed and still are associated with the visual variable (e.g.: how many shades of gray are

recognizable with confidence of separation) (position, size, shape, value, color, orientation, texture)

Apart from intrinsic representations, which include visual variables, so called extrinsic representations can be used to visualize uncertainty (Brown [27]). These include dials, thermometers, arrows, bars, different shapes and complex objects – pie charts, graphs, bars, or complex error bars. Further possibilities to map uncertainty will be discussed in the next section.

9.6.2. Other Possibilities to Map Uncertainty

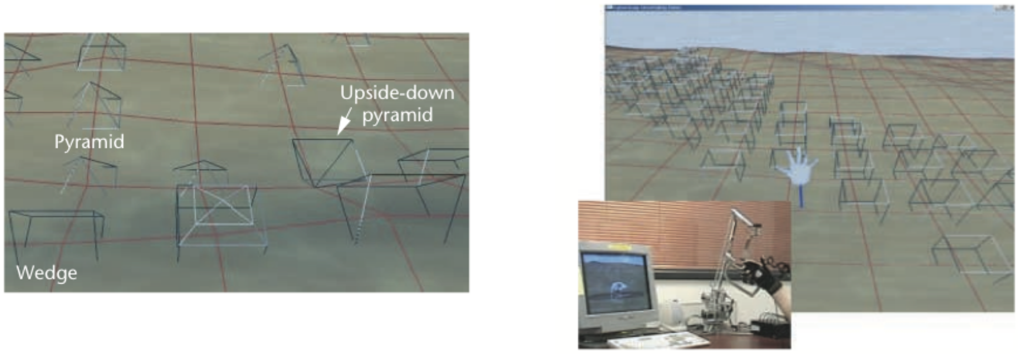
Using additional graphical objects, animation or different modalities are alternatives when visual variables are not the best option for mapping uncertainties.

Additional Graphical Objects As can be seen in Figure 9.4 uncertainty on one side can be used to parameterize the original data (free visual variables can be used for mapping), on the other side uncertainty can be visualized to additional graphical objects. Possible objects are: glyphs, labels or error bars (known from statistical diagrams). In contrast to the use of visual variables, additional graphical objects do not alter the original data. The observer can access this data in its raw format. A disadvantage though, is the additional graphical information that has to be processed by the observer.

Animation Due to advances in technology, not only static variables can be used to visualize information. Bartram [14] proposed the use of animation as an additional visual variable. Characteristics that support animation as a good visual variable are: the possibility to process motion pre-attentively and that motion is handled by a dedicated processing mechanism.
Brown [27] proposed to use vibration, or as he called it "blurring over time" as a visualization method for uncertainty. He argued that blurring is the most intuitive method to indicate uncertainty, and instead of taking away high frequency detail from the information, and therefore, which results in an reduction of clear information, animation it is a good method to extend blurring to the temporal domain.

Other Human Sensors Apart from visualizing uncertainty, there is the possibility to use other perceptional channels to communicate uncertainty. Lodha et al. [108] in their work proposed that sonification in combination with visualization can reduce typical problems of information overload, and can be an alternative where visualization is not sufficient, e.g. when two representations are very similar. In their work, sonification was used in two different systems in order to map uncertainty. Visualizing uncertainties in fluid flow and surface interpolants were two of their use cases. They conclude that the use of sonification can help to identify uncertainties which are hard to recognize visually as well as sonification reliefs the visual channel. No user evaluation was performed.
Bryden et al. [31] used the haptic channel to map uncertainty in the measurements of sonar readings of an underwater environment. In order to visualize a high degree of multivariate information, including "four dimensions of uncertainty for sea-bottom measurement with information about the physiographic regions, landmark features, map information, and

more", they decided to combine a haptic input/output device with the 4D graphical objects and mapped the depth uncertainty to the object's degree of stiffness (Figure 9.8). The observer was able to "feel" the uncertainty with the use of a haptic device (Figure 9.8b). Barely distinguishable 4D objects were the main problem. Therefore, it was concluded that the use of the haptic channel is a promising way for communicating information about data, but effective use would require improvements to the hardware's fidelity and usability.



(a) Different graphical objects representing uncertainty in measurement of sea-bottom

(b) Glyphs representing uncertainty, degree of uncertainty is mapped to the stiffness and can be felt with a exoskeleton device

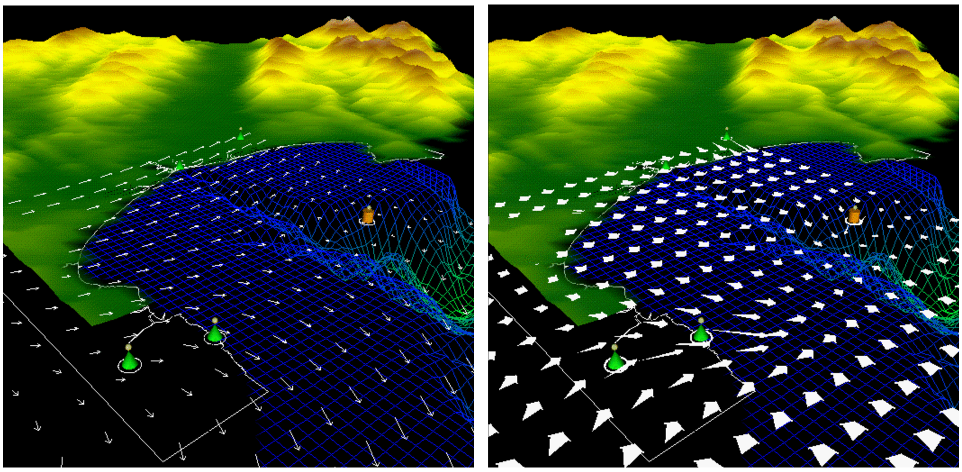
Figure 9.8.: Mapping uncertainty to haptic input/output device, from Bryden et al. [31]

Interactive Maps Not a different way to present uncertain data, but a different way to interact with uncertain data is mentioned by Van der Wel et al.[179]: the clickable map. A traditional colored map is extended by the possibility to interactively gain access to underlying uncertainty information. In a clickable map one is able to click on a certain pixel to unveil additional information, like the pixel's vector of probabilities, which is not directly visible in the map otherwise.

9.7. Related Work

This section will give an overview on work, that uses visual variables, additional graphical objects or other methods in order to visualize uncertain information. Main fields of interest are the geo-visualization, aviation and medical imaging.

Geographical Information System Visualizing uncertain information in geo visualization is well established. For example Appelton [9] in his work used color and transparency to indicate uncertainty. Wittenbrink et al. [202] in their work researched how uncertainty in measurements can be included in the shape of an arrow. Figure 9.9a shows the traditional way to visualize radar readings of currents with arrows. Figure 9.9b shows differently shaped arrows that include uncertainty in direction and magnitude. Wittenbrink et al. concluded "that the uncertainty glyphs are a substantial improvement as they provide more information, that is more accurately decodable than traditional glyphs". They also mentioned that not a single technique works best with all data, and that visualization strategies have to be adapted to the context.

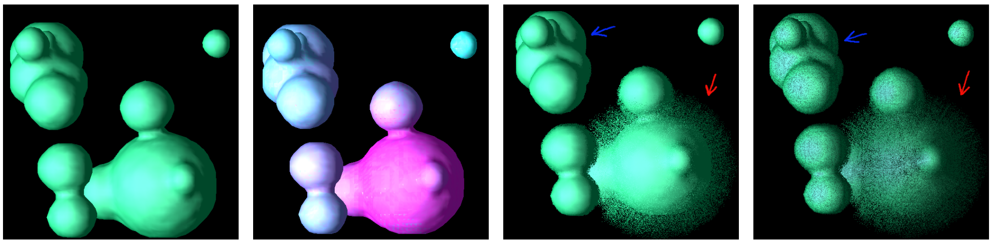


(a) "Normal" arrow shape in order to indicate sea current, no information about uncertainty is given

(b) Differently shaped arrows in order to visualize uncertainty in sea current directions

Figure 9.9.: Comparison of different arrow shapes, with and without indication of uncertainty in radar reading of current, from Wittenbrink et al. [202]

Medical Imaging In the context of medical imaging, Grigoryan & Rheingans [80] proposed to use point-based primitives in order to visualize uncertain information in medical scans. Figure 9.10 shows different visualization possibilities of a tumor structure scan. In Figure 9.10a information is optimistically visualized, meaning no uncertainties are shown and all readings are presented as if certain. In Figure 9.10b, uncertainty is shown by colors, in Figure 9.10c the point-based primitives are used and finally, in Figure 9.10d point-based primitives in combination with transparency is used.



(a) Scan visualization with no indication of uncertainty

(b) Scan visualization, colors are used to indicate areas of high uncertainty (pink), without additional information hard to understand

(c) Scan visualization, so called point-based primitives are used to indicate areas of uncertainty, intuitive to understand

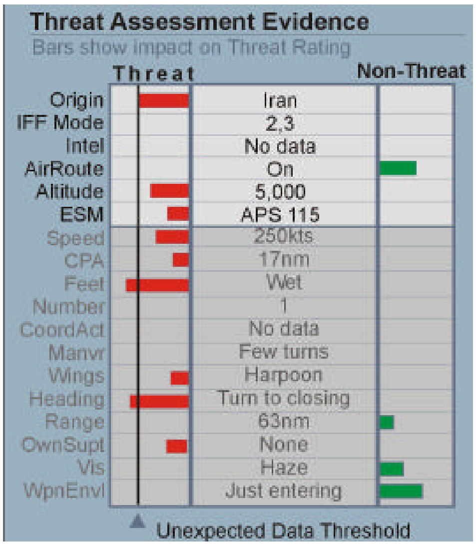
(d) Scan visualization, so called point-based primitives and transparency are used to indicate areas of uncertainty, intuitive to understand

Figure 9.10.: Different possibilities to visualize uncertainty regarding the shape of a tumor cell, from Grigoryan & Rheingans [80]

Grigoryan & Rheingans concluded that a visualization of uncertainty with the use of point-based primitives is intuitive and no guessing is necessary.

Aviation Bisantz et al. [21] (found in [84]) proposed blurred icons of planes in order to visualize the level of threat and the level of uncertainty. So far no empirical study of the usefulness has been conducted. Figure 9.11a presents an increase in blur on the plane icons as uncertainty rises.
Liebhaber & Feher [107] conducted a study in the context of an air defense decision support system. They proposed a visualization that offers an additional view, in which all evidences are shown that are taken into account when a detected object is identified as a threat. Figure 9.11b shows this view, including the bars, indicating “threat” or “no threat”, for each evidence. Longer bars do have more impact on the decision.

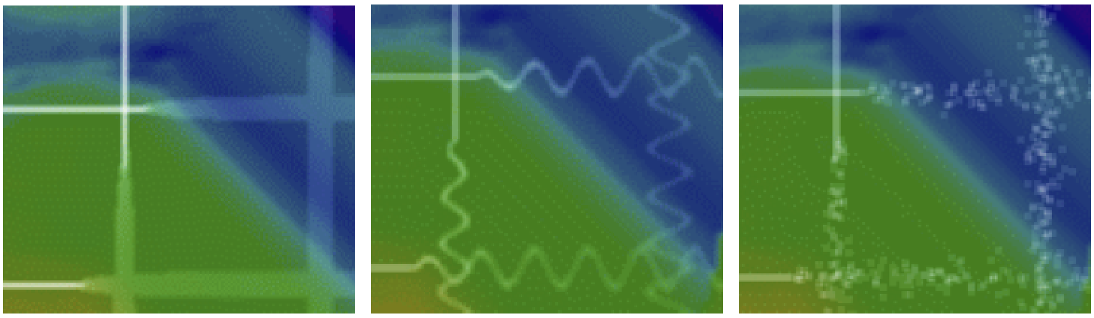
(a) Different level of uncertainty regarding the position, represented using a blur effect on a plane icon, from Bisantz et al. [21]



(b) Extra view for an air defense decision support system, the longer the bar the more impact the source of information has, from Liebhaber & Feher [107]

Figure 9.11.: Two different types of threat visualizations in the military context

Scientific Data Visualization Cedilnik & Rheingans [38] proposed a grid overlay for data in order to perceive conservation of perceptibility. Instead of mapping uncertain data to values of the data, they laid out a grid above the visualization and applied uncertainty visualization to the grid instead of the data. Cedilnik & Rheingans applied effects they called "width variation", "amplitude modulation distortion", "exponential sharpness" and more to the grid in order to visualize areas of high and low uncertainties. Figure 9.12 shows different possibilities of this technique. In Figure 9.12a width variation is applied to the grid; in areas of higher uncertainty the grid lines are wider and more transparent. In Figure 9.12b areas of uncertainty are marked with a higher amplitude distortion in the grid overlay. Finally, a noise technique is used on the grid in Figure 9.12c to indicate uncertainty.



(a) Width variation, the large the width of the grid the higher the uncertainty

(b) Amplitude modulation distortion: more distortion therefore higher uncertainty

(c) Noise technique, the line of grid dissolves more in areas of uncertainty

Figure 9.12.: Different possibilities to visualize uncertainty in scientific data by a grid overlay, by Cedilnik & Rheingans [38]

An advantage of this technique lies in the fact that the original data is not modified and the uncertainty only is applied to the grid. Therefore, it is possible to examine the original data, simply by removing the grid.

9.8. Conceptional Work, Mapping Uncertain Speed Limit Information

In the first part of this work, a system was introduced that supported the driver in early deceleration by providing and visualizing relevant information in the instrument cluster. It was shown that information presentation is considered to be low level automation and that a system failure ("misses") can lead to negative consequences regarding the driver’s performance. Considering the fact that information sources in the automotive context will not be 100% reliable in near the future, it is necessary to deal with visualizing uncertainties. This chapter already provided some background on the possibilities to visualize uncertain information, including visual variables, additional graphical objects and more.
In this section conceptional work is presented which includes uncertain information about the upcoming speed limit into the visualization. For the conceptional work, additional graphical objects as well as visual variables were used. All presented concepts follow the “cautious” uncertainty visualization paradigma, proposed by Chalmers et al. [39], as mentioned in the previous section.

9.8.1. Concepts

The concepts presented in this section will be categorized into three parts. (1) Concepts that are based on uncertainty mapping with **visual variables**, (2) concepts that use **additional graphical objects** for uncertainty mapping and that have the possibility **to visualize a concrete level of uncertainty** and finally, (3) concepts that are based on mapping uncertainty to **an additional graphical object**, respectively a **question mark “?”**. A short description of the idea, pros and cons are presented for each concept. The concept chosen in this work then was evaluated in an user study, which can be found in Chapter 10.

Mapping Uncertainty to Visual Variables A first approach for mapping uncertainty considers visual variables. In Table 9.2 the concept, a short description, the pros and cons can be seen. Concepts include the mapping of uncertainty to saturation, edge sharpness and size. The pros and cons are taken from expert opinions collected in a pre-study of the user evaluation.

	Gray	Blur 1	Blur2	Blur3
Concept				
Descr.	Uncertain information is presented by the **gray border** of the speed limit sign.	Using a blur in order to map uncertainty. The **whole sign** is blurred.	Using a blur in order to visualize the uncertainty. Only the speed limit **text** is blurred.	A blur that is just affecting the **edge** of the sign, but leaves the text untouched.
Pros	No additional graphical object is necessary as well as it is easily recognizable.	Using a blur as a free visual variable to map uncertainty can be considered intuitive.	Uncertainty is mapped to the "correct" part of the sign, not the sign is uncertain, the limit is.	Speed limit information is well readable.
Cons	The mapping of uncertainty to a color change has to be learned and cannot be considered intuitive.	Blurring the whole sign results in a low quality image, thes speed limit is hardly readable.	Speed limit not well readable, impression of a low quality image.	Effect is hardly recognizable and not intuitive.

Table 9.2.: Concepts for visualizing uncertainty with the use of visual variables (1)

Table 9.3 shows three more variants that use a visual variable for uncertainty mapping: size, rotation and transparency.

	Size	Rotation	Transparency
Concept			
Descr.	Uncertain information is presented by a decrease in **size** of the sign.	Using a **rotation** in order to map uncertainty.	Uncertain information is presented by a **transparent** sign.
Pros	No additional graphical objects or graphical artifacts are necessary.	No additional graphical objects or graphical artifacts are necessary.	Result is rather intuitive and worthy looking. Also no additional graphical objects are necessary.
Cons	Not intuitive and the sign becomes hard to read. Effect is hardly detectable.	Speed limit becomes hard to read. Also not an intuitive metaphor.	Speed limit is hard to read. Depending on the amount of transparancy, the effect is hard to recognize.

Table 9.3.: Concepts for visualizing uncertainty with the use of visual variables (2)

In Table 9.4 to Table 9.5 visualization options that use an additional graphical object to map uncertainty are presented. Additional graphical objects that are presented in this table all have the capability to indicate more than two different states of certainty. Originally, three or even more states were thought of, but with the consideration that the driver is not interested in the exact reliability, these ideas were dropped.
In Table 9.4, two visualizations are shown that present the amount of uncertainty using a ring or bar. The "Ring" variant was divided into 3 segments in order to be able to realize the original three different levels. The "Bar" was connected to the speed sign using a rounded rectangle.

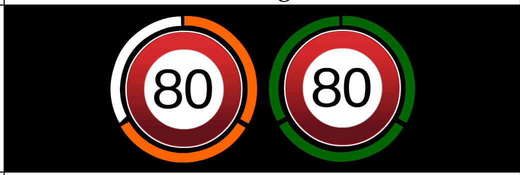
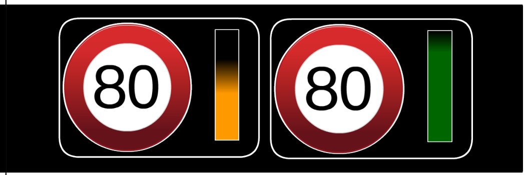
	Ring	Sidebar
Concept		
Descr.	A ring with three segments indicates the level of uncertainty. Color is used in redundancy.	Status bar on the right side indicates uncertainty. Color and degree of fill are used to indicate level of uncertainty.
Pros	Uncertainty is well integrated in the visual appearance of the sign.	Well visible and the user is able to indicate finely grained level of uncertainty.
Cons	Visualization is visually too complex and draws too much attention. Also, different shapes of signs are difficult to realize.	The bar can wrongly be associated with a distance bar.

Table 9.4.: Concepts for visualizing uncertainty using an additional graphical object (1), several different states of uncertainty are possible

In Table 9.5, two visualizations are shown using graphical objects that are able to indicate at least two states: The "Quarter Ring" and the "Glow". The "Quarter Ring" is a visually less obtrusive variant of the "Ring". A glow over two segments was used to visualize the two segments at all times, which should indicate that there is no further states. In the "Glow" visualization, a glow of different color and intensity behind the speed limit sign was used to indicate data reliability.

	Quarter Ring	Glow
Concept		
Descr.	A quarter ring with two segments and two colors is used to indicate uncertainty.	A glow behind the sign in different colors is used to indicate uncertainty.
Pros	Visualization is visually less complex than the "Ring"	Visualization got a worthy look and is adoptable to each sign.
Cons	It is problematic to tell the number of states.	Visualization has a low visual impact and the color is conflicting with the colored border of the sign.

Table 9.5.: Concepts for visualizing uncertainty using an additional graphical object (2), lower visual impact than in Table 9.4

Finally, Table 9.6 shows different concepts for visualizing uncertainty by a question mark. With the use of this additional graphical element, only two states of uncertainty are possible (certain and uncertain). The question mark itself is an intuitive representation of uncertainty. Yet, it is unclear how to integrate the additional element into the speed limit information.

	Question1	Question2	Question3	Question4
Concept				
Descr.	A half transparent question mark is added to the sign by overlay.	The question mark is added to the right of the speed limit text.	The question mark is located at the right of the sign, a connection is made using a drop shadow.	An **animation** that fades out the text of the sign and, at the same time, fades in the question mark.
Pros	The speed limit and the question mark are visible at the same time.	Question mark and speed limit are well readable.	Sign is untouched, speed limit and the question mark are well readable.	Information does not disturb each other.
Cons	Due to the transparency the question mark is hard to see.	Position of the question mark can lead to confusion, e.g. that system is not sure whether it is km/h or mph.	Relation between the question mark and the sign is not 100% clearly recognizable.	Possibility of just seeing one of the two pieces of information (speed limit or question mark).

Table 9.6.: Concepts for visualizing uncertainty with the use of a question mark “?”

9.8.2. Conclusion of Conceptional Work

The presented concepts can be mainly categorized into three parts. (1) Concepts which use visual variables to map the uncertainty information, (2) concepts that use an additional graphical object to indicate the amount of uncertainty in an information and (3) concepts that use an additional question mark “?” (also an additional graphical object) with two possible states of uncertainty.
An expert (designer of driver assistance system) evaluation was performed with the help of a prototype. This evaluation resulted in a number of comments and advices. Concepts which use visual variables to map uncertainty do have one problem in common: apart from

the "Blur" concept, no visual variable is intuitively mapped to uncertainty and therefore might lead to misconception in a first contact scenario. The "Blur" variant on the other hand is not visually appealing enough. Many experts were concerned that the driver might wonder whether he needs better glasses or whether the display is broken.

Concepts with an additional graphical object as status indicator do have the problem of being visually complex. When only two states of uncertainty have to be displayed, the question arises whether such a visualization is simply "too much".

During the expert evaluation, a concept including a question mark "?" emerged as the favorite concept. The question mark is the most intuitive and most clear mapping of uncertainty. Regarding the incorporation of the question mark into the sign, it is necessary that both pieces of information are well visible and well readable at all times.

After deciding on a question mark concept for uncertainty visualization, a final concept was created. The concept can be found in Chapter 10.1.3

10. Evaluation of Uncertainty Visualizations

User study to evaluate the effects of unreliable data on the user's acceptance. Experimental design and results.

As shown in Chapter 8, negative effects on anticipation and driver reaction can be the result of not correctly visualized data. The main reason for this problem is the unfortunate fact that data sources, especially in a highly dynamical environment like the automotive traffic, are not 100% reliable. Different approaches are necessary in order to improve data reliability in the future, from improving sensors over the use of redundant sensors to mathematical approaches. Despite all, 100% data reliability in a highly dynamic system will not be achieved soon. Therefore, addressing this problem from an MMI standpoint of view is necessary. The question that has to be answered is: How can we present uncertain data, to be the most helpful for the driver?
The topic was approached by the conception of a multitude of visual variants to display uncertain data (cf. Chapter 9.8). With the help of a pre-study and focus groups, a concept with a question mark "?" to indicate uncertainty was chosen to be further evaluated. In order to do so, a driving simulator experiment was conducted, in which subjects were confronted with uncertain speed limit information in a deceleration assistance system. The speed limit information was chosen due to its uncritical nature, which made is possible to exclude questions about controllability from the experiment. This chapter provides an overview on the experiment and its results.

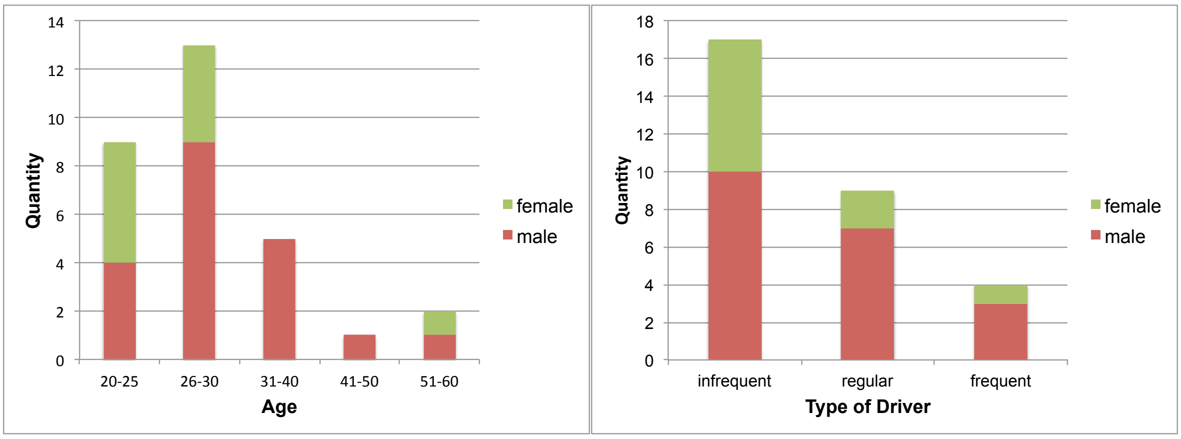
10.1. Experimental Design

A within subjects design was chosen. The following section describes the composition of the subjects, the apparatus, the independent and dependent variables and the procedure of the experiment.

10.1.1. Subjects

30 subjects (20 male and 10 female) participated in the study. All subjects helped a valid category B license with at least five years of driving experience. The age average was 29.7 years, with a standard deviation of 8.9 years. The study was conducted in a driving simulator at the "BMW Group Forschung und Technik", with mainly employees participating in the experiment. Subjects were not paid. Figure 10.1 shows the distribution of age, gender and driving experience. Regarding the driving experience, one can see in Figure 10.1b that 57% (17) can be categorized as infrequent drivers with up to 10,000 km per year, 30% (9) were

regular drivers with 10,000-20,000 km per year and 13% (4) can be categorized as frequent drivers with over 20,000 km per year.



(a) Age distribution of the subjects (b) Driving experience distribution of the subjects

Figure 10.1.: Subject distribution for the uncertainty experiment

10.1.2. Apparatus

As a driving simulator, a mock-up construction was used, consisting of a BMW 5 series dashboard, a driver's seat and a 50 inch plasma screen to display the driving simulation. The analogue instrument cluster was removed and replaced by an 11 inch freely accessible LCD screen. As a driving simulation, a software called Spider was used, which allowed to implement realistic simulation environments and to record of driving data at a 60hz frequency.

10.1.3. Independent and Dependent Variables

To explore uncertainty visualization concepts, a deceleration assisting system was used, which in this case showed two kinds of information to the driver: the current speed limit and the upcoming speed limit. An abstract user interface of the system can be seen in Figure 10.2, it shows a virtual piece of a street including the current speed limit (in red) in the lower left corner and the upcoming speed limit, with a gray border, above the current limit and a little smaller.
Subjects had to drive manually and were asked to obey the recommendation of the system as closely as possible. For the subjects this meant: early deceleration (reaching a lower speed limit with the arrival at the sign) as well as late acceleration (acceleration after passing a higher speed limit sign).

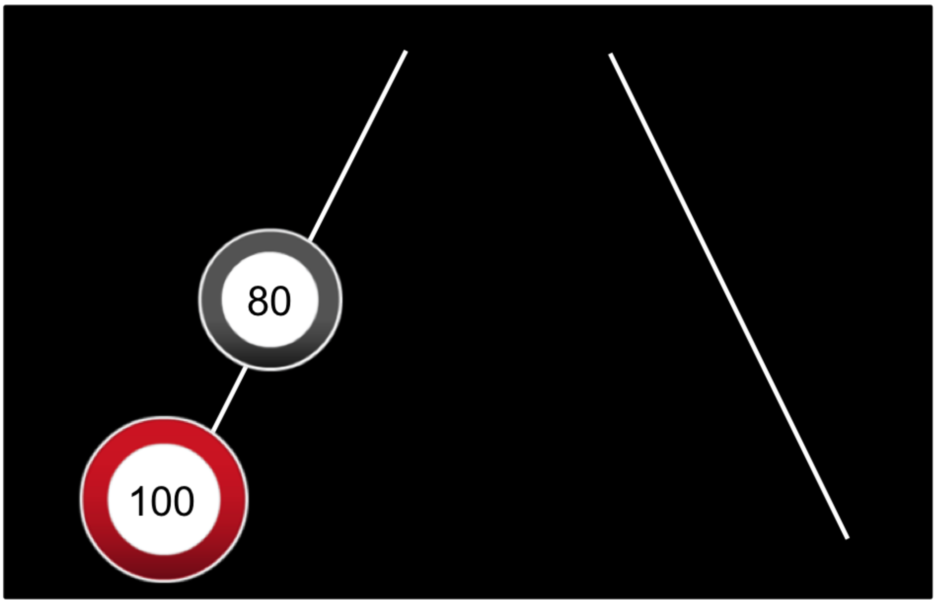


Figure 10.2.: Abstract visualization of the user Interface of the deceleration assisting system, lower left corner: currently valid speed limit sign (ref border); above: next speed limit sign (gray border); signs are on piece of virtual street

Independent Variables Within the deceleration assistance system two speed limits were shown: The current speed limit (red border) and the upcoming speed limit indicated by a gray border. The "?", as a result of the pre-study, was chosen to be the metaphor for uncertain information. The question mark was incorporated in the speed limit sign in the upper right corner as an additional icon (Table 10.1). For the upcoming speed limit it was decided to reduce the realistic nature of the sign even further, which resulted in a more abstract visualization of the sign and an inversion of the colors. This visualization had the advantage of being more easily distinguishable from certain information. A clear representation of the uncertainty was achieved, with no occlusion of the original speed limit information as well as a good differentiability between certain and uncertain data.

	Certain Data	Uncertain Data
Upcoming Limit		
Current Limit		

Table 10.1.: Certain and uncertain speed limit visualization for current and upcoming sign; uncertain speed limit informations are marked by a question mark; inversion of colors for uncertain upcoming speed limit, for better differentiation

As an independent variable four different ways to deal with uncertainty based on Chalmers et al. [39] categorization (cf. Chapter 9.5) were chosen. Optimistic, pessimistic and two cautious variants were realized. The possibility to handle uncertain data opportunistically was not realized in this study. One restriction was made for the experiment: data that was presented as certain, was correct. This means that during the course of the experiment speed limit informations that were shown without the "?" were 100% correct. In a real life scenario this restriction might not be realistic. Subjects knew about this restriction.
Table 10.2 shows the optimistic and the pessimistic variant. In the optimistic variant, uncertain data was presented as if certain, therefore, no difference in visualization between the certain data and the uncertain data could be seen. In the pessimistic variant certain data is presented as mentioned above, while uncertain data was not presented at all. For the uncertain data in this variant a production line visualization was taken, using three dashes instead of the speed limit.

	Optimistic		Pessimistic	
	Certain Data	Uncertain Data	Certain Data	Uncertain Data
Upcoming Limit	100	100	100	---
Current Limit	100	100	100	---

Table 10.2.: Optimistic and pessimistic variant for the uncertainty experiment; Optimistic: no differentiation between certain and uncertain information; Pessimistic: uncertain data is not shown

Table 10.3 shows the two cautious variants. In the first cautious variant, certain data again is presented as mentioned above, while uncertain data is presented with the "?" in the upper right corner of the sign and the more abstract visualization for the upcoming sign. Finally, in a second cautious variant (very cautious), certain data was additionally marked with a checkmark "✓" in the upper right hand corner. Uncertain data again was visualized with the use of the "?". Regarding the overall expert opinion from the pre-evaluation (Chapter 9.8) that the exact amount of certainty is irrelevant to the driver - extended by comments like: "visually to complex" and "confusing" - no "pretty sure" variant, was evaluated in the experiment.

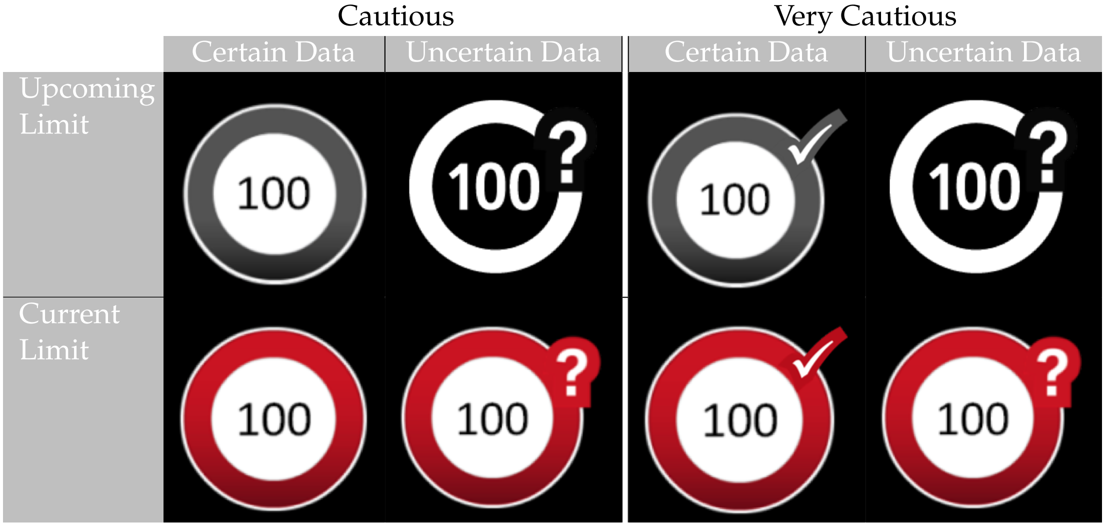


Table 10.3.: Cautious and very cautious variant for the uncertainty experiment; Cautious: uncertain data is marked by the "?"; Very Cautious: uncertain data is marked by "?", certain data is additionally marked with a "✓"

Situations As a second independent variable, three different situations were created, in which uncertain information was shown to the subjects. A short description of the situations follows, a detailed description can be found in Appendix C.2

The first situation is called "Construction Site": The driver is in a construction site situation, with a current speed limit of 80 km/h. An upcoming 80 km/h sign is not recognized with certainty; instead, an uncertain information of 120 km/h as the upcoming speed limit is presented to the driver. After he passes the situation, a correct 80 km/h is shown as the current speed limit (Table 10.4).

Approach	Correct Reality	Sign passed
Display: 120 km/h (Uncertain)		Display: 80 km/h (certain)

Table 10.4.: Display and reality in the construction site situation, during approach and after passing the sign

The second situation is called "100 km/h": The driver is on a highway with 120 km/h as the current speed limit. The system shows an uncertain 100 km/h upcoming speed limit, which is correct. The uncertainty in the information is shown during the approach as well as after passing the sign (Table 10.5).

Approach	Correct Reality	Sign passed
Display: 100 km/h (uncertain)		Display: 100 km/h (uncertain)

Table 10.5.: Display and reality in the 100 km/h situation, during approach and after passing the sign

The third situation is called “Highway Exit”: The driver is on a highway with 100 km/h as the current speed limit. The driver intends to stay on the highway (no navigation system is active). The system shows an uncertain 80km/h speed limit as the upcoming sign. The speed limit is only applicable to the highway exit. The uncertainty is shown during the approach as well as after passing the sign (Table 10.6).

Approach	Correct Reality	Sign passed
Display: 80s km/h (uncertain)	no sign	Display: 80 km/h (uncertain)

Table 10.6.: Display and reality in the highway exit situation, during approach and after passing the sign

Dependent Variables Dependent variables were:

- Subjective workload: measured using the one dimensional SEA scale, which rates the subjectively felt workload, by a value from 0 (no workload) to 240 (the maximum amount of workload).
- System acceptance regarding the items of: “likability”, “safety”, “usefulness”, “trust”, “malfunction recognizable” and “quantity of malfunction”.
- Desirable system attributes: Measured by the use of a semantic differential questionnaire right after the test drive of each variant. Adjectives that were prompted were e.g.: “helpful”, “appropriate”, “predictable”, “relieving”, etc.
- Helpfulness of the variants within the three different situations: Measured by a questionnaire after the completion of all three test drives.
- Wish to use a certain variant in one’s own vehicle.

10.1.4. Procedure

Subjects were welcomed and asked to fill out the demographic questionnaire. Afterwards, the instrument cluster and the functionality of the deceleration assistance system were explained to the subjects, without mentioning uncertain data. Subjects then were introduced to the driving simulator and went through a five minute introduction drive. No uncertain data was presented to the subjects during this drive.
During the main test drive 26 deceleration/acceleration situations were presented to the subjects , which took about eight minutes to complete. 3 out of 26 situations included uncertain information. The introduction as well as the main test drive was situated on a three

lane highway with little to medium traffic. After each variant, subjects received a questionnaire regarding the just driven variant, including questions about mental workload and acceptance of the variant. After the completion of all four variants, subjects received a final questionnaire regarding a comparison of the variants as well as a comparison of the helpfulness within the three situations. The original questionnaire can be found in Appendix C.1. In order to help subjects with the rating of the situations, they were supported by a screenshot of the situation and the visualization in the instrument cluster during the situation. The order of the variants was permuted throughout the course of the experiment.

10.1.5. Evaluation Procedure

A repeated measure ANOVA was used in order to analyze the subjective data. The post-hoc analysis was performed with the use of the least significant different test (LSD) by Fisher. The results of the ANOVA can be found at each item, including the F-value, df and p-value.

10.2. Hypotheses

Hypothesis 1: The additional information in the "Very Cautious" compared to the "Cautious" visualization will be considered redundant. Therefore, an overall lower rating compared to the "Cautious" visualization is expected.
Hypothesis 2: The "Optimistic" visualization will not be perceived as uncertain information but as a malfunction in the system. Therefore, results in workload and perceived system functionality will be worse compared to all other visualizations.
Hypothesis 3: Due to the additional and honest information that is presented in the "Cautious" variant, it will be perceived beneficial and helpful. Therefore, the "Cautious" visualization will receive better ratings than the "Pessimistic" visualization regarding system functionality.
Question: Is it possible to show additional visual information as a metaphor for uncertainty without overloading the observer's visual system and without reducing the subjective acceptance?

10.3. Results

This section includes the subjective results collected via questionnaires during and after the driving simulator experiment. The results include a comparison of the subjective workload, results on system acceptance and the ratings of desirable system attributes. Finally, a comparison regarding the helpfulness of the different variants within the three different situations is given and a final comparison between the four variants is presented.

Workload Figure 10.3 shows a comparison of the workload between the four variants. The workload was measured with the use of the one-dimensional SEA scale, which covers a workload from 0 (not exhausting) to 240 (more than extraordinary exhausting). Results showed a very stable workload regarding the optimistic, pessimistic and very cautious variant, with mean values of 53.2, 53.3 and 53.4. Only the workload for the **cautious variant** with 39.6 was located below the other mean values. A **significant difference** between the variants was detected with F=3.594, df=2.420 and p=0.025. The post-hoc analysis showed significant differences between the **cautious** and very cautious variant with p=.016, between the cautious and optimistic variant with p=.029 as well as a highly significant difference between the cautious and the pessimistic variant with p=.010. All other differences were not statistically significant.

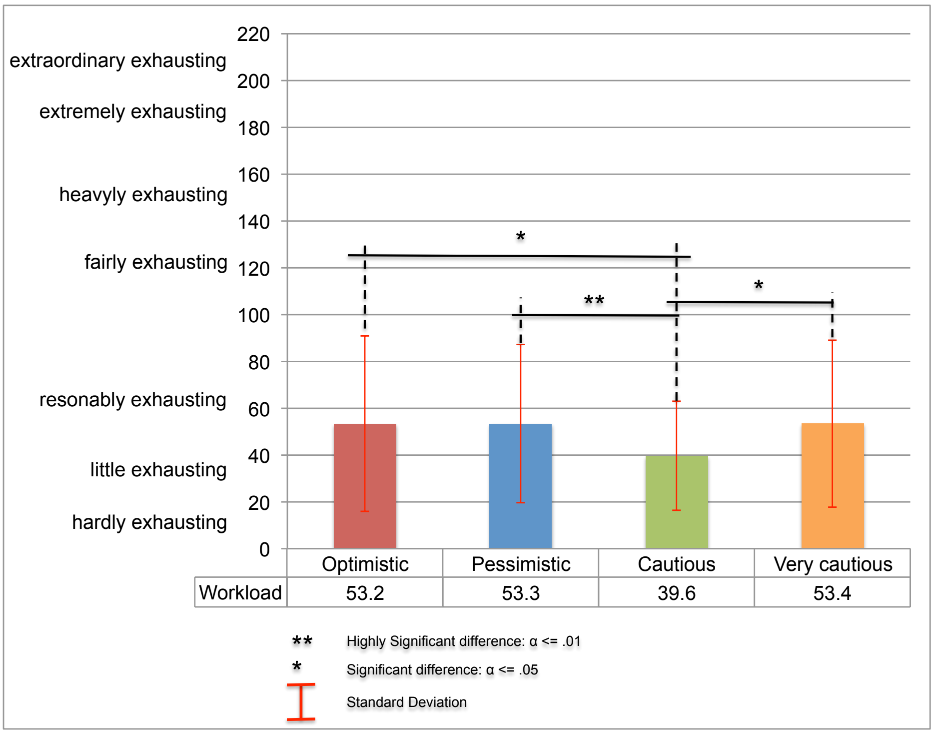


Figure 10.3.: Comparison of subjective workload for the four variants during the complete drive, measure using the one dimensional SEA scale

Table 10.7 shows the results of the ANOVA including the post-hoc analysis.

Workload				
F=3.594, df=2.420, p=.025				
	Opt.	Pes.	Cau1	Cau2
Opt.		.991	.029	.966
Pes	.991		.010	.969
Cau1	.029	.010		.016
Cau2	.966	.969	.016	

Table 10.7.: Results of the ANOVA including the post-hoc analysis considering the workload measurement

Subjective System Acceptance After each drive, subjects were asked to answer questions about the subjective system acceptance. These questions included the following items: **Likability**; Did the visualization of uncertainty increase traffic **safety**; **Usefulness** of the uncertain information presentation; **Trust** into the system; How easy system **malfunctions** were **recognizable** and if the system had a large **quantity** of system **malfunctions**.

Figure 10.4 shows an overview of the comparison of the mean values for all four variants throughout all six items. The complete results of the repeated measures ANOVA as well as the results of the post-hoc analysis for all six items can be found in Table 10.8 to Table 10.10. A complete overview of mean values, the standard deviations, minima, maxima and standard errors of the results can be found in Table C.5 in Appendix C.3.
The optimistic variant received the lowest rating, with all mean values except the rating for "Quantity of Malfunctions" in the negative part of the scale. The two cautious variants received the highest ratings, with positive ratings for all items except for the "Safety" item in the very cautious condition. All other ratings for both cautious variants did lay around an average of 4.0. No significant difference between both variants could be found. The pessimistic variant was located between the optimistic and both cautious variants. The difference to both cautious variants was only significant at the item "Safety" and "Usefulness". The overall rating for the pessimistic variant was intermingled, only at the items "Trust", "Malfunction recognizable" and "Quantity Malfunction" the results were in the positive part of the scale.

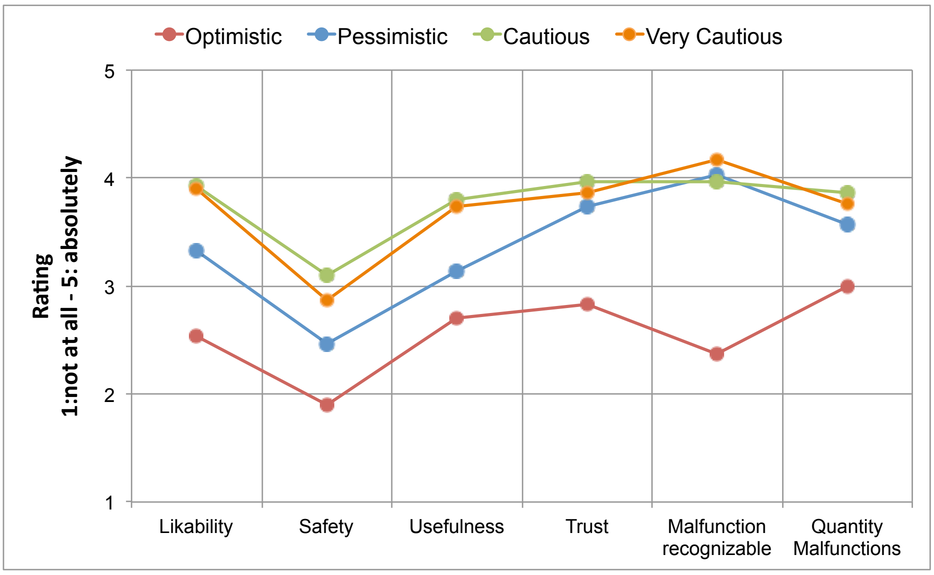


Figure 10.4.: Comparison of the mean values of the four variant regarding six different system acceptance items in the uncertainty experiment

Likability: Both cautious variants, with mean ratings of 3.9, received a positive rating in this item. The rating of the pessimistic variant with 3.3 was marginally on the positive part of the scale. The optimistic variant with a rating of 2.53 was located on the negative part of the scale. A highly significant difference was found with F=9.156, df=3 and p=.000. The post-hoc analysis showed a highly significant difference between the optimistic and the two cautious variants and a significant difference between the pessimistic and the optimistic variant with p=.024. All other differences were not significant.
Safety: The worst rated items for all variants. Only the cautious variant with a mean rating of 3.1 was marginally in the positive part of the scale. The very cautious variant with a mean rating of 2.9 already was in the marginally negative part of the scale. Both ratings can be considered neutral though. The ratings for the pessimistic and the optimistic variant, with

mean values of 2.4 and 1.9, both were located in the negative part of the scale. The rating for the optimistic variant was the lowest of all items and variants. A highly significant difference was found with F=11.970, df=3 and p=.000. The post-hoc analysis showed a highly significant difference between the optimistic and the two cautious variants and a significant difference between the pessimistic and the optimistic variant (p=.030) as well as between the pessimistic and the two cautious variants (with p=.030 for the cautious variant and p=.043 for the very cautious variant). No significant difference could be found between the two cautious variants.
The complete results of the repeated measures ANOVA as well as the results of the post-hoc analysis can be found in Table 10.8

Likability				
F=9.156, df=3 p=.000				
	Opt.	Pes.	Cau1	Cau2
Opt.		.024	.000	.000
Pes	.024		.089	.077
Cau1	.000	.089		.899
Cau2	.000	.077	.899	

(a) Results of ANOVA and post-hoc analysis for Likability

Safety				
F=11.970, df=3, p=.000				
	Opt.	Pes.	Cau1	Cau2
Opt.		.030	.000	.000
Pes	.030		.003	.043
Cau1	.000	.003		.214
Cau2	.000	.043	.214	

(b) Results of ANOVA and post-hoc analysis for Safety

Table 10.8.: Results of ANOVA and post-hoc analysis for Likability and Safety

Usefulness: Both cautious ratings with mean values of 3.8 and 3.9 did lie in the positive part of the scale. The pessimistic rating with an average of 3.1 was located in the neutral part of the scale. The optimistic variant (2.7) was in the negative part of the scale. A highly significant difference was found with F=7.038, df=3 and p=.000. The post-hoc analysis showed a highly significant difference between the optimistic and the very cautious variant as well as between the optimistic and the cautious variant. A significant difference was found between the pessimistic and the two cautious variants (with p=.024 for the cautious variant and p=.026 for the very cautious variant). All other differences were not significant.
Trust: All ratings for the cautious (4.0), the very cautious (3.9) and the pessimistic (3.7) variant were very similar and lay in the positive part of the scale. Only the rating for the optimistic variant with a mean value of 2.8, was located marginally in the negative part of the scale. A highly significant difference was found. The post-hoc analysis showed a highly significant difference between the optimistic and all other variants. All other differences were not significant.
The complete results of the repeated measures ANOVA as well as the results of the post-hoc analysis can be found in Table 10.9.

Usefulness				
F=7.038, df=3, p=.000				
	Opt.	Pes.	Cau1	Cau2
Opt.		.141	.003	.001
Pes	.141		.024	.026
Cau1	.003	.024		.769
Cau2	.001	.026	.769	

(a) Results of ANOVA and post-hoc analysis for Usefulness

Trust				
F=9.847, df=3, p=.000				
	Opt.	Pes.	Cau1	Cau2
Opt.		.000	.000	.000
Pes	.000		.315	.489
Cau1	.000	.315		.693
Cau2	.000	.489	.693	

(b) Results of ANOVA and post-hoc analysis for Trust

Table 10.9.: Results of ANOVA and post-hoc analysis for Usefulness and Trust

Malfunction recognizable: The three mean ratings for the cautious (4.0), the very cautious (4.2) and the pessimistic (4.0) variant were very similar and lay in the positive part of the scale. This item was rated the highest for all three variants. Only the rating for the optimistic variant, with a mean value of 2.4, was located in the negative part of the scale. A highly significant difference was found with F=21.675, df=2.461 and p =.000. The post-hoc analysis showed a highly significant difference between the optimistic and all other variants. All other differences were not significant.
Quantity Malfunction: Both cautious variants, with mean values of 3.8 for the very cautious variant and 3.9 for the cautious variant, received a positive rating and were rated marginally higher than the pessimistic variants, with a mean rating of 3.6. The optimistic variant received a neutral rating of 3.0. A highly significant difference was found with F=11.970, df=2.183 and p=.000. The post-hoc analysis showed a highly significant difference between the optimistic and the cautious variant as well a between the optimistic and very cautious variant. A significant difference was found between the optimistic and pessimistic variant with p=.027. All other differences were not significant.
The complete results of the repeated measures ANOVA as well as the results of the post-hoc analysis can be found in Table 10.10.

Malfunction Recognizable				
F=21.675, df=2.461, p =.000				
	Opt.	Pes.	Cau1	Cau2
Opt.		.000	.000	.000
Pes	.000		.783	.555
Cau1	.000	.783		.281
Cau2	.000	.555	.281	

(a) Results of ANOVA and post-hoc analysis for Malfunction Recognizable

Quantity Malfunction				
F=11.970, df=2.183, p=.000				
	Opt.	Pes.	Cau1	Cau2
Opt.		.027	.001	.003
Pes	.027		.083	.161
Cau1	.001	.083		.501
Cau2	.003	.161	.501	

(b) Results of ANOVA and post-hoc analysis for Quantity Malfunction

Table 10.10.: Results of ANOVA and post-hoc analysis for Malfunction Recognizable and Quantity of Malfunction

Desirable System Attributes With the use of a semantical differential on a seven point scale, desirable system attributes were evaluated. Figure 10.5 shows the result. The complete results of the repeated measures ANOVA as well as the results of the post-hoc analysis for all items can be found in Table C.2 in Appendix C.3. Also a complete overview of the mean

values, the standard deviations, minima, maxima and standard errors of the results of the semantic differential can be found in Table C.3 to Table C.4 in Appendix C.3.
The optimistic variant received the lowest rating of all four variants. Especially in the items "distracting", "liberating" and "cautious" this variant was rated lower than all other variants, with all above mentioned ratings in the negative part of the scale. Only at the items "direct" and "simple" the ratings of the optimistic variant were similar to the ratings of the two cautious variants. The two cautious variants received the highest rating in this section, only at the item "not disturbing" the pessimistic variant achieved a better rating. The cautious variant with a mean rating above 5.0 for all items (expect for the items "distracting", "liberating" and "professional") received the overall highest rating. The very cautious variant received lower ratings in almost all items than the cautious variant, expect in the items "cautious" and "predictable". Between the optimistic and the very cautious variant the pessimistic variant was located, with five ratings above the very cautious variant and nine below.

- **Distracting/Not Distracting:** The mean values of the pessimistic, cautious and very cautious variant lay in the marginally positive part of the scale, while the rating for the optimistic variant was located in the negative part. A highly significant difference was found with F=5.238, df=3 and p=.002. The post-hoc analysis showed a significant difference between the optimistic and pessimistic variant as well as a highly significant difference between the optimistic and cautious variant. All other differences were not significant.

- **Inappropriate/Appropriate:** The mean values of the pessimistic, cautious and very cautious variant lay in the clear appropriate side of the scale, with mean values above 5.0. The optimistic variant only was located marginally on the "appropriate" side. A significant difference was found with F=4.392, df=2.118 and p=.015. The post-hoc analysis showed a highly significant difference between the optimistic and cautious as well as a significant difference between the optimistic and very cautious variant. All other differences were not significant.

- **Disturbing/not Disturbing:** The ratings of the cautious and the pessimistic variant, with a mean value of above 5.0, lay clearly on the "not disturbing side" of the scale. Followed by the very cautious variant and the optimistic variant, which was located only marginally on the "not disturbing" side of the scale. A significant difference was found with F=4.421, df=2.158 and p=.014. The post-hoc analysis showed a significant difference between the optimistic and the pessimistic as well as between the very cautious and pessimistic variant. A highly significant difference was found between the optimistic and cautious variant. All other differences were not significant.

- **Not Helpful/Helpful:** The cautious and the very cautious variant, with mean values of above 5.5, lay clearly in the "helpful" side of the scale. The pessimistic variant with an average of above 5.0 still was conceived as rather helpful. The optimistic variant was located only marginally in the helpful side. A highly significant difference was found with F=7.388, df=2.259 and p=.001. The post-hoc analysis showed highly significant differences between the optimistic and both cautious variants as well as a significant difference between the optimistic and pessimistic variant. All other differences were not significant.

- **Patronizing/Liberating:** The mean values of the optimistic and the very cautious variant were around the neutral part of the scale at 4.0. Only the cautious variant, with a mean value of above 4.5, was considered rather liberating. The rating of the pessimistic variant lay between the very cautious and the cautious rating. A highly significant difference was found with F=6.502, df=3 and p=.001. The post-hoc analysis showed a highly significant difference between the optimistic and the cautious as well as between the cautious and very cautious variant. A significant difference could be found between the optimistic and the pessimistic variant. All other differences were not significant.

- **Wearing/Relieving:** The mean rating for the optimistic variant with 4.0 was neutral. Only the cautious and the very cautious variant with mean values of around 5.0 were considered rather relieving. The pessimistic variant was located just below the two cautious variants. A highly significant difference was found with F=7.352, df=2.192 and p=.001. The post-hoc analysis showed a significant difference between optimistic and the pessimistic variant as well as a highly significant difference between the optimistic and both cautious variants. A significant difference could also be found between the pessimistic and cautious variant. All other differences were not significant.

- **Courageous/Cautious:** The mean values for the optimistic, cautious and very cautious variant all lay in the neutral part of the scale, only the pessimistic variant, with a mean value above 4.5, was considered marginally cautious. A significant difference was found with F=4.588, df=2.120 and p=.012. The post-hoc analysis showed a significant difference between the optimistic and cautious variant. All other differences were not significant.

- **Confusing/ Obvious:** While the optimistic variant, with a mean value just above 4.0, could be considered undecided, the cautious variant, with a mean value around 5.5, was clearly rated “obvious”. The mean value of the pessimistic and very cautious variant, both around 5.0, could be considered rather “obvious”. A significant difference was found with F=4.511, df=3 and p=.043. The post-hoc analysis only showed a significant difference between the optimistic and the cautious variant. All other differences were not significant.

- **Bad/Good:** The cautious and very cautious variant, with mean ratings of around 5.0, were located on the “good” side of scale. The optimistic variant, with a mean rating above 4.5, still was on the “good” side of the scale as well. The pessimistic variant lay between the optimistic and very cautious variant. A significant difference was found with F=4.511, df=2.243 and p=.012. The post-hoc analysis only showed a highly significant difference between the optimistic and the cautious variant as well as a significant difference between the optimistic and the very cautious variant. All other differences were not significant.

- **Cheap/Valuable:** The optimistic variant, with a mean value of 4.5, lay on the rather “valuable” side of the scale. Both, the pessimistic and very cautious variant, with mean values of 4.8, were rated more “valuable”. The cautious variant, with a mean value of 5.4, could be considered clearly “valuable”. A significant difference was found with F=3.470, df=2.460 and p=.028. The post-hoc analysis showed a high significant difference between optimistic and cautious as well as between the cautious and very cautious variant. All other differences were not significant.

- **Unpredictable/Predictable:** With mean values between 5.3 and 5.6 the pessimistic, cautious and very cautious variant could be considered clearly "predictable", with the very cautious variant having received the highest rating. Only the optimistic variant with a mean value of 4.3 was located only marginally on the "predictable" side of the scale. A highly significant difference was found with F=7.352, df=2.192 and p=.001. The post-hoc analysis showed a highly significant difference between the optimistic and both cautious variants. A significant difference between the optimistic and pessimistic variant was found. All other differences were not significant.

- **Indirect/Direct:** All variants could be considered "direct", with mean values between 5.0 and 5.5. No significant difference was found with F=.802, df=3 and p=.496.

- **Unprofessional/Professional:** With mean values between 4.2 and 4.7, all variants were on the marginally to rather "professional" side of the scale, with the cautious and very cautious variant having received the highest ratings. No significant difference was found with F=.977, df=3 and p=.407.

- **Complicated/Simple:** With mean values between 5.6 and 6.1, all visualizations could be considered clearly "simple", with the cautious variant having received the highest rating. No significant difference was found with F=1.559, df=3 and p=.203.

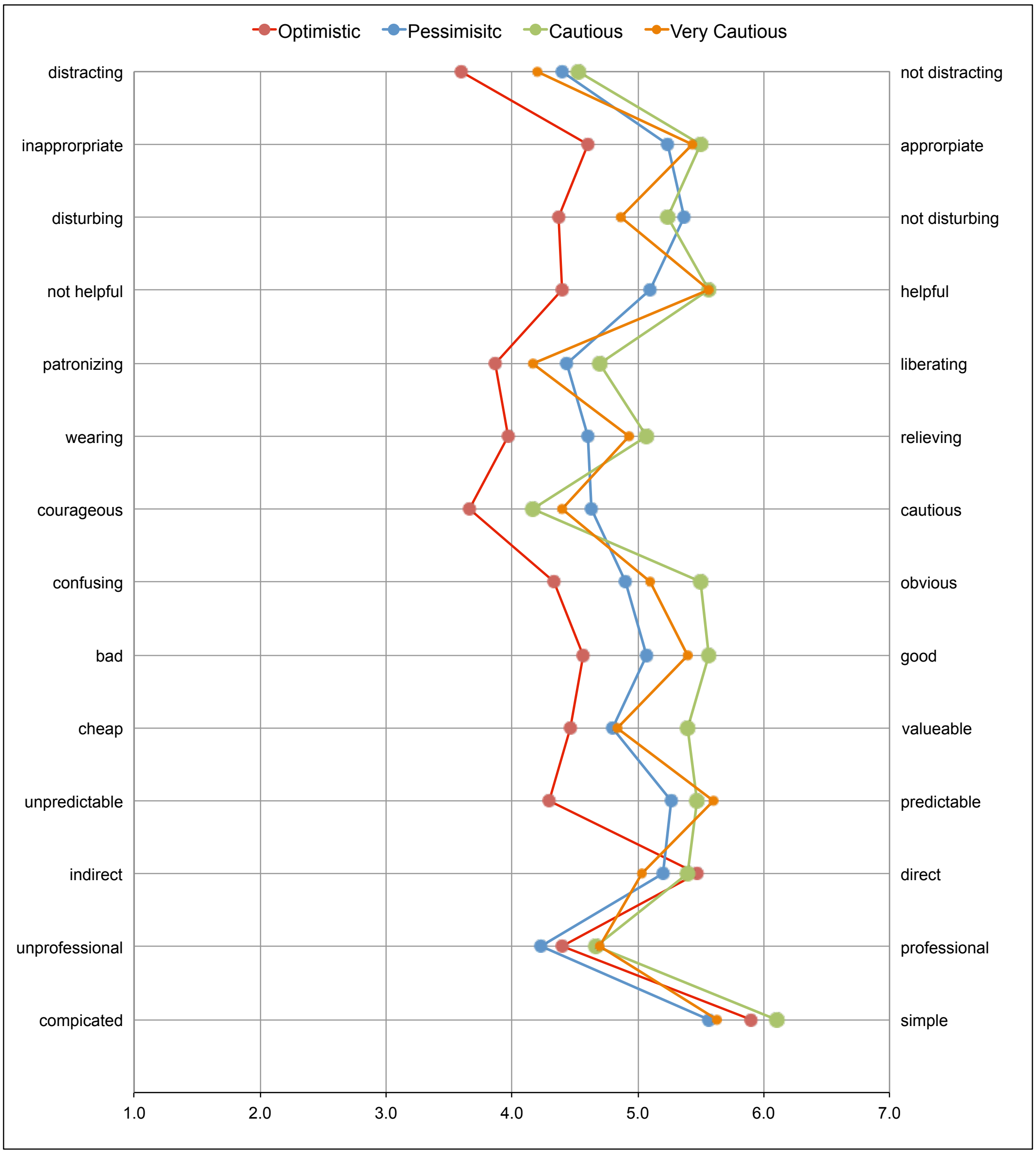


Figure 10.5.: Comparison of the mean values for the four variants regarding 14 desirable system attributes on a seven point scale

Comparison of Situations Figure 10.6 shows a comparison of the variants within the three situations regarding the question, how helpful each variant was considered in each situation. A complete overview on the results of the repeated measures ANOVA as well as a complete overview of the statistical values can be found in Table C.6 and Table C.7 in Appendix C.3.

The optimistic variant had the overall lowest rating: with a mean rating of 1.5 in the "Highway Exit" situation and 2.2 in the "Construction Site" situation, this visualization was considered not helpful. The mean value of 4.1 in the "100km/h" situation resulted from the fact that in this situation the optimistic variant correctly showed the speed limit without any sign

of uncertainty.
The “Construction Site” received the overall highest ratings from 2.2 for the optimistic variant to 4.0 for the cautious variant. The “100km/h” situation received the second best ratings from 2.1 in the pessimistic variant to 4.1 in the optimistic variant. Finally, the “Highway Exit” situation received the lowest ratings with 1.5 in the optimistic case to 3.0 in the cautious variant.
Regarding the visualizations, the cautious variant received the highest rating over all situations with no ratings in the negative part of the scale.

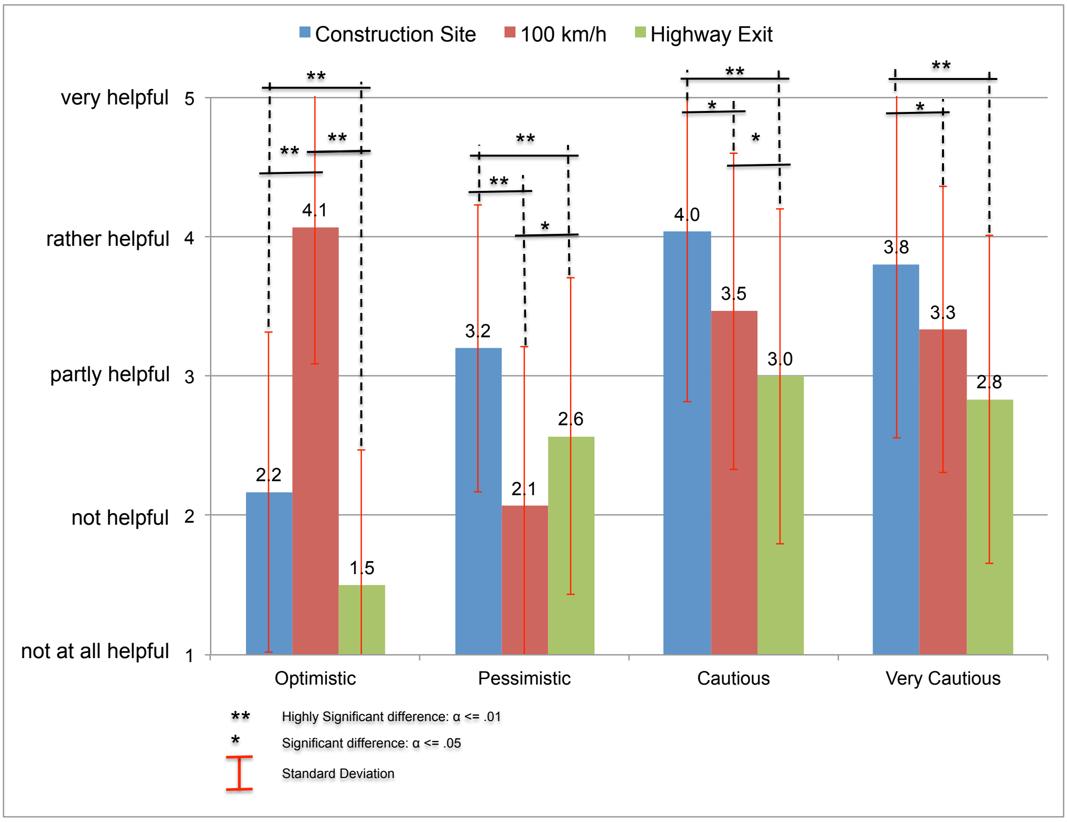


Figure 10.6.: Comparison of the helpfulness regarding each variant in the three situations (Construction Site, 100km/h, Highway Exit)

Optimistic: A highly significant difference was found between the three situations with F=63.099, df=2 and p=.000. The post-hoc analysis showed that all differences were highly significant.
Pessimistic: A highly significant difference was found between the three situations with F=15.044, df=2 and p=.000. The post-hoc analysis showed a significant difference between the “Highway Exit” and the “100 km/h” situations. All other differences were highly significant.
Cautious: A highly significant difference was found between the three situations with F=15.227, df=2 and p=.000. The post-hoc analysis showed a highly significant difference between the “Construction Site” and the “Highway Exit”. All other differences were significant.
Very cautious: A highly significant difference was found between the three situations with

F=11.303, df=2 and p=.000. The post-hoc analysis showed a highly significant difference between the "Construction Site" and the "Highway Exit" and a significant difference between the "Construction Site" and the "100 km/h" situation. No significant difference between the "100 km/h" and the "Highway Exit" could be found.

Final Rating Also after the completion of all four test drives, subjects were asked: If their vehicle was equipped with a deceleration assistance system, how much they would wish for each visualization. Figure 10.7 shows the results of this question. A complete overview on the results of the repeated measures ANOVA as well as a complete overview of the statistical values can be found in Table C.9 and Table C.8 in Appendix C.3.
With a mean value of 4.0 the cautious variant was clearly picked as a favorite and the result was clearly in the positive part of the sale. With a mean value of 3.2 respectively 2.7 the very cautious and pessimistic variant were "partly" wished. The optimistic variant with an average of 1.4 was not favored by the subjects.

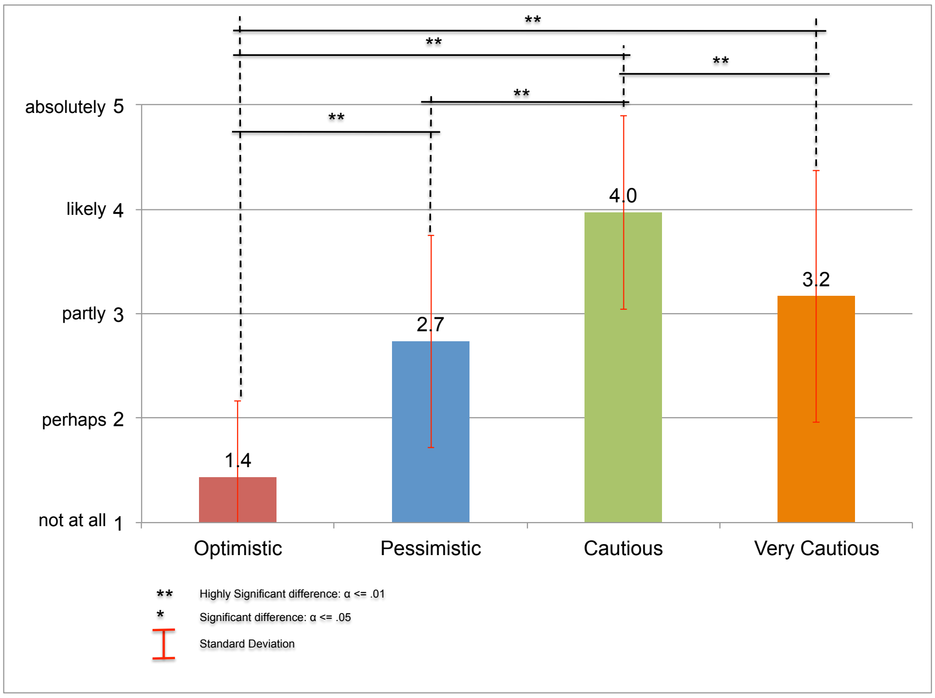


Figure 10.7.: Comparison regarding the wish for each visualization variant in case the subjects vehicle would be equipped with a deceleration assistance system

Using a repeated measures ANOVA, a highly significant difference was found with F=33.349, df=3 and p=.000. The post-hoc analysis showed a highly significant difference between all ratings, only the difference between the pessimistic and the very cautious variant was not significant.

10.4. Discussion

The optimistic variant clearly received the overall worst rating. In the case of uncertain and false information, handling uncertain information in an optimistic way is perceived as a system failure - not as a way of displaying uncertain data (confirming Hypothesis 2). This impression is supported by the results of items like "safety", "malfunction recognizable" and "quantity of malfunction". Also verdicts calling the optimistic variant "distracting" and "courageous" support this hypothesis. On the other side, and most possible due to the absence of any additional visual information, this variant also received ratings like being "simple" and "direct", which especially in case of an uncertain but correct information is rather favorable, as can be seen by the high rating for the 100 km/h situation. It should be mentioned that e.g. in a pure camera-based system the possibility that an uncertain information is actually correct lies at about 30%.
The pessimistic variant was located between the optimistic and the two cautious variants. It was considered less "useful", which could be ascribed to the lack of information that was given to the driver. This variant's behavior was conceived "not helpful" in the case of an uncertain but correct information as in the 100 km/h situation. This could be attributed to the lack of information that was given to the driver. A pessimistic way to handle uncertain data also was considered the most "cautious" and least "disturbing" by the subjects. This might have resulted from the fact, that no false data was presented to the subjects. Including certain but false data could have a positive influence on this rating, tough.
The cautious visualization is clearly favored in this evaluation. Not only did it accomplish to reduce the workload significantly during the drive, it also was picked as a clear favorite when asked about the wish to be in one's own vehicle (confirming Hypothesis 3). It seemed that subjects appreciated the honest presentation. This is supported by being attributed an "appropriate", "relieving" and especially "obvious" style. The visualization with the question mark also seemed to be well received, as subjects rated the system "predictable", "simple" and gave a high rating in "likability". These results also gave an indication on the question, if an additional visual element, the "?", might be too much visual information. Additional objective gaze tracking data (e.g. the mean gaze duration) could verify these results in the future.
An additional mark, the "✓", for the certain data was not considered sensible. Although the very cautious variant in the overall rating was rated second best, it received, in almost all categories, worse ratings than the cautious variant (confirming Hypothesis 1). It especially seems to be more "patronizing" and "complicated" than the cautious variant, which also resulted in a higher workload. Only in the ratings for the items "predictable" and "cautious" the very cautious variant had a small advantage over the cautious variant, which is explainable by the extra visual indicator that was used.

Results regarding the "helpfulness" of the visualization within the different situations showed that uncertain information does not equal uncertain information. It can be correct (like in the 100 km/h situation) totally irrelevant (like in the highway exit situation) or first wrong then right (like in the construction site situation). Results comparing the construction site and the 100 km/h situation, demonstrated that changing the speed limit information to a certain correct value is more helpful than showing uncertain but correct information all the time (like it was the case in the 100 km/h situation). Interestingly, the cautious variant was perceived more helpful in the highway exit situation than the pessimistic variant, although, the uncertain information in this situation was incorrect. Therefore, the pessimistic variant, which did not show any information should have been preferable. An explanation for that might be the overall better rating for the cautious variant, which might have influenced the rating in this specific situation.

10.5. Conclusion

The evaluation showed that presenting uncertain information was well received by the subjects. Indicating uncertain information with the use of a question mark "?" proved to be an effective and visually attractive way. An additional indication of certain data was not necessary and, at least for a manual drive with a deceleration assistance system, an optimistic or pessimistic visualization is not recommendable. Also, the additional visual information in the cautious variant did not have negative effects, which was suspected to be due to an already heavily loaded visual channel. The situation, in which uncertain information was shown, had a rather big influence on the perceived helpfulness and therefore should be considered in detail.

The evaluation of visualizing incorrect data as certain and correct, as well as an extension of the use cases to safety critical situations, in future work seems to be necessary. On one side, the specific visualization of uncertainty might be influenced by this extension. On the other side, results indicate that the overall verdict, which stated that if uncertain data is available it should be visualized, ought to remain valid.

11. Conclusion

The BEV is a good and well accepted visualization for supporting early deceleration. Problems in case of an automation failure arise but a first step in the approach of dealing with this problem was made by visualizing uncertain data.

11.1. Contribution and Conclusion

The BEV, a visualization that allows to visualize information from the electric horizon to the driver, was presented. In the use case of a deceleration assistance system, the BEV allows to visualize any possible situation with ease compared to a more generic approach using an Iconic visualization. The BEV was well accepted in two driving simulator experiments: the naturalistic and well-known presentation allows the human driver to cope with the information easily, though the amount of information presented is large compared to other visualizations. Therefore, this work can be seen as a basis for future development in the automotive context, where more and more information needs to be displayed.

The BEV as an information visualization system (a low level automated system) suffers from the same effect as a high level automated system in case of an automation failure. Automation failure mainly affected the anticipation ability of the driver and resulted in a delayed reaction of the driver. This effect was only observable in a total miss situation, though. Regarding these results, further research on the reasons and possible consequences in case of an automation failure in a low level automated system are necessary, before implementing such a system in a production line vehicle.

By having developed and evaluated visualizations for uncertainty in a deceleration assistance system, a first approach was made in order to deal with the consequences of a possible system failure. A visualization of uncertain data was well accepted and the used visualization (a question mark "?") for representing uncertainty was well received and intuitively understood; An additional indication of certain data is not necessary. This work showed in one specific use case that displaying uncertainty, if available, can lead to better acceptance and system trust. Moreover, this result, though not universally verified, is a good indicator for uncertainty visualization in other use cases and systems.

11.2. Discussion

With the introduction of the BEV, a very specific information visualization was proposed. The BEV uses detailed information from the Car2X infrastructure and digital maps and therefore, is able to visualize any possible situation in a natural and easy comprehensible way. In contrast to the specific approach used in the BEV stands e.g the work by Samper &

Kuhn [147] or the “Iconic” visualization, both of which tried to use a symbolic representation of the situation in order to visualize the reason for deceleration. In work by Thoma [171] a generic warning system was proposed, in order to be able to incorporate several different warning systems into one visual representation. As a rationale, Thoma mentioned that the driver is able to easily identify the source of the hazard, in contrast to in-vehicle warning systems like motor temperature warning. The same is true for the situations that were evaluated in this work: they are not visible to the driver. Therefore, a specific and natural way seems to be more promising than an abstract visualization. It has to be kept in mind that the BEV was tested as a visualization to support the driver’s anticipation and did not serve any warning purposes. Therefore, the transfer of the results to a wider range of systems cannot be done without further research. Another specific and natural way of representing warnings can also be found in Perry et al. [134], who proposed several different, specific and natural auditory icons for warnings in civil aviation instead of an abstract sound. Regarding the direct comparisons between the evaluated variants, the unfortunate visualization of the pedal animation in the Iconic visualizations has to be mentioned.

The proposed “Navimap” was well received in the video experiment, but did not show any significant differences over the BEV. The “Navimap” does require more display space. The possible distracting animation and the inconsistent visualization were the reason the “BEV” and not the “Navimap” was further investigated. Using a video experiment in order to reduce the amount of variants did prove to be effective. Although subjects did only have minutes to make a decision, results were confirmed in the interactive driving simulator study.

In the second part of this work, it was shown that in a driving simulator environment the time to the reaction of a driver, in case of an automation failure in a low level automated system is longer than in a baseline drive, in which no additional information was presented. This is in line with research of automation failure in high level automated systems (e.g. Dixon et al. [53]) and indicates that the out-of-the loop consequences are at least partly applicable for low level automated systems. In a work by Niederee & Vollrath [124] this effect already was shown, but the consequences were neglected. In the presented work, it was shown that a complete miss, in a highly safety critical situation, led to delayed anticipation of the situation. In a situation, which has no margin for error, such a delayed anticipation led to a delayed reaction and consequently to an increase in accidents, in the conducted driving simulator experiment. The complete miss situation was developed with the goal to be as critical as possible (7 accidents in the Baseline condition) but the increase in accidents (12 accidents in the system failure condition), showed that in highly critical situations even a 610 ms delayed reaction can be enough for a critical development. Although the results were collected in a driving simulator, it gives us an indication to the driver’s reaction in a real-life scenario. It should be mentioned that the brake pedal in a driving simulator is often the matter of complaints; either the brake pedal is too hard or too soft. Although, the subjects had the possibility to get used to the reaction of the brake pedal, a ten minute introduction drive cannot replace a life long experience. Therefore, the results have to be considered with care. It has to be kept in mind that the subjects in a real-life situation might have been able to compensate the delayed reaction.

A way to visualize uncertain data in a deceleration assistance system was presented. As in other fields of research, the main question to be answered is: Does the visualization of the information’s uncertainty have an advantage over not showing uncertainty? Whereas today’s automotive user interfaces do not visualize any kind of uncertainty, the visualization of uncertainty in other fields of research is far more advanced. In air traffic management for example Nicholls [123] mentioned that "a proper appreciation of uncertainty could help in decision-making, by providing a more complete picture of the situation". This is in line with the positive perception by the subjects, which stated that uncertain data, if available, should be visualized. Uncertainty was mapped by an additional graphical element the "?", an approach that allows to equally visualize both information (speed limit and "?"), while letting the original information untouched and well readable. This approach also has be favored e.g. in the work by Cedilnik & Rheingans [38], who used a grid-overlay on the visualization of scientific data. Others (e.g. Bisantz et. al [21] or Grigoryan & Rheingans [80]) tried to visualize uncertainty with the help of a free graphical variable - a way that allows us to include uncertainty without an additional graphical element. The disadvantages though are the fact that the mapping has to be learned and alters the original data. This is especially problematic in case of a safety critical application such as in the automotive environment. Regarding the experiment: Only one user study was conducted with one element including uncertainties, the speed limit sign. The transferability to other elements, which might include questions of traffic safety (e.g. curve warnings) was not evaluated. The conclusion that uncertainty should be displayed, if available, can be considered universal and should be transferable, while the specific visualization might needs to be adapted.

11.3. Future Work

The BEV is only a basis for possible future developments in visualizing information from the electric horizon. Problems that can occur were demonstrated but not further researched. In one specific use case the effectiveness of visualizing uncertain data was shown. But in order to bring the developments to the production line further work is necessary.

Visualization for Supporting Prospective Action A driving simulator scenario was used to evaluate the BEV, with the main attention to deceleration situations. Therefore, future work should incorporate a larger variety of situations, including the question of controllability. In order to see if the results from the driving simulator experiments are transferable to reality, it is necessary to transfer the visualization to an experimental vehicle and conduct further experiments in real-life traffic scenarios. Especially the behavior of possible rearward traffic can be of interest. This behavior might have an influence on the behavior of the driver, especially in cases where the other traffic is not able to see the reason for early deceleration. In this context, an information system for the rearward traffic (e.g. a display in the rear window) might be an approach to this problem.
The integration of different systems into the BEV is another worthwhile approach. The BEV does utilize a large display space, therefore, the integration of systems like the navigation, curve warnings, intersection warnings, general warning, etc. is necessary. Other possible future works are the extension of the system to a multi modal approach as well as further evaluations regarding the driver distraction.

Misses and System Boundaries of Low Level Automated Systems This work presented the research of possible automation failures in a low level automated system (information presentation via the BEV). In two exemplary situations the consequences of an automation failure on the driver's behavior were shown. Future work should be directed

at the research of the reasons for the delayed reaction in the complete miss situation. This can include further driving simulator experiments, which utilize the possibilities of a gaze tracker and more specify question on the situations in form a questionnaire. Also further research regarding the specific situations as well as the specific failures are necessary in order to receive a concrete statement.
Finally, a transfer from the driving simulator to a real-life scenario, probably on an isolated test field, is necessary in order to validate the results. Apart from these questions, consequences on the overall acceptance as well as solutions to reduce these consequences should be the subject of further research.

Uncertainty Visualization In this work, the visualization of uncertain information was researched as a first step to approach the problem of possible automation failure. Results indicate that the visualization of uncertainty is generally preferred and accepted. In order to verify this statement, further research is necessary. This includes the integration of uncertainty in a larger variety of systems and situations. Especially safety critical use cases like curve warning, traffic jam warning or intersection warnings should be the subject of this research. This additional factor might influence the general statement on visualizing uncertain data as well as the specific visualization. Therefore, other possible visualization metaphors should be kept in mind in future research.
The opportunistic way to visualize uncertainty, a possibility to exploit uncertainty and use it to the driver's advantage, can also be the target of future work. Regarding the evaluation method: The proclamation that all data that is displayed as certain was actually correct needs to be revoked; The subsequent consequences on the general statement and on the specific visualization need to be researched.

11.4. Summary

In this work, a way to deal with the amount of information from the Car2X infrastructure was presented and evaluated. The chosen use case scenario was a deceleration assistance system, which supports the driver in anticipation beyond the visual horizon and thereby in a more ecological and economical driving style. It was shown that in a perfect driving simulator environment this visualization is effective and well accepted. Consequences that arise in case of a system failure were shown, and a first step in order to approach these consequences - the visualization of uncertainty - was made. Results are promising, but until the realization in a production line vehicle further work is necessary, from technical questions regarding the Car2X infrastructure to a wide variety of evaluations on the user interface side. The possibilities and the challenges of the future indicate that such an effort is more than promising.

A. Video Experiment

A.1. Questionnaire

VP-Nr.:	Startvariante:	Datum:

Fragebogen zum Videoexperiment

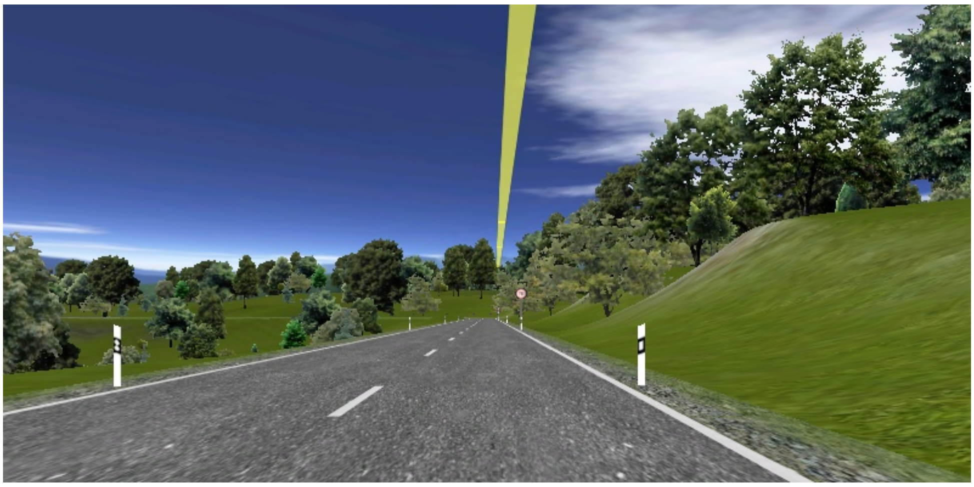
1) Geschlecht: ○ männlich ○ weiblich

2) Alter: __________ Jahre

3) Beruf: ________________________________ (Ex. ○)

4) Jährl. Fahrleistung: ○ bis 5.000 km ○ 5.000-10.000 km ○ 10.000-15.000 km ○ 15.000-20.000km ○ über 20.000km

Variante 1



1.1) Würden Sie die Anzeige in Ihrem Fahrzeug benutzen?

Auf keinen Fall	○	○	○	○	○	Auf jeden Fall

1.2) Finden Sie die Anzeige optisch ansprechend?

Überhaupt nicht	○	○	○	○	○	Sehr

1.3) Haben Sie die Anzeige intuitiv verstanden?

Überhaupt nicht	○	○	○	○	○	sehr

1.4) Half Ihnen die Anzeige beim vorausschauenden Fahren?

Überhaupt nicht	○	○	○	○	○	sehr

1.5) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

◄──────────►

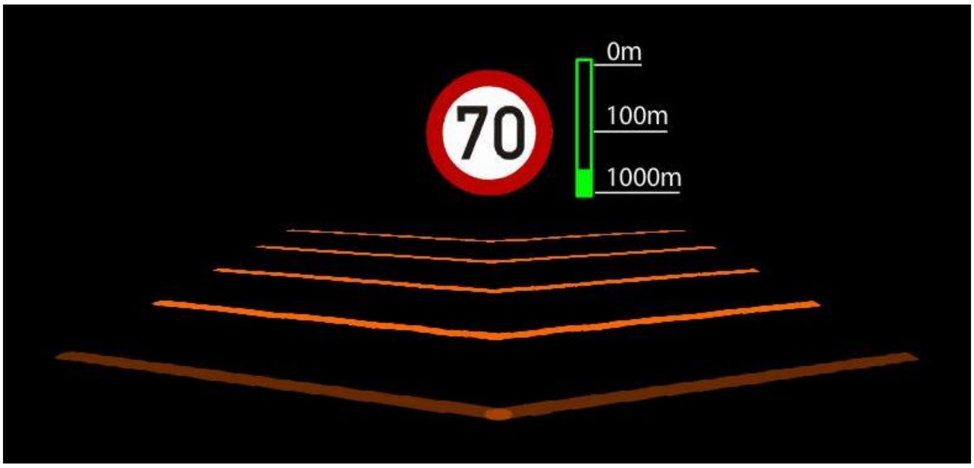
angenehm	○	○	○	○	○	unangenehm
träge	○	○	○	○	○	dynamisch
innovativ	○	○	○	○	○	konservativ
ablenkend	○	○	○	○	○	nicht ablenkend
aufdringlich	○	○	○	○	○	zurückhaltend
störend	○	○	○	○	○	nicht störend
zweckmäßig	○	○	○	○	○	unzweckmäßig
nicht hilfreich	○	○	○	○	○	hilfreich
eindeutig	○	○	○	○	○	verwirrend
macht Freude	○	○	○	○	○	frustrierend
bevormundend	○	○	○	○	○	befreiend
voraussagbar	○	○	○	○	○	unberechenbar
dumm	○	○	○	○	○	intelligent
belastend	○	○	○	○	○	entlastend
besonders	○	○	○	○	○	gewöhnlich
einfach	○	○	○	○	○	kompliziert
plump	○	○	○	○	○	elegant
übersichtlich	○	○	○	○	○	verwirrend

1.6) Gab es Elemente in der Anzeige, die Ihnen besonders **gut** gefallen haben?

1.7) Gab es Elemente in der Anzeige, die Ihnen besonders **schlecht** gefallen haben?

1.8) Haben Sie weitere Vorschläge oder Anmerkungen zu dieser Variante? Bitte notieren Sie diese hier:

Variante 2



2.1) Würden Sie die Anzeige in Ihrem Fahrzeug benutzen?

Auf keinen Fall	○	○	○	○	○	Auf jeden Fall

2.2) Finden Sie die Anzeige optisch ansprechend?

Überhaupt nicht	○	○	○	○	○	sehr

2.3) Haben Sie die Anzeige intuitiv verstanden?

Überhaupt nicht	○	○	○	○	○	sehr

2.4) Half Ihnen die Anzeige beim vorausschauenden Fahren?

Überhaupt nicht	○	○	○	○	○	sehr

2.5) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

◄————————►

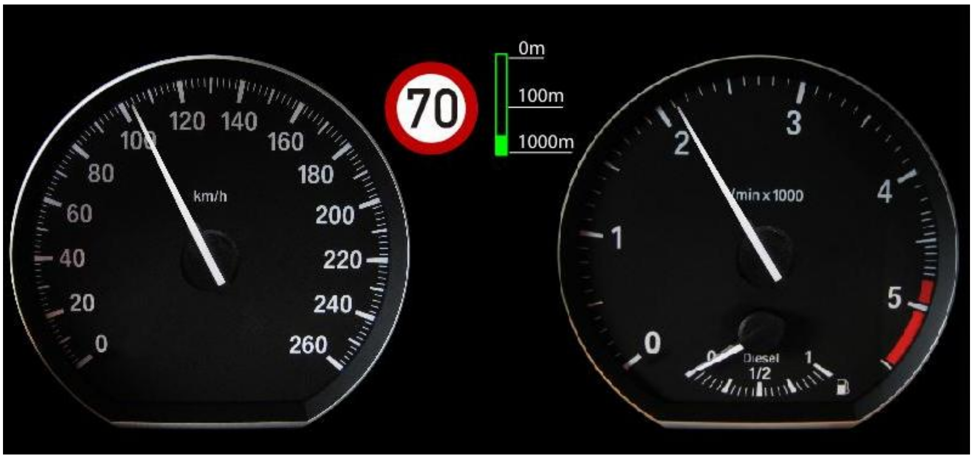
angenehm	○	○	○	○	○	unangenehm
träge	○	○	○	○	○	dynamisch
innovativ	○	○	○	○	○	konservativ
ablenkend	○	○	○	○	○	nicht ablenkend
aufdringlich	○	○	○	○	○	zurückhaltend
störend	○	○	○	○	○	nicht störend
zweckmäßig	○	○	○	○	○	unzweckmäßig
nicht hilfreich	○	○	○	○	○	hilfreich
eindeutig	○	○	○	○	○	verwirrend
macht Freude	○	○	○	○	○	frustrierend
bevormundend	○	○	○	○	○	befreiend
voraussagbar	○	○	○	○	○	unberechenbar
dumm	○	○	○	○	○	intelligent
belastend	○	○	○	○	○	entlastend
besonders	○	○	○	○	○	gewöhnlich
einfach	○	○	○	○	○	kompliziert
plump	○	○	○	○	○	elegant
übersichtlich	○	○	○	○	○	verwirrend

2.6) Gab es Elemente in der Anzeige, die Ihnen besonders **gut** gefallen haben?

2.7) Gab es Elemente in der Anzeige, die Ihnen besonders **schlecht** gefallen haben?

2.8) Haben Sie weitere Vorschläge oder Anmerkungen zu dieser Variante? Bitte notieren Sie diese hier:

Variante 3



3.1) Würden Sie die Anzeige in Ihrem Fahrzeug benutzen?

Auf keinen Fall	○	○	○	○	○	Auf jeden Fall

3.2) Finden Sie die Anzeige optisch ansprechend?

Überhaupt nicht	○	○	○	○	○	sehr

3.3) Haben Sie die Anzeige intuitiv verstanden?

Überhaupt nicht	○	○	○	○	○	sehr

3.4) Half Ihnen die Anzeige beim vorausschauenden Fahren?

Überhaupt nicht	○	○	○	○	○	sehr

3.5) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

	◄			►		
angenehm	○	○	○	○	○	unangenehm
träge	○	○	○	○	○	dynamisch
innovativ	○	○	○	○	○	konservativ
ablenkend	○	○	○	○	○	nicht ablenkend
aufdringlich	○	○	○	○	○	zurückhaltend
störend	○	○	○	○	○	nicht störend
zweckmäßig	○	○	○	○	○	unzweckmäßig
nicht hilfreich	○	○	○	○	○	hilfreich
eindeutig	○	○	○	○	○	verwirrend
macht Freude	○	○	○	○	○	frustrierend
bevormundend	○	○	○	○	○	befreiend
voraussagbar	○	○	○	○	○	unberechenbar
dumm	○	○	○	○	○	intelligent
belastend	○	○	○	○	○	entlastend
besonders	○	○	○	○	○	gewöhnlich
einfach	○	○	○	○	○	kompliziert
plump	○	○	○	○	○	elegant
übersichtlich	○	○	○	○	○	verwirrend

3.6) Gab es Elemente in der Anzeige, die Ihnen besonders **gut** gefallen haben?

____

____

____

3.7) Gab es Elemente in der Anzeige, die Ihnen besonders **schlecht** gefallen haben?

____

____

____

3.8) Haben Sie weitere Vorschläge oder Anmerkungen zu dieser Variante? Bitte notieren Sie diese hier:

____

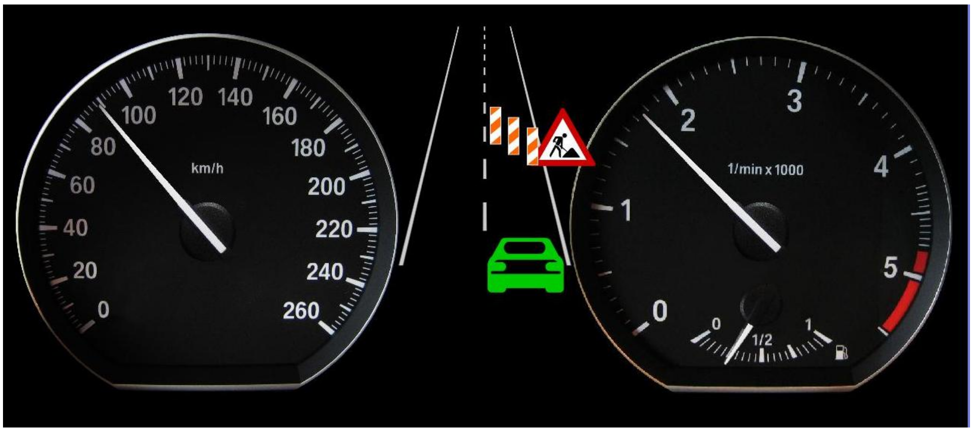
____

____

____

____

Variante 4



4.1) Würden Sie die Anzeige in Ihrem Fahrzeug benutzen?

Auf keinen Fall	○	○	○	○	○	Auf jeden Fall

4.2) Finden Sie die Anzeige optisch ansprechend?

Überhaupt nicht	○	○	○	○	○	sehr

4.3) Haben Sie die Anzeige intuitiv verstanden?

Überhaupt nicht	○	○	○	○	○	sehr

4.4) Half Ihnen die Anzeige beim vorausschauenden Fahren?

Überhaupt nicht	○	○	○	○	○	sehr

4.5) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

◄────────────────────►

angenehm	○	○	○	○	○	unangenehm
träge	○	○	○	○	○	dynamisch
innovativ	○	○	○	○	○	konservativ
ablenkend	○	○	○	○	○	nicht ablenkend
aufdringlich	○	○	○	○	○	zurückhaltend
störend	○	○	○	○	○	nicht störend
zweckmäßig	○	○	○	○	○	unzweckmäßig
nicht hilfreich	○	○	○	○	○	hilfreich
eindeutig	○	○	○	○	○	verwirrend
macht Freude	○	○	○	○	○	frustrierend
bevormundend	○	○	○	○	○	befreiend
voraussagbar	○	○	○	○	○	unberechenbar
dumm	○	○	○	○	○	intelligent
belastend	○	○	○	○	○	entlastend
besonders	○	○	○	○	○	gewöhnlich
einfach	○	○	○	○	○	kompliziert
plump	○	○	○	○	○	elegant
übersichtlich	○	○	○	○	○	verwirrend

4.6) Gab es Elemente in der Anzeige, die Ihnen besonders **gut** gefallen haben?

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4.7) Gab es Elemente in der Anzeige, die Ihnen besonders **schlecht** gefallen haben?

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4.8) Haben Sie weitere Vorschläge oder Anmerkungen zu dieser Variante? Bitte notieren Sie diese hier:

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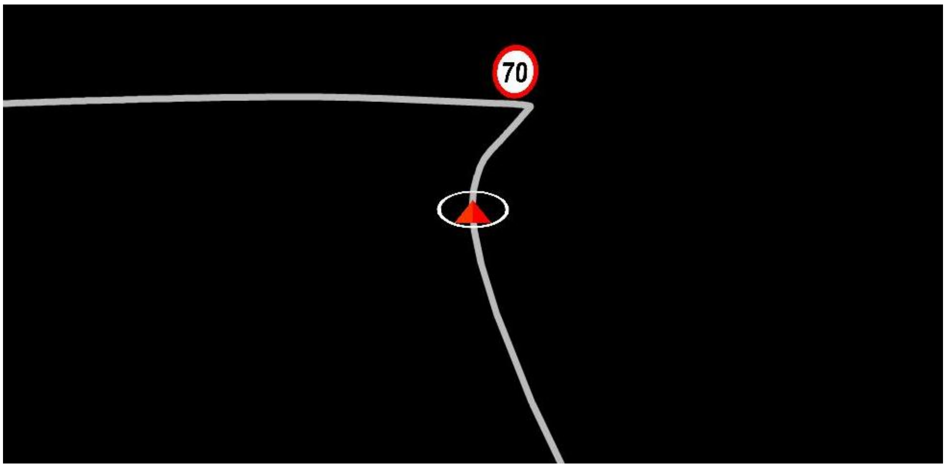
Variante 5



5.1) Würden Sie die Anzeige in Ihrem Fahrzeug benutzen?

Auf keinen Fall	○	○	○	○	○	Auf jeden Fall

5.2) Finden Sie die Anzeige optisch ansprechend?

Überhaupt nicht	○	○	○	○	○	sehr

5.3) Haben Sie die Anzeige intuitiv verstanden?

Überhaupt nicht	○	○	○	○	○	sehr

5.4) Half Ihnen die Anzeige beim vorausschauenden Fahren?

Überhaupt nicht	○	○	○	○	○	sehr

5.5) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

angenehm	○	○	○	○	○	unangenehm
träge	○	○	○	○	○	dynamisch
innovativ	○	○	○	○	○	konservativ
ablenkend	○	○	○	○	○	nicht ablenkend
aufdringlich	○	○	○	○	○	zurückhaltend
störend	○	○	○	○	○	nicht störend
zweckmäßig	○	○	○	○	○	unzweckmäßig
nicht hilfreich	○	○	○	○	○	hilfreich
eindeutig	○	○	○	○	○	verwirrend
macht Freude	○	○	○	○	○	frustrierend
bevormundend	○	○	○	○	○	befreiend
voraussagbar	○	○	○	○	○	unberechenbar
dumm	○	○	○	○	○	intelligent
belastend	○	○	○	○	○	entlastend
besonders	○	○	○	○	○	gewöhnlich
einfach	○	○	○	○	○	kompliziert
plump	○	○	○	○	○	elegant
übersichtlich	○	○	○	○	○	verwirrend

5.6) Gab es Elemente in der Anzeige die, Ihnen besonders **gut** gefallen haben?

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5.7) Gab es Elemente in der Anzeige, die Ihnen besonders **schlecht** gefallen haben?

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5.8) Haben Sie weitere Vorschläge oder Anmerkungen zu dieser Variante? Bitte notieren Sie diese hier:

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Variante 6

6.1) Würden Sie die Anzeige in Ihrem Fahrzeug benutzen?

Auf keinen Fall	○	○	○	○	○	Auf jeden Fall

6.2) Finden Sie die Anzeige optisch ansprechend?

Überhaupt nicht	○	○	○	○	○	sehr

6.3) Haben Sie die Anzeige intuitiv verstanden?

Überhaupt nicht	○	○	○	○	○	sehr

6.4) Half Ihnen die Anzeige beim vorausschauenden Fahren?

Überhaupt nicht	○	○	○	○	○	sehr

6.5) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

◄────────────────────►

angenehm	○	○	○	○	○	unangenehm
träge	○	○	○	○	○	dynamisch
innovativ	○	○	○	○	○	konservativ
ablenkend	○	○	○	○	○	nicht ablenkend
aufdringlich	○	○	○	○	○	zurückhaltend
störend	○	○	○	○	○	nicht störend
zweckmäßig	○	○	○	○	○	unzweckmäßig
nicht hilfreich	○	○	○	○	○	hilfreich
eindeutig	○	○	○	○	○	verwirrend
macht Freude	○	○	○	○	○	frustrierend
bevormundend	○	○	○	○	○	befreiend
voraussagbar	○	○	○	○	○	unberechenbar
dumm	○	○	○	○	○	intelligent
belastend	○	○	○	○	○	entlastend
besonders	○	○	○	○	○	gewöhnlich
einfach	○	○	○	○	○	kompliziert
plump	○	○	○	○	○	elegant
übersichtlich	○	○	○	○	○	verwirrend

6.6) Gab es Elemente in der Anzeige, die Ihnen besonders **gut** gefallen haben?

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6.7) Gab es Elemente in der Anzeige, die Ihnen besonders **schlecht** gefallen haben?

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6.8) Haben Sie weitere Vorschläge oder Anmerkungen zu dieser Variante? Bitte notieren Sie diese hier:

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Abschlussfrage

Welche Kombinationen der Varianten könnten Sie sich gut vorstellen?

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Generelle Anmerkungen

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A.2. Results

A.2.1. System Acceptance

Descriptive Values for the System Acceptance

	N	Min.	Max.	Mean	Std. error	Std. Deviation
VRL-Use	30	1	5	2.53	.224	1.224
VRL-Appealing	30	1	5	2.43	.233	1.278
VRL-Intuitive	30	1	5	3.80	.242	1.324
VRL-Antici. Support	30	1	5	2.70	.210	1.149
BEV-Use	30	1	5	3.60	.207	1.133
BEV-Appealing	30	1	5	3.87	.190	1.042
BEV-Intuitive	30	4	5	4.53	.093	.507
BEV-Antici. Support	30	1	5	3.90	.147	.803
Navimap-Use	30	1	5	3.43	.290	1.591
Navimap-Appealing	30	1	5	3.40	.256	1.404
Navimap-Intuitive	30	3	5	4.57	.114	.626
Navimap-Antici. Support	30	1	5	4.03	.200	1.098

Table A.1.: Statistical values regarding the system acceptance of the three variants in the video experiment

A.2.2. Desirable System Attributes

Helpful / not helpful			
df = 2, F= 12.824, p=0.000			
	VRL	BEV	Navimap
VRL		0.000	0.001
BEV	0.000		.282
Navimap	0.001	.282	
appropriate/not appropriate			
df = 2, F= 11.168, p=0.000			
	VRL	BEV	Navimap
VRL		0.000	0.002
BEV	0.000		.638
Navimap	0.002	.683	
Conservative/Innovative			
df = 2, F= 4.268, p=0.019			
	VRL	BEV	Navimap
VRL		0.009	0.023
BEV	0.009		.902
Navimap	0.023	.902	
Dynamic/Sluggish			
df = 2, F= 6.652, p=0.003			
	VRL	BEV	Navimap
VRL		0.055	0.000
BEV	0.055		.163
Navimap	0.000	.163	
Confusing / Obvious			
df = 2, F= 0.440, p=0.646			
	VRL	BEV	Navimap
VRL		0.463	0.440
BEV	0.463		.889
Navimap	0.440	.889	

Unpredictable / Predictable			
df = 1.512, F= 1.052, p=0.356			
	VRL	BEV	Navimap
VRL		0.405	0.222
BEV	0.405		.139
Navimap	0.222	.139	
Stupid / Intelligent			
df = 2, F= 4.268, p=0.019			
	VRL	BEV	Navimap
VRL		0.011	0.015
BEV	0.011		.610
Navimap	0.015	.610	
Common / Special			
df = 2, F= 6.652, p=0.003			
	VRL	BEV	Navimap
VRL		0.020	0.257
BEV	0.020		.294
Navimap	0.257	.294	
Unpleasant / Pleasant			
df = 2, F= 0.958 p=0.380			
	VRL	BEV	Navimap
VRL		0.190	0.239
BEV	0.190		.923
Navimap	0.239	.923	

Table A.2.: Results for repeated measures ANOVA and post-hoc analysis for desirable system attributes (1) in the video experiment

Complicated / Simple			
df = 2, F= 7.616 p=0.001			
	VRL	BEV	Navimap
VRL		0.001	0.002
BEV	0.001		.423
Navimap	0.002	.423	
Confusing / Clear			
df = 2, F= 0.213, p=0.809			
	VRL	BEV	Navimap
VRL		0.493	0.912
BEV	0.493		.625
Navimap	0.912	.625	
Frustrating / Makes Fun			
df = 2, F= 4.228, p=0.019			
	VRL	BEV	Navimap
VRL		0.013	0.023
BEV	0.013		.669
Navimap	0.023	.669	
Rough / Elegant			
df = 2, F= 5.587, p=0.006			
	VRL	BEV	Navimap
VRL		0.004	0.013
BEV	0.004		1.000
Navimap	0.013	1.000	
Wearing / Relieving			
df = 2, F= 3.523, p=0.036			
	VRL	BEV	Navimap
VRL		0.024	0.063
BEV	0.024		.196
Navimap	0.063	.196	

Disturbing / Not Disturbing			
df = 2, F= 0.972, p=0.384			
	VRL	BEV	Navimap
VRL		.184	.531
BEV	.184		.452
Navimap	.531	.452	
Patronizing / Liberating			
df = 2, F= 2.326 p=0.107			
	VRL	BEV	Navimap
VRL		.070	.305
BEV	.070		.214
Navimap	.305	.214	
Distracting / Not Distracting			
df = 2, F= 0.130, p=0.878			
	VRL	BEV	Navimap
VRL		.725	.895
BEV	.725		.641
Navimap	.895	.641	
Pushing / Reserved			
df = 2, F= 1.526, p=0.226			
	VRL	BEV	Navimap
VRL		.631	.095
BEV	.631		.245
Navimap	.095	.245	

Table A.3.: Results for repeated measures ANOVA and post-hoc analysis for desirable system attributes (2) in the video experiment

Descriptive Values for the VRL

	N	Min.	Max.	Mean	Std. error	Std. Deviation
VRL - pleasant	30	1	5	3.20	.217	1.186
VRL - dynamic	30	1	5	3.23	.190	1.040
VRL - innovative	30	1	5	3.27	.203	1.112
VRL - not distracting	30	1	5	2.87	.257	1.408
VRL - reserved	30	1	5	3.10	.222	1.213
VRL - not disturbing	30	1	5	2.97	.232	1.273
VRL - appropriate	30	1	5	3.03	.200	1.098
VRL - helpful	30	1	5	2.87	.224	1.224
VRL - clear	30	2	5	3.57	.202	1.104
VRL - makes fun	30	1	5	2.87	.157	.860
VRL - liberating	29	1	5	2.79	.160	.861
VRL - predictable	30	2	5	3.50	.196	1.075
VRL - intelligent	30	2	5	3.17	.152	.834
VRL - relieving	30	1	5	2.90	.162	.885
VRL - special	30	2	5	3.23	.177	.971
VRL - simple	30	3	5	4.23	.104	.568
VRL - elegant	30	1	4	2.77	.164	.898
VRL - obvious	30	1	5	3.63	.206	1.129

Table A.4.: Statistical values regarding desirable system attributes for the VRL in the video experiment

Descriptive Values for the BEV

	N	Min.	Max.	Mean	Std. error	Std. Deviation
BEV - pleasant	30	1	5	3.60	.195	1.070
BEV - dynamic	30	1	5	3.70	.187	1.022
BEV - innovative	30	1	5	3.93	.185	1.015
BEV - not distracting	30	2	5	2.97	.182	.999
BEV - reserved	30	1	5	2.97	.169	.928
BEV - not disturbing	30	1	5	3.37	.200	1.098
BEV - appropriate	30	2	5	3.97	.148	.809
BEV - helpful	30	2	5	4.10	.130	.712
BEV - clear	30	2	5	3.77	.164	.898
BEV - makes fun	30	2	5	3.40	.149	.814
BEV - liberating	30	2	5	3.20	.130	.714
BEV - predictable	30	3	5	3.70	.128	.702
BEV - intelligent	30	2	5	3.67	.130	.711
BEV - relieving	30	2	5	3.43	.177	.971
BEV - special	29	2	5	3.76	.146	.786
BEV - simple	30	1	5	3.43	.196	1.073
BEV - elegant	30	2	5	3.47	.164	.900
BEV - obvious	30	1	5	3.47	.202	1.106

Table A.5.: Statistical values regarding desirable system attributes for the BEV in the video experiment

Descriptive Values for the Navimap

	N	Min.	Max.	Mean	Std. error	Std. Deviation
Navimap - pleasant	30	1	5	3.57	.248	1.357
Navimap - dynamic	30	2	5	4.00	.166	.910
Navimap - innovative	30	1	5	3.90	.227	1.242
Navimap - not distracting	30	1	5	2.83	.215	1.177
Navimap - reserved	30	1	5	2.63	.217	1.189
Navimap - not disturbing	30	1	5	3.13	.238	1.306
Navimap - appropriate	30	2	5	3.87	.184	1.008
Navimap - helpful	30	2	5	3.87	.190	1.042
Navimap - clear	30	2	5	3.80	.194	1.064
Navimap - makes fun	30	1	5	3.50	.224	1.225
Navimap - liberating	30	1	5	2.97	.169	.928
Navimap - predictable	30	2	5	3.80	.162	.887
Navimap - intelligent	30	2	5	3.77	.164	.898
Navimap - relieving	30	1	5	3.30	.193	1.055
Navimap - special	30	1	5	3.50	.218	1.196
Navimap - simple	30	1	5	3.63	.195	1.066
Navimap - elegant	30	1	5	3.47	.218	1.196
Navimap - obvious	30	1	5	3.60	.212	1.163

Table A.6.: Statistical values regarding desirable system attributes for the Navimap in the video experiment

A.2.3. Overall System Acceptance

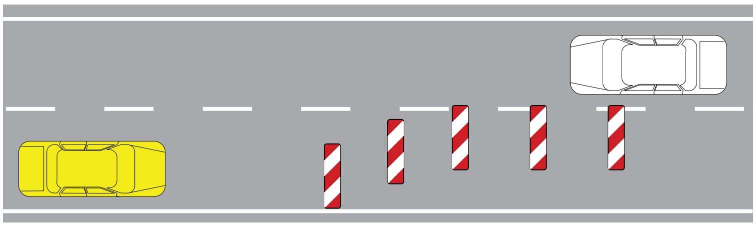
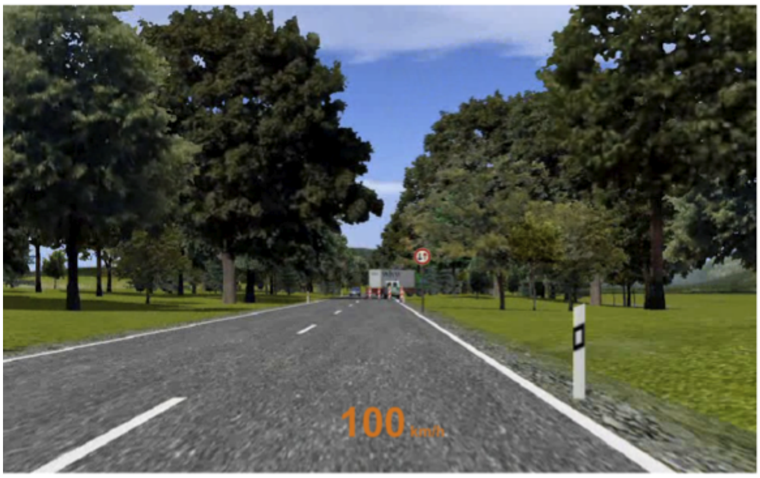
Descriptive Values for the VRL, BEV and Navimap

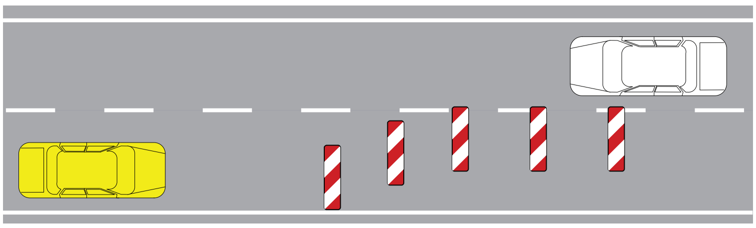
	N	Min.	Max.	Mean	Std. error	Std. Deviation
VRL	29	0	86	35.66	4.626	24.913
BEV	29	4	100	53.52	4.195	22.590
Navimap	29	11	100	61.93	5.056	27.228

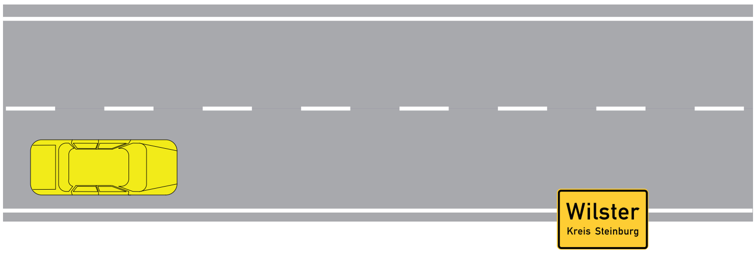
Table A.7.: Statistical values regarding the overall acceptance rating in the video experiment

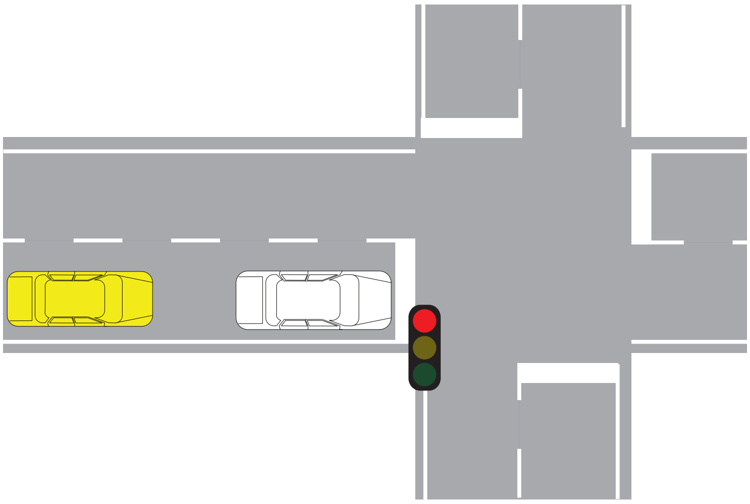
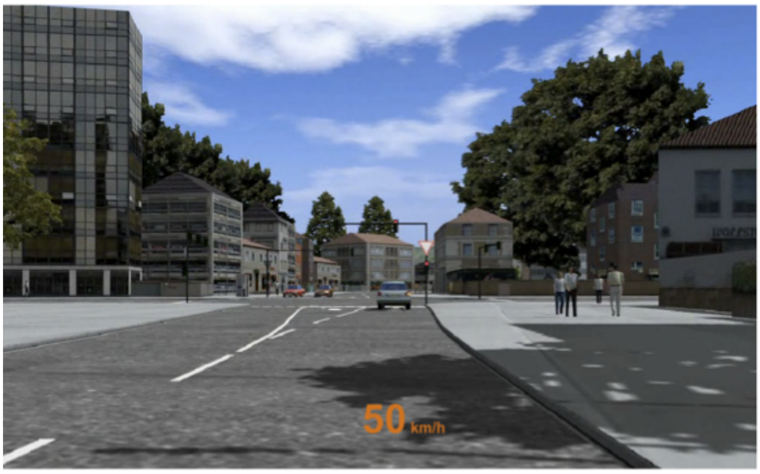
B. Usability Experiment

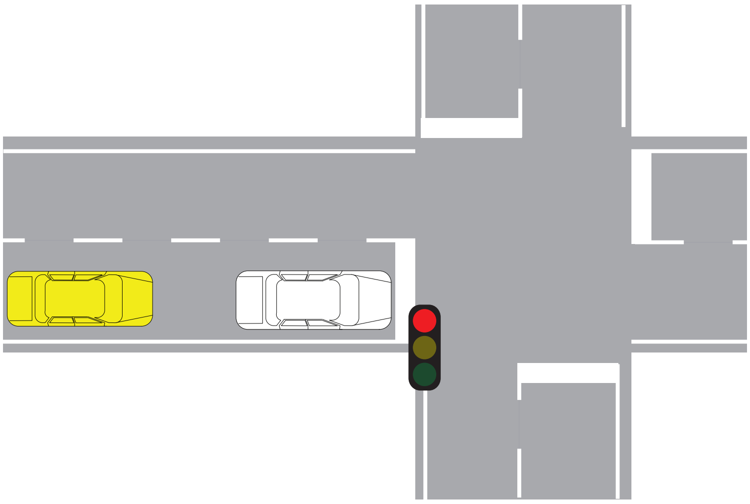
B.1. Situations

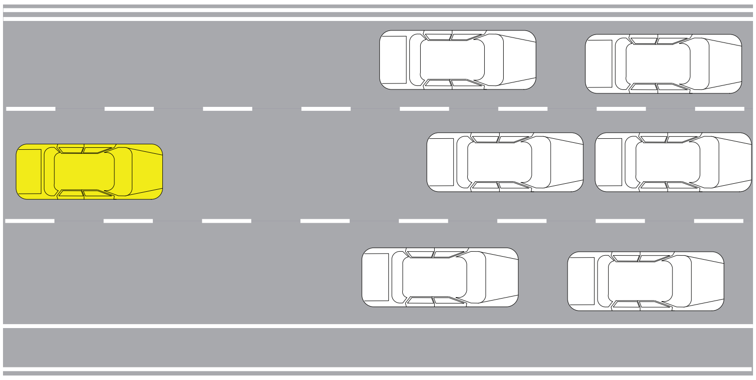
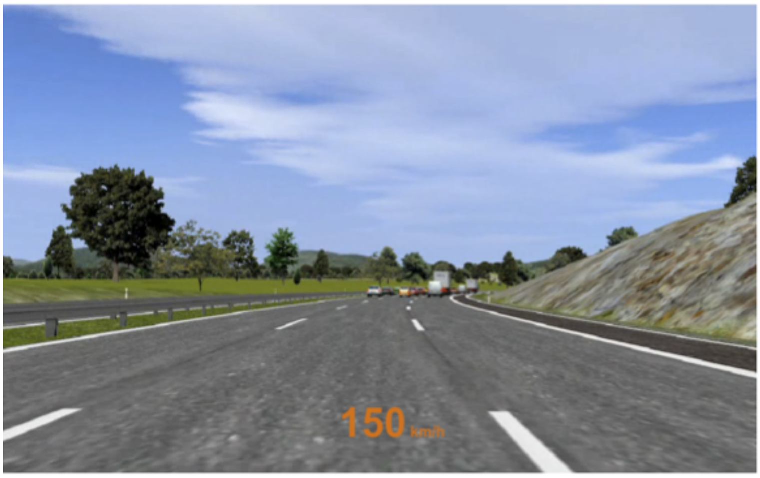
Name	AccidentStraight
Description	The ego vehicle is on a rural road with a speed limit of 100 km/h. After a right turn, an accident blocks the ego vehicle's lane. The situation itself is on a straight. The oncoming lane is blocked due to oncoming traffic. The ego vehicle has to decelerate in order to be able to pass the accident site.
Images	 
Potential	The situation is safety critical. The oncoming vehicles are hardly detectable behind the accident site. With the use of Car2X data the driver can be informed about the situation early. The additional coasting time can reduce fuel consumption.

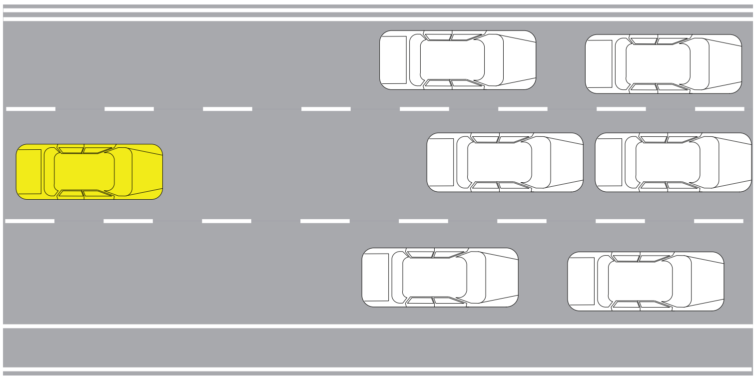
Name	AccidentLeft
Description	The ego vehicle is on a rural road with a speed limit of 100 km/h. In a left hand bend, an accidents blocks the ego vehicle's lane. The oncoming lane is blocked due to oncoming traffic. The ego vehicle has to decelerate in order to be able to pass the accident site.
Images	 
Potential	The situation is safety critical. The oncoming vehicles are hardly detectable behind the accident site. With the use of Car2X data the driver can be informed about the situation early. The additional coasting time can reduce fuel consumption.

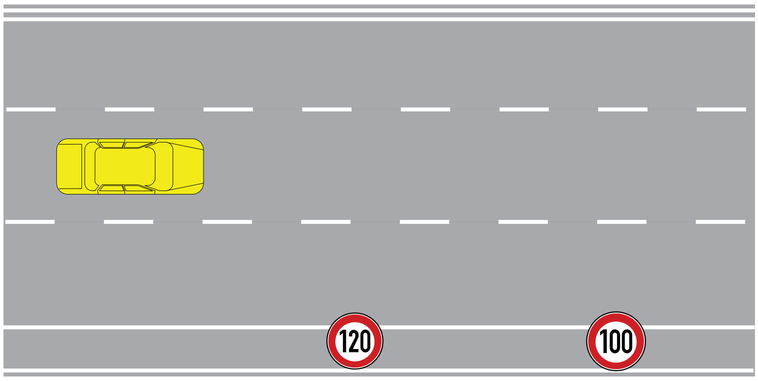
Name	CityLimit
Description	The ego vehicle is on a rural road with a speed limit of 100 km/h. The ego vehicle is approaching a city limit. The driver has to decelerate in order to reach the 50 km/h.
Images	 
Potential	The situation itself in not safety critical. The city limit sign is visible rather late, therefore the driver has to brake in order to reach the 50 km/h in time. With the use of digital maps and GPS it is possible to inform the driver in advance. With this information, coasting time can be extended and fuel consumption can be reduced.

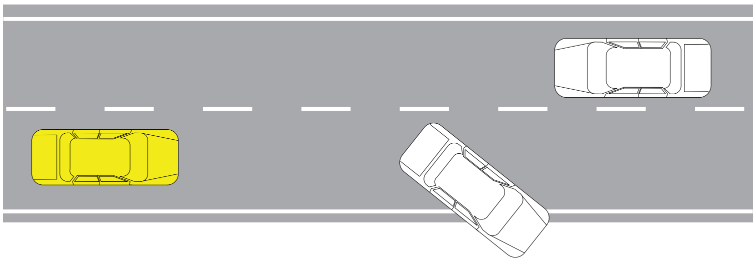
Name	CrossingSmall
Description	The ego vehicle is in an urban environment with a 50 km/h speed limit. After a bend, the vehicle is approaching a crossing with a red light and a vehicle waiting at the red light.
Images	 
Potential	The situation itself in not safety critical. At normal driving speed, the driver has to slow down and possibly stop before the traffic light turns green. With the use of Car2X data it could be possible to support the driver in advance. The driver then is able to start coasting early and pass the traffic light without stopping.

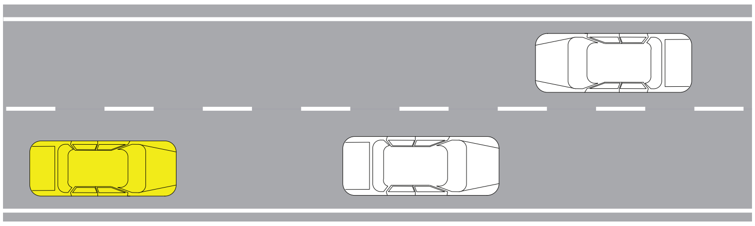
Name	CrossingLarge
Description	The ego vehicle is in an urban environment with a 60 km/h speed limit. The vehicle is approaching a crossing with a red light and a vehicle waiting at the red light.
Images	 
Potential	The situation itself in not safety critical. At normal driving speed, the driver has to slow down and possibly stop before the traffic light turns green. With the use of Car2X data it could be possible to support the driver in advance. The driver then is able to start coasting early and pass the traffic light without stopping.

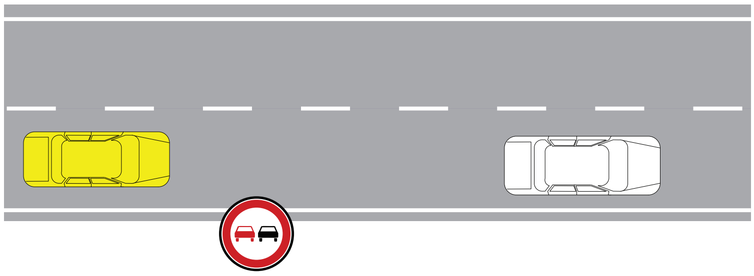
Name	HighwayJam
Description	The ego vehicle is on a highway with no speed limit and little traffic. In a right hand bend the end of a traffic jam is appearing. Under normal condition the driver is able to stop the vehicle before s/he reaches the traffic jam.
Images	 
Potential	The situation is safety critical. A late reaction of the driver can lead to an accident. With the use of Car2X data it would be possible to warn the driver in advance and heavily reduce the risk factor of the situation. Additionally, fuel consumption could be reduced by extending coasting time.

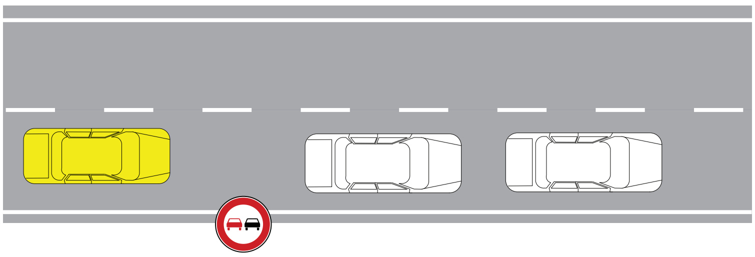
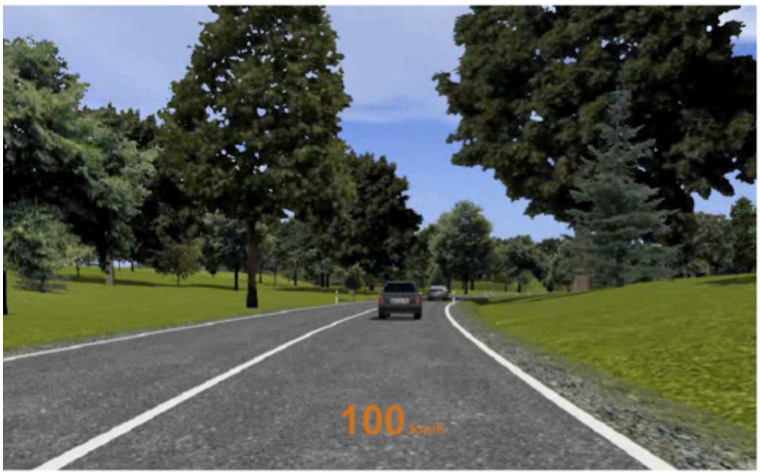
Name	HighwayJam60
Description	The ego vehicle is on a highway with no speed limit and little traffic. In a left hand bend slow moving traffic (60 km/h) is appearing. Under normal conditions the driver is able to slow down the vehicle before s/he reaches the slow moving traffic.
Images	 
Potential	The situation is slightly safety critical. A late reaction of the driver can lead to an accident. With the use of Car2X data it would be possible to warn the driver in advance and additionally reduce the risk factor of the situation. Additionally, fuel consumption could be reduced by extending coasting time.

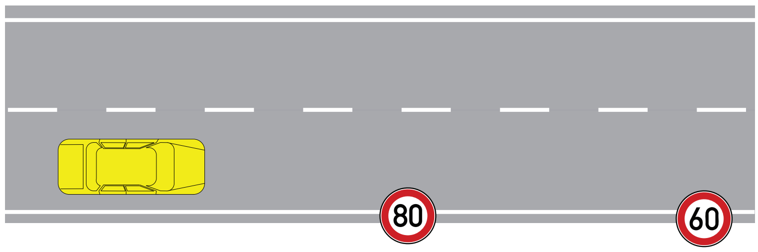
Name	HighwayLimit
Description	The ego vehicle is highway with no speed limit. A 120 km/h speed limit sign followed by a 100 km/h speed limit sign is coming up.
Images	 
Potential	The situation is not safety critical. Due to other traffic the speed limit is visible late and the driver has to brake in order to reach the speed limit in time. With the use of Car2X data, the driver could be informed in advance and the coasting time could be extended.

Name	ParkedCar
Description	The ego vehicle is in an urban environment with a speed limit of 50 km/h. A parking vehicle blocks the own lane. Two oncoming vehicles are blocking the oncoming lane. After the two vehicles have passed, the ego vehicle can pass the parking car.
Images	 
Potential	The situation is slightly safety critical. With no assistance the driver has to slow down and stop right before the parking vehicle. With the use of Car2X data the driver could be informed about the situation early. Early deceleration would result in a smoother drive and fuel consumption can be reduced.

Name	SlowOncoming
Description	The ego vehicle is on a rural road with a speed limit of 100 km/h. A slow driving vehicle (70 km/h) is in front of the ego vehicle. Oncoming traffic makes it hard to overtake the slow vehicle.
Images	 
Potential	The situation is slightly safety critical. Car2X data can help to reduce the risk factor of this situation by informing the driver early about the oncoming traffic.

Name	SlowProhibit
Description	The ego vehicle is on a rural road with a speed limit of 100 km/h. A slow driving vehicle (70 km/h) is in front of the ego vehicle. Overtaking is prohibited.
Images	 
Potential	The situation is not safety critical. Car2X data allows the driver to extend the coasting time by early decelerating to the speed of the slow vehicle in front.

Name	SlowProhibit2nd
Description	The ego vehicle is on a rural road with a speed limit of 100 km/h. A vehicle is driving in front with the same velocity. A second vehicle in front of this vehicle is driving at 70 km/h. Both vehicles (ego vehicle and vehicle in front) have to slow down due to the second vehicle. Overtaking is prohibited.
Images	 
Potential	The situation is not safety critical. Car2X data allows the driver to extend the coasting time by early decelerating to the speed of slow vehicle in front.

Name	SpeedLimitRural
Description	The ego vehicle is on a rural road with a speed limit of 100 km/h. An 80 km/h speed limit sign followed by a 60 km/h speed limit sign is coming up.
Images	 
Potential	The situation is not safety critical. Car2X data allows the driver to extend the coasting time by early decelerating to the upcoming speed limits. Fuel consumption can be reduced this way.

B.2. Questionnaire

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

A Allgemeine Angaben (vor der Versuchsdurchführung)

1) Geschlecht: ○ männlich ○ weiblich

2) Alter: __________ Jahre

3) Beruf: ___________________________________

4) Pkw-Führerschein (Kl. 3 bzw. B) erworben mit ________ Jahren

5) Zusätzliche Fahrberechtigung(en) (ggf. ankreuzen):

○ Motorrad (Kl. A bzw. 1)

○ LKW (Kl. C bzw. 2)

○ Bus (Kl. D)

○ Taxischein

○ Sonstige: ________________________

6) Wie viele Kilometer sind Sie im letzten Jahr mit dem Auto gefahren?

Bis 5.000 km	5.001 - 10.000 km	10.001 - 15.000 km	15.001 - 20.000 km	Mehr als 20.000 km
○	○	○	○	○

7) Wie häufig sind Sie im letzten Jahr mit dem Auto auf folgenden Straßentypen gefahren?

	Überhaupt nicht	Weniger als einmal pro Monat	Mindestens einmal pro Monat	Mindestens einmal pro Woche	(Fast) täglich
Stadt	○	○	○	○	○
Landstraße	○	○	○	○	○
Autobahn	○	○	○	○	○

8) Wie viele Kilometer sind Sie in Ihrem Leben insgesamt mit dem Auto gefahren?

Bis 25.000 km	25.001 - 50.000 km	50.001 - 100.000 km	100.001 - 500.000 km	Mehr als 500.000 km
○	○	○	○	○

9) Als wie vorausschauend würden Sie Ihre Fahrweise bezeichnen?

Überhaupt nicht vorausschauend	○	○	○	○	○	Sehr vorausschauend

10) Wann vermindern Sie normalerweise Ihre Geschwindigkeit, wenn Sie sich einem Hindernis nähern (z.B. rote Ampel)?

In allerletzter Sekunde	○	○	○	○	○	Sobald ich es sehe

11) Berücksichtigen Sie bei der Verminderung Ihrer Geschwindigkeit den nachfolgenden Verkehr? ○ ja ○ nein

Wenn ja, inwiefern?

____

____

____

____

12) Sind Sie vor diesem Versuch schon mal im Fahrsimulator am Lehrstuhl für Ergonomie der TU München gefahren? ○ ja ○ nein

13) Wenn nein, ist dies Ihre erste Fahrt in einem Fahrsimulator? ○ ja ○ nein

14) Liegt bei Ihnen eine Sehschwäche vor? ○ ja ○ nein

15) Haben Sie sonstige Augenerkrankungen, die Sie beinträchtigen? ○ ja ○ nein

16) Haben Sie eine Farbfehlsichtigkeit? ○ ja ○ nein

17) Benötigen Sie eine Sehhilfe? ○ ja ○ nein

18)	Benötigen Sie beim Fahren eine Sehhilfe?	○ ja	○ nein
19)	Tragen Sie diese Sehhilfe jetzt im Fahrsimulator?	○ ja	○ nein
20)	Leiden Sie manchmal unter Gleichgewichtsstörungen?	○ ja	○ nein
21)	Leiden Sie manchmal unter Schwindelgefühl?	○ ja	○ nein
22)	Wird Ihnen schwindelig, wenn Sie aus einer großen Höhe hinabschauen?	○ ja	○ nein
23)	Sind Sie beim Hören beeinträchtigt?	○ ja	○ nein
24)	Sind Sie in Ihrer körperlichen Beweglichkeit z.B. Nacken beeinträchtigt?	○ ja	○ nein
25)	Leiden Sie unter niedrigen Blutdruckwerten?	○ ja	○ nein
26)	Leiden Sie unter hohen Blutdruckwerten?	○ ja	○ nein
27)	Leiden Sie unter Herzstörungen?	○ ja	○ nein
28)	Sonstige Beschwerden?	○ ja	○ nein
	Wenn ja, welche?____		
29)	Nehmen Sie täglich Medikamente?	○ ja	○ nein
	Wenn ja, wofür? ____		

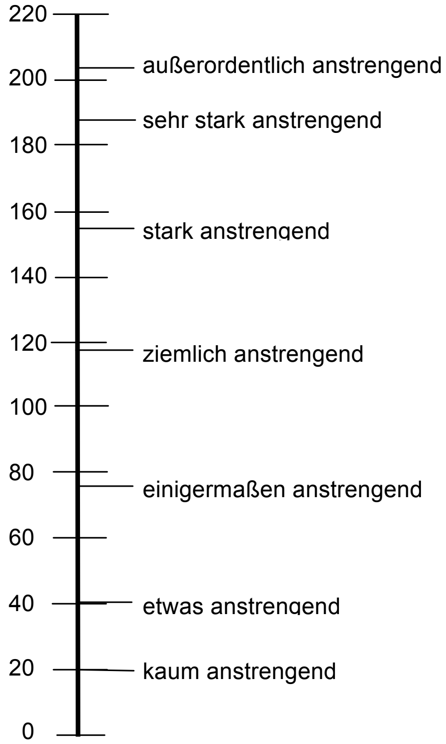
30) Vor wie viel Stunden/Minuten haben Sie zuletzt etwas gegessen? ____________

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B1 Fragen nach der Fahrt ohne Unterstützung beim vorausschauenden Fahren (Baseline)

Bitte kreuzen Sie auf der folgenden Skala an, wie **anstrengend** die gerade absolvierte **Fahrt** für Sie war. Hierbei können Sie das Kreuz an jeder beliebigen Stelle der Skala machen – auch zwischen den Markierungsstrichen.

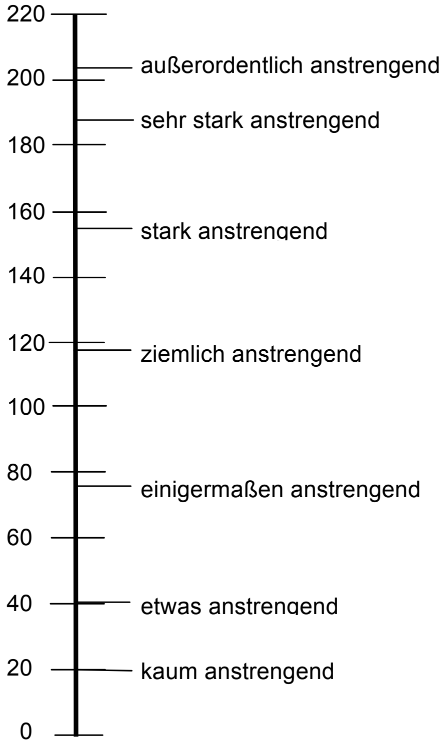


VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B2 Fragen nach der Fahrt mit Anzeige A zur Unterstützung beim vorausschauenden Fahren (2D-Anzeige)

1) Bitte kreuzen Sie auf der folgenden Skala an, wie **anstrengend** die gerade absolvierte **Fahrt** für Sie war. Hierbei können Sie das Kreuz an jeder beliebigen Stelle der Skala machen – auch zwischen den Markierungsstrichen.



2) Wie **gefällt** Ihnen die eben gesehene **Anzeige** zur Unterstützung beim voraus-schauenden Fahren?

Sehr schlecht	○	○	○	○	○	Sehr gut

3) Haben Sie sich bei der eben gesehenen Darstellung **sicher gefühlt** bzgl. der von Ihnen erwarteten Handlung?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

4) Empfanden Sie bei der eben gesehenen Darstellung den **Zeitpunkt der Information** als angemessen?

Viel zu früh	○	○	○	○	○	Viel zu spät

5) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

←→

angenehm	○	○	○	○	○	unangenehm
träge	○	○	○	○	○	dynamisch
innovativ	○	○	○	○	○	konservativ
ablenkend	○	○	○	○	○	nicht ablenkend
aufdringlich	○	○	○	○	○	zurückhaltend
störend	○	○	○	○	○	nicht störend
zweckmäßig	○	○	○	○	○	unzweckmäßig
nicht hilfreich	○	○	○	○	○	hilfreich
eindeutig	○	○	○	○	○	verwirrend
macht Freude	○	○	○	○	○	frustrierend
bevormundend	○	○	○	○	○	befreiend
voraussagbar	○	○	○	○	○	unberechenbar
dumm	○	○	○	○	○	intelligent
belastend	○	○	○	○	○	entlastend
besonders	○	○	○	○	○	gewöhnlich
einfach	○	○	○	○	○	kompliziert
plump	○	○	○	○	○	elegant
übersichtlich	○	○	○	○	○	verwirrend

6) Was hat Ihnen an dieser Anzeige insgesamt **besonders gut gefallen**? (Farbe, Größe, Form, Bewegung, Schnelligkeit der Informationsdarbietung etc.)

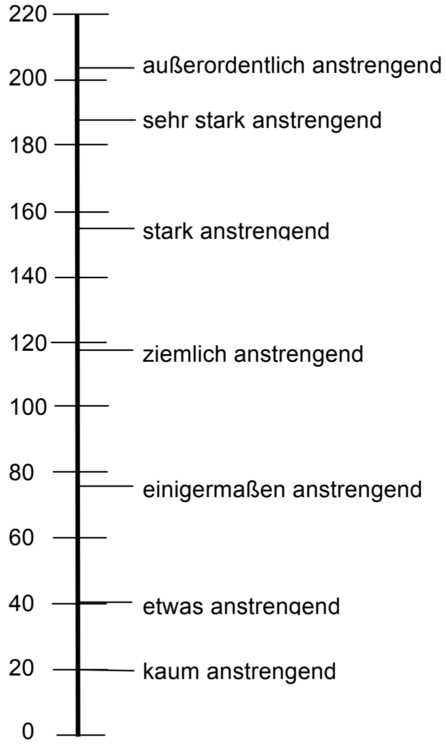
7) Was sollte **unbedingt verbessert** werden? Nehmen Sie hier bitte insbesondere Bezug auf Fragen und Aussagen, die Sie auf den vorangegangenen Seiten des Fragebogens negativ bewertet haben.

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B3 Fragen nach der Fahrt mit Anzeige B zur Unterstützung beim vorausschauenden Fahren (3D-Anzeige)

1) Bitte kreuzen Sie auf der folgenden Skala an, wie **anstrengend** die gerade absolvierte **Fahrt** für Sie war. Hierbei können Sie das Kreuz an jeder beliebigen Stelle der Skala machen – auch zwischen den Markierungsstrichen.



2) Wie **gefällt** Ihnen die eben gesehene **Anzeige** zur Unterstützung beim voraus-schauenden Fahren?

Sehr schlecht	○	○	○	○	○	Sehr gut

3) Haben Sie sich bei der eben gesehenen Darstellung **sicher gefühlt** bzgl. der von Ihnen erwarteten Handlung?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

4) Empfanden Sie bei der eben gesehenen Darstellung den **Zeitpunkt der Information** als angemessen?

Viel zu früh	○	○	○	○	○	Viel zu spät

5) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

←→

angenehm	○	○	○	○	○	unangenehm
träge	○	○	○	○	○	dynamisch
innovativ	○	○	○	○	○	konservativ
ablenkend	○	○	○	○	○	nicht ablenkend
aufdringlich	○	○	○	○	○	zurückhaltend
störend	○	○	○	○	○	nicht störend
zweckmäßig	○	○	○	○	○	unzweckmäßig
nicht hilfreich	○	○	○	○	○	hilfreich
eindeutig	○	○	○	○	○	verwirrend
macht Freude	○	○	○	○	○	frustrierend
bevormundend	○	○	○	○	○	befreiend
voraussagbar	○	○	○	○	○	unberechenbar
dumm	○	○	○	○	○	intelligent
belastend	○	○	○	○	○	entlastend
besonders	○	○	○	○	○	gewöhnlich
einfach	○	○	○	○	○	kompliziert
plump	○	○	○	○	○	elegant
übersichtlich	○	○	○	○	○	verwirrend

6) Was hat Ihnen an dieser Anzeige insgesamt **besonders gut gefallen**? (Farbe, Größe, Form, Bewegung, Schnelligkeit der Informationsdarbietung etc.)

7) Was sollte **unbedingt verbessert** werden? Nehmen Sie hier bitte insbesondere Bezug auf Fragen und Aussagen, die Sie auf den vorangegangenen Seiten des Fragebogens negativ bewertet haben.

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

C Abschlussfragebogen

C1 Fragen zu Anzeige A (2D-Anzeige)

1) Wie **störend bzw. hilfreich** fanden Sie **Anzeige A** (2D-Anzeige) in den folgenden Situationen?

	Sehr störend	Eher störend	Weder hilfreich noch störend	Eher hilfreich	Sehr hilfreich
Baustelle	○	○	○	○	○
Einparkendes Vorderfahrzeug	○	○	○	○	○
Ampel	○	○	○	○	○
Langsames Vorderfahrzeug	○	○	○	○	○
Geschwindigkeits-begrenzung	○	○	○	○	○
Zähfließender Verkehr	○	○	○	○	○
Stau	○	○	○	○	○

2) Gab es bei **Anzeige A** (2D-Anzeige) **Symbole**, die Sie **nicht verstanden** haben?

○ ja ○ nein

Wenn ja, welche waren das?

____

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____

3) Haben Sie bei **Anzeige A** (2D-Anzeige) bestimmte **Informationen vermisst**?

○ ja ○ nein

Wenn ja, welche waren das?

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4) Haben Sie bei **Anzeige A** (2D-Anzeige) **überflüssige Informationen** bemerkt?

○ ja ○ nein

Wenn ja, welche waren das?

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C2) Fragen zu Anzeige B (3D-Anzeige)

1) Wie **störend bzw. hilfreich** fanden Sie **Anzeige B** (3D-Anzeige) in den folgenden Situationen?

	Sehr störend	Eher störend	Weder hilfreich noch störend	Eher hilfreich	Sehr hilfreich
Baustelle	○	○	○	○	○
Einparkendes Vorderfahrzeug	○	○	○	○	○
Ampel	○	○	○	○	○
Langsames Vorderfahrzeug	○	○	○	○	○
Geschwindigkeits-begrenzung	○	○	○	○	○
Zähfließender Verkehr	○	○	○	○	○
Stau	○	○	○	○	○

2) Gab es bei **Anzeige B** (3D-Anzeige) **Symbole**, die Sie **nicht verstanden** haben?

○ ja ○ nein

Wenn ja, welche waren das?

____

____

____

____

____

3) Haben Sie bei **Anzeige B** (3D-Anzeige) bestimmte **Informationen vermisst**?

○ ja ○ nein

Wenn ja, welche waren das?

____

____

____

____

____

4) Haben Sie bei **Anzeige B** (3D-Anzeige) **überflüssige Informationen** bemerkt?

○ ja ○ nein

Wenn ja, welche waren das?

____

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C3) Fazit zu den beiden Anzeigen

1) Wenn mein Auto ein System zur Unterstützung vorausschauenden Fahrens besitzt, dann **wünsche** ich mir folgende Anzeigevariante:

	Auf keinen Fall	Vielleicht	Teils/teils	Gerne	unbedingt
Anzeige A	○	○	○	○	○
Anzeige B	○	○	○	○	○

2) Wenn Sie sich ein Auto nach Ihren **Wünschen** zusammenstellen könnten, hätten Sie darin gern ein **System zur Unterstützung vorausschauenden Fahrens**?

Auf keinen Fall	Vielleicht	Teils/teils	Gerne	unbedingt
○	○	○	○	○

3) Wenn Sie sich **für eine Anzeige entscheiden** müssten – Welche von beiden würden Sie wählen?

○ Anzeige A ○ Anzeige B

4) Was gab den Ausschlag für Ihre oben getroffene Wahl? Was ist Ihnen am wichtigsten?

____

____

____

____

____

____

____

____

5) Haben Sie weitere Vorschläge oder Anmerkungen? Bitte notieren Sie diese hier:

____

Vielen Dank für Ihre Unterstützung!

C. Uncertainty Experiment

C.1. Questionnaire

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

A Allgemeine Angaben (vor der Versuchsdurchführung)

1) Geschlecht: ○ männlich ○ weiblich

2) Alter: __________ Jahre

3) Beruf: ___________________________________

4) Pkw-Führerschein (Kl. 3 bzw. B) erworben mit ________ Jahren

5) Zusätzliche Fahrberechtigung(en) (ggf. ankreuzen):

○ Motorrad (Kl. A bzw. 1)

○ LKW (Kl. C bzw. 2)

○ Bus (Kl. D)

○ Taxischein

○ Sonstige: ________________________

6) Wie viele Kilometer sind Sie im letzten Jahr mit dem Auto gefahren?

Bis 5.000 km	5.001 - 10.000 km	10.001 - 15.000 km	15.001 - 20.000 km	Mehr als 20.000 km
○	○	○	○	○

7) Wie viele Kilometer sind Sie in Ihrem Leben insgesamt mit dem Auto gefahren?

Bis 25.000 km	25.001 - 50.000 km	50.001 - 100.000 km	100.001 - 500.000 km	Mehr als 500.000 km
○	○	○	○	○

8) Haben Sie bereits Fahrsimulatorerfahrung

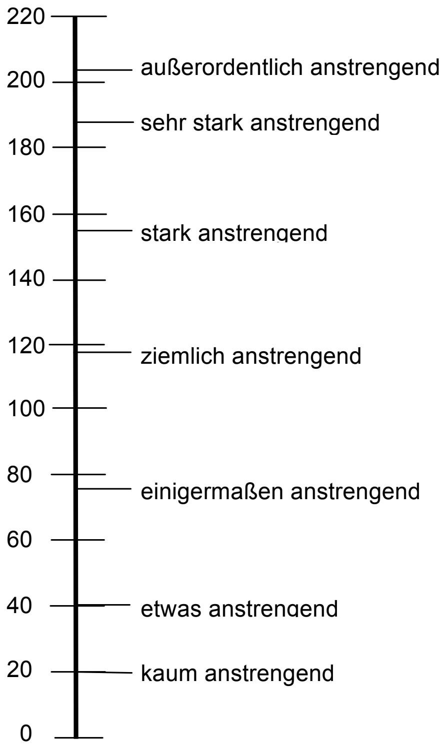
○ ja ○ nein

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B1 Fragen zu Fahrt mit Anzeigevariante A (Op)

Bitte kreuzen Sie auf der folgenden Skala an, wie **anstrengend** die gerade absolvierte **Fahrt** für Sie war. Hierbei können Sie das Kreuz an jeder beliebigen Stelle der Skala machen – auch zwischen den Markierungsstrichen.



1) Wie **gefällt** Ihnen die eben gesehene **Anzeige** zur Darstellung von unsicheren Daten?

←→

Sehr schlecht	○	○	○	○	○	Sehr gut

2) Inwieweit hat die Darstellung der Datenunsicherheiten Ihre **Fahrsicherheit erhöht**?

←→

Überhaupt nicht	○	○	○	○	○	Voll und ganz

3) Wie **nützlich** bewerten Sie die Darstellung der unsicheren Informationen?

←→

Überhaupt nicht	○	○	○	○	○	Voll und ganz

4) Inwiefern konnten Sie dem System zur Verzögerungsunterstützung **vertrauen**?

←→

Überhaupt nicht	○	○	○	○	○	Voll und ganz

5) Konnten **Fehlfunktionen** des Systems zur Verzögerungsunterstützung leicht **erkannt** werden?

←→

Überhaupt nicht	○	○	○	○	○	Voll und ganz

6) Inwiefern stimmen Sie der Aussage zu: Das System zur Verzögerungsunterstützung hatte **viele Fehlfunktionen**.

←→

Überhaupt nicht	○	○	○	○	○	Voll und ganz

7) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

◄────────────────►

einfach	○	○	○	○	○	○	○	kompliziert
fachmännisch	○	○	○	○	○	○	○	laienhaft
umständlich	○	○	○	○	○	○	○	direkt
voraussagbar	○	○	○	○	○	○	○	unberechenbar
minderwertig	○	○	○	○	○	○	○	wertvoll
gut	○	○	○	○	○	○	○	schlecht
verwirrend	○	○	○	○	○	○	○	übersichtlich
mutig	○	○	○	○	○	○	○	vorsichtig
belastend	○	○	○	○	○	○	○	entlastend
bevormundend	○	○	○	○	○	○	○	befreiend
hilfreich	○	○	○	○	○	○	○	nicht hilfreich
nicht störend	○	○	○	○	○	○	○	störend
zweckmäßig	○	○	○	○	○	○	○	unzweckmäßig
ablenkend	○	○	○	○	○	○	○	nicht ablenkend

8) Was hat Ihnen an dieser Anzeige insgesamt **besonders gut gefallen**? (Farbe, Größe, Form, Bewegung, Schnelligkeit der Informationsdarbietung etc.)

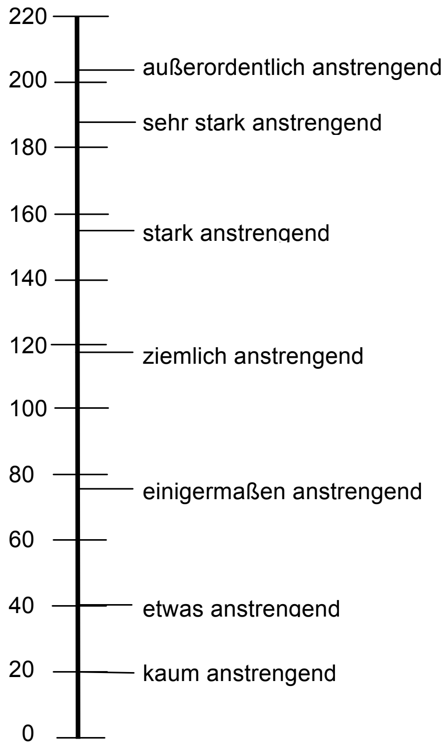
9) Was sollte **unbedingt verbessert** werden? Nehmen Sie hier bitte insbesondere Bezug auf Fragen und Aussagen, die Sie auf den vorangegangenen Seiten des Fragebogens negativ bewertet haben.

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B2 Fragen nach der Fahrt mit Anzeige B (pes)

Bitte kreuzen Sie auf der folgenden Skala an, wie **anstrengend** die gerade absolvierte **Fahrt** für Sie war. Hierbei können Sie das Kreuz an jeder beliebigen Stelle der Skala machen – auch zwischen den Markierungsstrichen.



1) Wie **gefällt** Ihnen die eben gesehene **Anzeige** zur Darstellung von unsicheren Daten?

Sehr schlecht	○	○	○	○	○	Sehr gut

2) Inwieweit hat die Darstellung der Datenunsicherheiten Ihre **Fahrsicherheit erhöht**?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

3) Wie **nützlich** bewerten Sie die Darstellung der unsicheren Informationen?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

4) Inwiefern konnten Sie dem System zur Verzögerungsunterstützung **vertrauen**?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

5) Konnten **Fehlfunktionen** des Systems zur Verzögerungsunterstützung leicht **erkannt** werden?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

6) Inwiefern stimmen Sie der Aussage zu: Das System zur Verzögerungsunterstützung hatte **viele Fehlfunktionen**.

Überhaupt nicht	○	○	○	○	○	Voll und ganz

7) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

←——————————→

einfach	○	○	○	○	○	○	○	kompliziert
fachmännisch	○	○	○	○	○	○	○	laienhaft
umständlich	○	○	○	○	○	○	○	direkt
voraussagbar	○	○	○	○	○	○	○	unberechenbar
minderwertig	○	○	○	○	○	○	○	wertvoll
gut	○	○	○	○	○	○	○	schlecht
verwirrend	○	○	○	○	○	○	○	übersichtlich
mutig	○	○	○	○	○	○	○	vorsichtig
belastend	○	○	○	○	○	○	○	entlastend
bevormundend	○	○	○	○	○	○	○	befreiend
hilfreich	○	○	○	○	○	○	○	nicht hilfreich
nicht störend	○	○	○	○	○	○	○	störend
zweckmäßig	○	○	○	○	○	○	○	unzweckmäßig
ablenkend	○	○	○	○	○	○	○	nicht ablenkend

8) Was hat Ihnen an dieser Anzeige insgesamt **besonders gut gefallen**? (Farbe, Größe, Form, Bewegung, Schnelligkeit der Informationsdarbietung etc.)

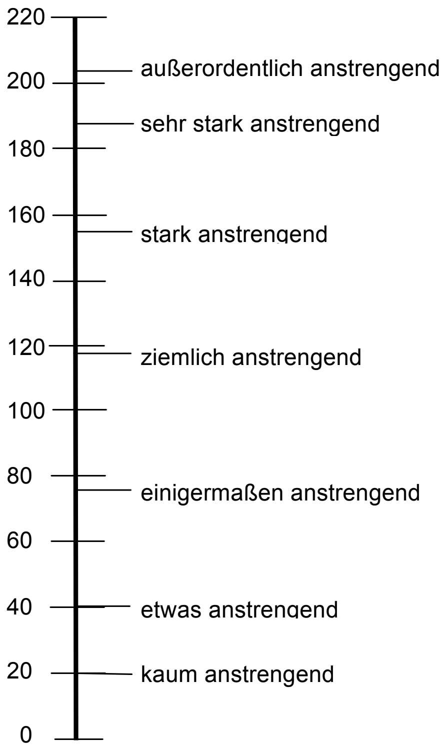
9) Was sollte **unbedingt verbessert** werden? Nehmen Sie hier bitte insbesondere Bezug auf Fragen und Aussagen, die Sie auf den vorangegangenen Seiten des Fragebogens negativ bewertet haben.

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B3 Fragen nach der Fahrt mit Anzeige C (V1)

Bitte kreuzen Sie auf der folgenden Skala an, wie **anstrengend** die gerade absolvierte **Fahrt** für Sie war. Hierbei können Sie das Kreuz an jeder beliebigen Stelle der Skala machen – auch zwischen den Markierungsstrichen.



1) Wie **gefällt** Ihnen die eben gesehene **Anzeige** zur Darstellung von unsicheren Daten?

Sehr schlecht	○	○	○	○	○	Sehr gut

2) Inwieweit hat die Darstellung der Datenunsicherheiten Ihre **Fahrsicherheit erhöht**?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

3) Wie **nützlich** bewerten Sie die Darstellung der unsicheren Informationen?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

4) Inwiefern konnten Sie dem System zur Verzögerungsunterstützung **vertrauen**?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

5) Konnten **Fehlfunktionen** des Systems zur Verzögerungsunterstützung leicht **erkannt** werden?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

6) Inwiefern stimmen Sie der Aussage zu: Das System zur Verzögerungsunterstützung hatte **viele Fehlfunktionen**.

Überhaupt nicht	○	○	○	○	○	Voll und ganz

7) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

einfach	○	○	○	○	○	○	○	kompliziert
fachmännisch	○	○	○	○	○	○	○	laienhaft
umständlich	○	○	○	○	○	○	○	direkt
voraussagbar	○	○	○	○	○	○	○	unberechenbar
minderwertig	○	○	○	○	○	○	○	wertvoll
gut	○	○	○	○	○	○	○	schlecht
verwirrend	○	○	○	○	○	○	○	übersichtlich
mutig	○	○	○	○	○	○	○	vorsichtig
belastend	○	○	○	○	○	○	○	entlastend
bevormundend	○	○	○	○	○	○	○	befreiend
hilfreich	○	○	○	○	○	○	○	nicht hilfreich
nicht störend	○	○	○	○	○	○	○	störend
zweckmäßig	○	○	○	○	○	○	○	unzweckmäßig
ablenkend	○	○	○	○	○	○	○	nicht ablenkend

8) Was hat Ihnen an dieser Anzeige insgesamt **besonders gut gefallen**? (Farbe, Größe, Form, Bewegung, Schnelligkeit der Informationsdarbietung etc.)

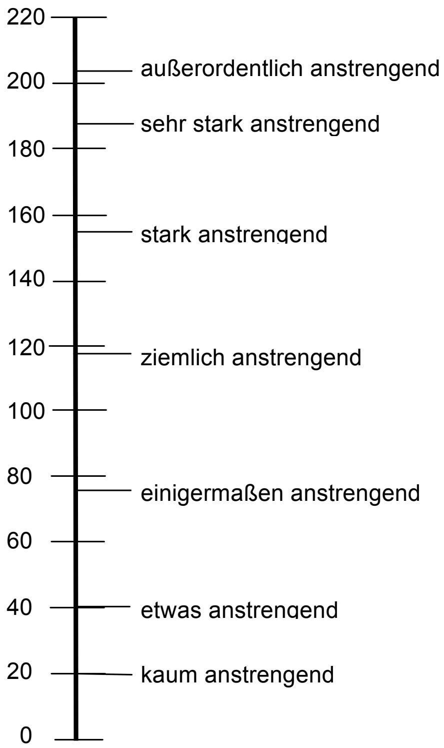
9) Was sollte **unbedingt verbessert** werden? Nehmen Sie hier bitte insbesondere Bezug auf Fragen und Aussagen, die Sie auf den vorangegangenen Seiten des Fragebogens negativ bewertet haben.

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B4 Fragen nach der Fahrt mit Anzeige D (V2)

Bitte kreuzen Sie auf der folgenden Skala an, wie **anstrengend** die gerade absolvierte **Fahrt** für Sie war. Hierbei können Sie das Kreuz an jeder beliebigen Stelle der Skala machen – auch zwischen den Markierungsstrichen.



1) Wie **gefällt** Ihnen die eben gesehene **Anzeige** zur Darstellung von unsicheren Daten?

Sehr schlecht	○	○	○	○	○	Sehr gut

2) Inwieweit hat die Darstellung der Datenunsicherheiten Ihre **Fahrsicherheit erhöht**?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

3) Wie **nützlich** bewerten Sie die Darstellung der unsicheren Informationen?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

4) Inwiefern konnten Sie dem System zur Verzögerungsunterstützung **vertrauen**?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

5) Konnten **Fehlfunktionen** (eine unsichere Verkehrszeichendarstellung) des Systems zur Verzögerungsunterstützung leicht **erkannt** werden?

Überhaupt nicht	○	○	○	○	○	Voll und ganz

6) Inwiefern stimmen Sie der Aussage zu: Das System zur Verzögerungsunterstützung hatte **viele Fehlfunktionen**.

Überhaupt nicht	○	○	○	○	○	Voll und ganz

7) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstufen, kreuzen Sie bitte den Mittelpunkt der Skala an.

Diese Anzeige ist …

←————————————→

einfach	○	○	○	○	○	○	○	kompliziert
fachmännisch	○	○	○	○	○	○	○	laienhaft
umständlich	○	○	○	○	○	○	○	direkt
voraussagbar	○	○	○	○	○	○	○	unberechenbar
minderwertig	○	○	○	○	○	○	○	wertvoll
gut	○	○	○	○	○	○	○	schlecht
verwirrend	○	○	○	○	○	○	○	übersichtlich
mutig	○	○	○	○	○	○	○	vorsichtig
belastend	○	○	○	○	○	○	○	entlastend
bevormundend	○	○	○	○	○	○	○	befreiend
hilfreich	○	○	○	○	○	○	○	nicht hilfreich
nicht störend	○	○	○	○	○	○	○	störend
zweckmäßig	○	○	○	○	○	○	○	unzweckmäßig
ablenkend	○	○	○	○	○	○	○	nicht ablenkend

8) Was hat Ihnen an dieser Anzeige insgesamt **besonders gut gefallen**? (Farbe, Größe, Form, Bewegung, Schnelligkeit der Informationsdarbietung etc.)

9) Was sollte **unbedingt verbessert** werden? Nehmen Sie hier bitte insbesondere Bezug auf Fragen und Aussagen, die Sie auf den vorangegangenen Seiten des Fragebogens negativ bewertet haben.

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

C Abschlussfragebogen

In der Situation „**Baustelle**“, wie **hilfreich** fanden Sie die einzelnen Anzeigen?

	Überhaupt nicht hilfreich	nicht hilfreich	Teilweise hilfreich	Eher hilfreich	Sehr hilfreich
Anzeige A	○	○	○	○	○
Anzeige B	○	○	○	○	○
Anzeige C	○	○	○	○	○
Anzeige D	○	○	○	○	○

In der Situation „**100 km/h**“, wie **hilfreich** fanden Sie die einzelnen Anzeigen?

	Überhaupt nicht hilfreich	Nicht hilfreich	Teilweise hilfreich	Eher hilfreich	Sehr hilfreich
Anzeige A	○	○	○	○	○
Anzeige B	○	○	○	○	○
Anzeige C	○	○	○	○	○
Anzeige D	○	○	○	○	○

In der Situation „**Autobahnauffahrt**“, wie **hilfreich** fanden Sie die einzelnen Anzeigen?

	Überhaupt nicht hilfreich	Nicht hilfreich	Teilweise hilfreich	Eher hilfreich	Sehr hilfreich
Anzeige A	○	○	○	○	○
Anzeige B	○	○	○	○	○
Anzeige C	○	○	○	○	○
Anzeige D	○	○	○	○	○

C3) Fazit zu den Anzeigen

1) Wenn mein Auto einen Verzögerungsassistenten besitzt, dann **wünsche** ich mir folgende Anzeigevariante:

	Auf keinen Fall	Vielleicht	Teils/teils	Gerne	unbedingt
Anzeige A	○	○	○	○	○
Anzeige B	○	○	○	○	○
Anzeige C	○	○	○	○	○
Anzeige D	○	○	○	○	○

2) Bewerten Sie bitte die einzelnen Anzeigen mit den Ziffern 1 bis 4. Verwenden Sie jede Ziffer nur einmal (1: beste - 4: schlechteste).

Anzeige A: ______

Anzeige B: ______

Anzeige C: ______

Anzeige D: ______

3) Was gab den Ausschlag für Ihre oben getroffene Wahl? Was ist Ihnen am wichtigsten?

____

____

____

____

____

____

____

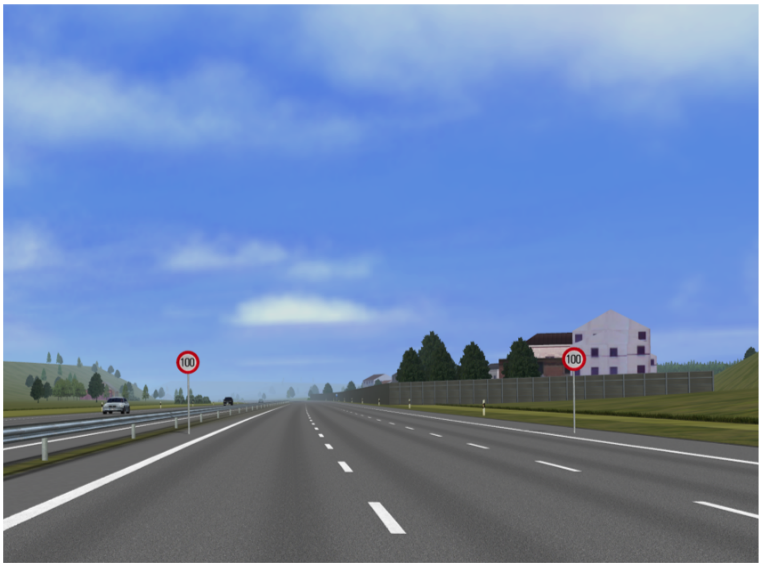
____

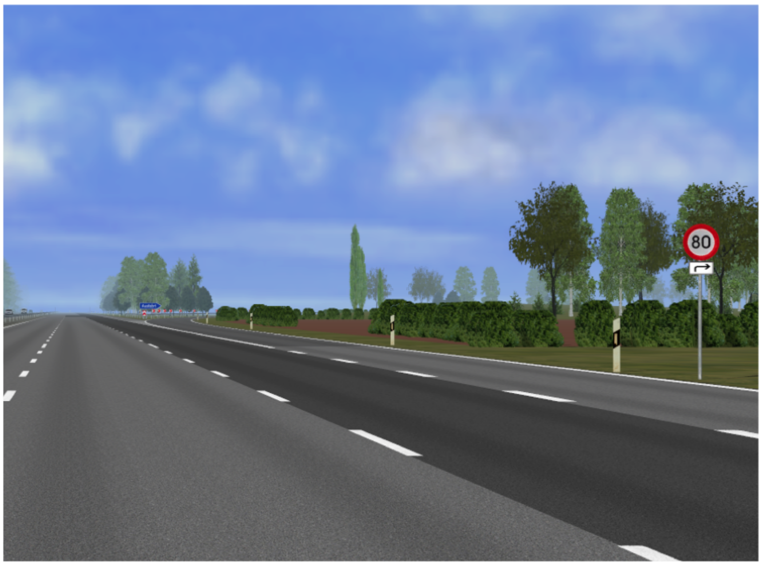
4) Haben Sie weitere Vorschläge oder Anmerkungen? Bitte notieren Sie diese hier:

Vielen Dank für Ihre Unterstützung!

C.2. Situations

<table>
<tr><td>Name</td><td>Construction Site</td></tr>
<tr><td>Description</td><td>The ego vehicle is in a construction site situation with a current speed limit of 80 km/h, which gets repeated once. During the approach of the situation the driver gets informed about an uncertain 120 km/h upcoming speed limit. After passing the speed limit sign, a correct and certain current speed limit is shown to the driver.</td></tr>
<tr><td>Images</td><td>
</td></tr>
<tr><td>Visualization</td><td><table>
<tr><th colspan="2">Approach</th><th colspan="2">Pass</th></tr>
<tr><th>shown</th><th>correct</th><th>shown</th><th>correct</th></tr>
<tr><td>120 (uncertain)</td><td>80</td><td>80 (certain)</td><td>80</td></tr>
</table></td></tr>
<tr><td>Reason</td><td>As a temporary obstacle, the construction site is not included in digital maps. During the approach, the system gets the speed limit information (120 km/h) from digital maps. Information from the camera shows a conflicting information but the confidentiality is not high enough. Therefore a 120 km/h speed sign is shown as uncertain information. When the vehicle passes the speed limit sign, the confidentiality is high enough to show a certain 80 km/h current speed limit sign</td></tr>
</table>

<table>
<tr><td>Name</td><td>100 km/h</td></tr>
<tr><td>Description</td><td>The ego vehicle is on a three lane highway, with a current speed limit of 120 km/h. An upcoming speed limit of 100 km/h is not detected with certainty, therefore the 100 km/h, although correct, is displayed to the driver with uncertainty during the approach and the pass of the traffic sign.</td></tr>
<tr><td>Images</td><td>
</td></tr>
<tr><td>Visualization</td><td><table>
<tr><td colspan="2">Approach</td><td colspan="2">Pass</td></tr>
<tr><td>shown</td><td>correct</td><td>shown</td><td>correct</td></tr>
<tr><td>100 (uncertain)</td><td>100</td><td>100 (uncertain)</td><td>100</td></tr>
</table></td></tr>
<tr><td>Reason</td><td>Although a static speed limit usually is included within digital maps, information from the camera is considered as being more up to date and therefore more reliable. A possible scenario for this situation is that the camera does provide a different information to the system than the information from the digital maps. Possible reasons for a bad information from the camera are: low standing sun, bad visual condition through rain, snow or fog or blockage through other traffic.</td></tr>
</table>

<table>
<tr><td>Name</td><td>Highway Exit Limit</td></tr>
<tr><td>Description</td><td>The ego vehicle is on a highway with a current speed limit of 100 km/h. The driver intends to stay on the highway. When approaching a highway exit with a speed limit only applicable for the exit, the system shows an uncertain 80 km/h as upcoming speed limit. When the driver passes the situation the system shows an uncertain 80 km/h as current speed limit</td></tr>
<tr><td>Images</td><td>
</td></tr>
<tr><td>Visualization</td><td><table>
<tr><td colspan="2">Approach</td><td colspan="2">Pass</td></tr>
<tr><td>shown</td><td>correct</td><td>shown</td><td>correct</td></tr>
<tr><td>80 (uncertain)</td><td>-</td><td>80 (uncertain)</td><td>-</td></tr>
</table></td></tr>
<tr><td>Reason</td><td>The camera sends information about an upcoming 80 km/h speed limit to the system. The additional sign which indicates that the limit is only applicable for the exit is not recognized correctly. Due to an information conflict between the camera and the digital map, an uncertain speed limit (80 km/h) is presented to the driver.</td></tr>
</table>

C.3. Results

C.3.1. Workload

Descriptive Values for the Workload

	N	Min.	Max.	Mean	Std. error	Std. Deviation
Optimistic	30	1.0	183	53.2	6.8	37.3
Pessimistic	30	7.0	118	53.3	6.1	33.7
Cautious	30	2.0	118	39.6	4.2	23.2
Very Cautious	30	0.0	150	53.4	6.5	35.7

Table C.1.: Statistical values regarding the subjective workload in the uncertainty experiment

C.3.2. Desirable System Attributes

Not distracting/Distracting				
F=5.238, df=3, p=.002				
	Opt.	Pes.	Cau1	Cau2
Opt.		.013	.010	.056
Pes	.013		.536	.423
Cau1	.010	.536		.086
Cau2	.056	.423	.086	
Inappropriate/Appropriate				
F=4.392, df=2.118, p=.015				
	Opt.	Pes.	Cau1	Cau2
Opt.		.075	.010	.016
Pes	.075		.265	.264
Cau1	.010	.265		.752
Cau2	.016	.264	.752	
Disturbing/Not Disturbing				
F=4.421, df=2.158, p=.014				
	Opt.	Pes.	Cau1	Cau2
Opt.		.013	.010	.191
Pes	.013		.580	.049
Cau1	.010	.580		.102
Cau2	.191	.049	.102	
Not Helpful/Helpful				
F=7.388, df=2.259, p=.001				
	Opt.	Pes.	Cau1	Cau2
Opt.		.050	.002	.001
Pes	.050		.109	.080
Cau1	.002	.109		1.000
Cau2	.001	.080	1.000	
Patronizing/Liberating				
F=6.502, df=3, p=.001				
	Opt.	Pes.	Cau1	Cau2
Opt.		.024	.000	.194
Pes	.024		.161	.133
Cau1	.000	.161		.001
Cau2	.194	.133	.001	
Wearing/Relieving				
F=7.352, df=2.192, p=.001				
	Opt.	Pes.	Cau1	Cau2
Opt.		.028	.000	.007
Pes	.028		.037	.186
Cau1	.000	.037		.423
Cau2	.007	.186	.423	
Courageous/Cautious				
F=4.588, df=2.120, p=.012				
	Opt.	Pes.	Cau1	Cau2
Opt.		.198	.002	.197
Pes	.198		.080	.402
Cau1	.002	.080		.229
Cau2	.197	.402	.229	

Confusing/Obvious				
F=4.511, df=3, p=.043				
	Opt.	Pes.	Cau1	Cau2
Opt.		.264	.013	.086
Pes	.264		.098	.610
Cau1	.013	.098		.216
Cau2	.086	.610	.216	
Bad/Good				
F=4.511, df=2.243, p=.012				
	Opt.	Pes.	Cau1	Cau2
Opt.		.166	.004	.028
Pes	.166		.070	.134
Cau1	.004	.070		.444
Cau2	.028	.134	.444	
Cheap/Valuable				
F=3.470, df=2.460, p=.028				
	Opt.	Pes.	Cau1	Cau2
Opt.		.330	.002	.222
Pes	.330		.080	.917
Cau1	.002	.080		.004
Cau2	.222	.917	.004	
Unpredictable/Predictable				
F=.7.341, df=2.16, p=.001				
	Opt.	Pes.	Cau1	Cau2
Opt.		.013	.002	.002
Pes	.013		.495	.161
Cau1	.002	.495		.489
Cau2	.002	.161	.489	
Indirect/Direct				
F=.802, df=3, p=.496				
	Opt.	Pes.	Cau1	Cau2
Opt.		.299	.829	.223
Pes	.299		.495	.600
Cau1	.829	.495		.239
Cau2	.223	.600	.239	
Unprofessional/Professional				
F=.977, df=3, p=.407				
	Opt.	Pes.	Cau1	Cau2
Opt.		.556	.374	.406
Pes	.556		.167	.174
Cau1	.374	.167		.921
Cau2	.406	.174	.921	
Complicated/Simple				
F=1.559, df=3, p=.203				
	Opt.	Pes.	Cau1	Cau2
Opt.		.277	.463	.423
Pes	.277		.021	.818
Cau1	.463	.021		.075
Cau2	.423	.818	.075	

Table C.2.: Results of repeated measures ANOVA and post-hoc analysis for desirable system attributes in the uncertainty experiment

Descriptive values for the desirable system attributes

	N	Min.	Max.	Mean	Std. error	Std. Deviation
Opt. simple	30	2	7	5.90	.22	1.21
Opt. professional	30	1	7	4.40	.29	1.59
Opt. direct	30	2	7	5.47	.22	1.22
Opt. predictable	30	1	7	4.30	.31	1.73
Opt. valuable	30	2	7	4.47	.24	1.33
Opt. good	30	2	7	4.57	.29	1.59
Opt. clear	30	1	7	4.33	.33	1.79
Opt. cautious	30	2	7	4.33	.25	1.35
Opt. relieving	30	2	7	3.97	.24	1.33
Opt. liberating	30	2	7	3.87	.22	1.22
Opt. helpful	30	2	6	4.40	.27	1.48
Opt. disturbing	30	2	7	4.37	.30	1.65
Opt. appropriate	30	2	7	4.60	.28	1.54
Opt. distracting	30	2	6	3.60	.23	1.25
Pes. simple	30	3	7	5.57	.24	1.30
Pes. professional	30	1	7	4.23	.28	1.52
Pes. direct	30	1	7	5.20	.28	1.52
Pes. predictable	30	3	7	5.27	.20	1.11
Pes. valuable	30	1	7	4.80	.26	1.42
Pes. good	30	1	7	5.07	.27	1.48
Pes. clear	30	1	7	4.90	.29	1.60
Pes. cautious	30	1	6	3.37	.25	1.35
Pes. relieving	30	1	7	4.60	.26	1.40
Pes. liberating	30	2	6	4.43	.20	1.07
Pes. helpful	30	1	7	5.10	.27	1.49
Pes. disturbing	30	1	7	5.37	.27	1.50
Pes. appropriate	30	1	7	5.23	.25	1.38
Pes. distracting	30	1	7	4.40	.30	1.63

Table C.3.: Statistical values regarding desirable system attributes for the "Optimisitc" and "Pessimistic" variant in the uncertainty experiment

Descriptive values for the desirable system attributes						
	N	Min.	Max.	Mean	Std. error	Std. Deviation
Cau1. simple	30	4	7	6.10	.17	.92
Cau1. professional	30	1	7	4.67	.31	1.71
Cau1. direct	30	3	7	5.40	.20	1.10
Cau1. predictable	30	2	7	5.47	.21	1.17
Cau1. valuable	30	2	7	5.40	.26	1.40
Cau1. good	30	2	7	5.57	.25	1.36
Cau1. clear	30	1	7	5.50	.29	1.57
Cau1. cautious	30	2	6	3.83	.17	.91
Cau1. relieving	30	3	6	5.07	.20	1.11
Cau1. liberating	30	3	6	4.70	.19	1.06
Cau1. helpful	30	1	7	5.57	.25	1.36
Cau1. disturbing	30	2	7	5.23	.25	1.38
Cau1. appropriate	30	2	7	5.50	.26	1.41
Cau1. distracting	30	2	6	4.53	.26	1.43
Cau2. simple	30	2	7	5.63	.26	1.43
Cau2. professional	30	1	7	4.70	.33	1.78
Cau2. direct	30	2	7	5.03	.31	1.69
Cau2. predictable	30	4	7	5.60	.17	.93
Cau2. valuable	30	1	7	4.83	.28	1.53
Cau2. good	30	1	7	5.40	.28	1.52
Cau2. clear	30	2	7	5.10	.27	1.49
Cau2. cautious	30	1	6	3.60	.22	1.22
Cau2. relieving	30	2	7	4.93	.22	1.23
Cau2. liberating	30	1	6	4.17	.22	1.21
Cau2. helpful	30	2	7	5.57	.22	1.19
Cau2. disturbing	30	1	7	4.87	.29	1.59
Cau2. appropriate	30	1	7	5.43	.21	1.17
Cau2. distracting	30	2	6	4.20	.24	1.32

Table C.4.: Statistical values regarding desirable system attributes for the two "Cautious" variants in the uncertainty experiment

C.3.3. System Acceptance

Descriptive value for the system acceptance

	N	Min.	Max.	Mean	Std. error	Std. Deviation
Opt. Likability	30	1	4	2.53	.21	1.14
Opt. Safety	30	1	4	1.90	.19	1.06
Opt. Usefulness	30	1	5	2.70	.24	1.29
Opt. Trust	30	1	5	2.83	.19	1.02
Opt. Malfunction rec.	30	1	5	2.37	.23	1.27
Opt. Quant. Malfunc.	30	1	5	3.00	.20	1.08
Pes. Likability	30	1	6	3.33	.25	1.35
Pes. Safety	30	1	4	2.47	.20	1.11
Pes. Usefulness	30	1	5	3.13	.21	1.14
Pes. Trust	30	2	6	3.73	.17	.94
Pes. Malfunction rec.	30	2	6	4.03	.18	.96
Pes. Quant. Malfunc.	30	2	5	3.57	.18	.97
Cau1. Likability	30	1	6	3.93	.24	1.31
Cau1. Safety	30	1	5	3.10	.26	1.40
Cau1. Usefulness	30	1	6	3.80	.22	1.21
Cau1. Trust	30	1	6	3.97	.21	1.13
Cau1. Malfunction rec.	30	1	6	3.97	.23	1.27
Cau1. Quant. Malfunc.	30	1	5	3.87	.18	1.01
Cau2. Likability	30	1	6	3.90	.23	1.27
Cau2. Safety	30	1	4	2.87	.20	1.07
Cau2. Usefulness	30	2	6	3.73	.22	1.20
Cau2. Trust	30	2	6	3.87	.21	1.14
Cau2. Malfunction rec.	30	2	6	4.17	.20	1.12
Cau2. Quant. Malfunc.	30	1	5	3.77	.16	.86

Table C.5.: Statistical values regarding subjective system acceptance in the uncertainty experiment

C.3.4. Situations

Situations Optimistic			
F=63.099, df=2, p=.000			
	Constr.	100kmh	Exit
Constr.		.000	.003
100kmh	.000		.000
Exit	.003	.000	
Situations Pessimistic			
F=15.044, df=2, p=.000			
	Constr.	100kmh	Exit
Constr.		.000	.003
100kmh	.000		.030
Exit	.003	.030	

Situations Cautious			
F=15.227, df=2, p=.000			
	Constr.	100kmh	Exit
Constr.		.012	.000
100kmh	.012		.020
Exit	.000	.020	
Situations Very Cautious			
F=11.303, df=2, p=.000			
	Constr.	100kmh	Exit
Constr.		.037	.000
100kmh	.037		.090
Exit	.000	.090	

Table C.6.: Results of repeated measures ANOVA and post-hoc analysis for the three situations in the uncertainty experiment

Descriptive values regarding the three situations

	N	Min.	Max.	Mean	Std. error	Std. Deviation
Construction Optimistic	30	1	4	2.2	.21	1.15
Construction Pessimistic	30	1	5	3.2	.19	1.03
Construction Cautious	30	1	5	4.0	.22	1.22
Construction Very Cautious	30	1	5	3.8	.23	1.24
100kmh Optimistic	30	1	4	4.1	.18	.98
100kmh Pessimistic	30	1	5	2.1	.21	1.14
100kmh Cautious	30	1	5	3.5	.21	1.14
100kmh Very Cautious	30	1	5	3.3	.19	1.03
Exit Optimistic	30	1	4	1.5	.18	.97
Exit Pessimistic	30	1	5	2.6	.21	1.14
Exit Cautious	30	1	5	3.0	.22	1.20
Exit Very Cautious	30	1	5	2.8	.21	1.18

Table C.7.: Statistical values regarding how helpful each variant was in each situation in the uncertainty experiment

C.3.5. Wish for Visualization

Descriptive values for the "Wish" item

	N	Min.	Max.	Mean	Std. error	Std. Deviation
Optimistic	30	1	3	1.43	.133	.728
Pessimistic	30	1	5	2.73	.185	1.015
Cautious	30	2	5	3.97	.169	.928
Very Cautious	30	1	3	3.17	.220	1.206

Table C.8.: Statistical values regarding the "Wish" item for an uncertainty visualization in the uncertainty visualization

Wish for an uncertainty visualization				
F=33.653, df=3, p=.000				
	Optimistic	Pessimistic	Cautious	Very Cautious
Optimistic		.000	.000	.000
Pessimistic	.000		.000	.196
Cautious	.000	.000		.001
Very Cautious	.000	.196	.001	

Table C.9.: Results of repeated measures ANOVA and post-hoc analysis regarding the "Wish" item in the uncertainty visualization

D. Contribution

My contribution in each Chapter.

A PhD thesis is hardly ever a work of a single person. In my case, a large part of the work was done in the context of the Car@TUM project "Intelligent Support for Prospective Action" (ISPA). Within this project, four PhD students (Dipl. Inf. Daria Popiv, Dipl. Ing. Folrian Laquai, Dipl. Psych. Kerstin Sommer and myself Dipl. Inf. Markus Duschl) and a supervisor from the BMW "Forschung & Technick GmbH" (Dipl. Ing. Mariana Just) were involved. This chapter gives an overview of how much these and other people were involved in this work.
In Chapter 4.3 the development of the BEV was presented. In this context, the idea for the visualization came from my predecessor in the ISPA project, Prof. Dr. Simon Nestler, who had the initial idea for the BEV concept. I was involved in the conception stage and complete responsible for the implementation of the visualization. I also was responsible for the specific design of the BEV (e.g. design and color of the ego vehicle, design of the other traffic)
The video experiment in Chapter 5 was a collaboration between Mr. Laquai and myself. The work, from the development of the questionnaire to the technical preparation, was equally shared between us. The videoplayer that was used in the experiment in order to visualize the situations and synchronize the simulation and visualization, was originally developed and implemented by myself for a project presentation. Mr. Laquai added additional functionality to it as well as he was responsible for the development of the touch screen interface and the custom HUD. The additional two mentioned visualizations (VLR and Navimap) were all conceptional developed and implemented by myself. Mrs. Sommer provided help during the development of the questionnaire and a student of Mr. Laquai conducted the experiment. The evaluation of the results was done by myself.
In Chaper 6, the experiment was a collaboration between the four PhD students in the ISPA project and one diploma student (Dipl. Ing. Christoph Rommerskirchen). Mr. Rommerskirchen was responsible for the creation of the driving simulator test course. The questionnaire was developed by Mrs. Sommer, the BEV and the connection between the visualization and the driving simulator was implemented by myself and Mrs. Popiv. The Iconic visualization was implemented by Mr. Laquai. Mr. Laquai, Mr. Rommerskirchen and myself shared the work of conducting the experiment. The evaluation of the subjective results was performed by myself. The objective results of the gaze tracker were evaluated by Mrs. Popiv.
In Chapter 8, the test course, the situations and the connection between the driving simulator and the visualization were developed and implemented by myself. The evaluation of the drive data was also done by myself with the use of the Matlab Software. The experiment itself was conducted by a student of mine (Dipl. Inf. Anton Pütz).
In Chapter 9.8, the concepts for visualizing uncertain information about the upcoming speed limit, were all developed and realized by myself.

Finally, in Chapter 10, the concepts with the question mark that were used in the evaluation were developed by myself in cooperation with the design studio “Kontrastmomente” [97]. For the user study, the instrument cluster as well as the test course previously existed; both components were changed, adapted and enhanced by myself in order to fit the needs. The questionnaire was developed by myself with the help of Mrs. Just (my supervisor) and Mrs. Sommer. The experiment was conducted by myself, as was the complete evaluation of the results.

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