TECHNISCHE UNIVERSITÄT MÜNCHEN

LEHRSTUHL FÜR ERGONOMIE

Enhancement of Driver Anticipation and Its Implications on Efficiency and Safety

Daria Popiv

Vollständiger Abdruck der von der Fakultät für Maschinenwesen der Technischen Universität München zur Erlangung des akademischen Grades eines

Doktors der Naturwissenschaften (Dr. rer. nat.)

genehmigten Dissertation.

Vorsitzender: Univ.-Prof. Dr.-Ing. Markus Lienkamp

Prüfer der Dissertation:

1. Univ.-Prof. Dr. phil. Klaus Bengler
2. Univ.-Prof. Gudrun J. Klinker Ph.D.
3. Univ.-Prof. Dr. rer.nat. Heiner Bubb (i.R.)

Die Dissertation wurde am 30.06.2011 bei der Technischen Universität München eingereicht und durch die Fakultät für Maschinenwesen am 20.12.2011 angenommen.

Посвещается моей семье

Kurzfassung

Die vorliegende Dissertation präsentiert die Ergebnisse von Forschungsstudien zu Fahrerassistenzsystemen mit visuellen und haptischen Interaktionsmodalitäten, welche die Antizipationsleistung des Fahrers verbessern und somit seine Fähigkeiten in Verzögerungssituationen hinsichtlich der Kriterien Effizienz (niedriger Kraftstoffverbrauch) und Fahrsicherheit erhöhen sollen. Die Unterstützung erfolgt dabei durch geeignete Informationspräsentation über anstehende Verzögerungssituationen und dem Vorschlag über durchzuführende Fahreraktionen. In diesen Situationen ist es das Ziel des Assistenzsystems, den Fahrer dazu zu bewegen die maximale Verzögerungsleistung der Motorbremse auszunutzen, anstelle die kinistetische Energie über die Fahrzeugbremse zu vernichten. Dem Fahrer wird hierzu durch das System der optimale Zeitpunkt zum Beginn der Ausrollphase angezeigt, das heißt, wann er den Fuß vom Gaspedal nehmen soll, um das Fahrzeug rein durch Ausnutzung des Schleppmoments und ohne Betätigen des Bremspedals auf das kommende niedrigere Geschwindigkeitsniveau zu verzögern. Wenn der Fahrer dem Systemvorschlag nicht sofort folgt, was dazu führt, dass die Geschwindigkeitsverringerung nur durch Ausrollen nicht erzielt werden kann, schlägt das System den richtigen Zeitpunkt für eine moderate Bremsverzögerung vor. Als Folge davon sollen starke Verzögerungen vermieden und durch eine Kombination von vorausgehenden Ausrollphasen und moderaten Bremsphasen ersetzt werden.

Es werden drei Experimente durchgeführt, um den Einfluss der vorgeschlagenen Assistenzsysteme auf das Fahrerverhalten zu untersuchen. Im ersten Experiment werden verschiedene optische Assistenzkonzepte evaluiert. Das innovative Bird's-Eye View Konzept wird subjektiv am besten beurteilt und führt durch seine Informationsbereitstellung über kommende Verzögerungssituationen und dem Vorschlag von Ausrollphasen zu einer geschätzter Kraftstoffverbrauchsreduktion von ca. 4%. Im zweiten Experiment werden mögliche Ungenauigkeiten der dargestellten Information berücksichtigt. Die Ergebnisse zeigen, dass die Fahrer durch teilweise fehlende Situationsinformationen nicht beeinflusst werden, solange die Informationen genügend Hinweise zum Verstehen der kommenden Situation beinhalten. Zudem ist keine Versuchsperson blind den Vorgaben des Systems gefolgt ohne die kommende Fahrsituation in Realität gesehen zu haben. Das dritte Experiment hat den zusätzlichen Nutzen von multimodaler Informationspräsentation gezeigt: haptisches Feedback mittels Kraftimpulsen am aktiven Gaspedal verringert die Reaktionszeit und führt zu einer geschätzter Kraftstoffverbrauchsreduktion von 7,5%.

Abstract

This dissertation presents the research performed on the anticipatory advanced driver assistance system with visual and haptic modalities of integrated human-machine interface, whose purpose is to enhance driver abilities in performing deceleration maneuvers in the most efficient (with reduced fuel consumption) and, which is applicable in potentially critical situations, safe manner. This is done by presenting information about upcoming deceleration situations and suggestions of recommended course of driving actions. The system's aim is to pursue the driver to extensively exploit the motor torque during deceleration phases instead of conventionally applying pressure on the brakes. The driver is advised by the system when the optimal coasting phase should be initiated, i.e. when to release the accelerator and let the vehicle slow down using engine braking to the upcoming lower speed without pressing the brake pedal. If the driver does not immediately follow the initial advice of the system and therefore is not able to solely coast the vehicle to the lower target speeds, moderate braking is suggested at the appropriate point in time. As an implication, the extreme decelerations are to be avoided in safety critical situations by assisted preceding coasting and moderate braking phases.

Three experiments are performed to validate the influence of proposed advanced driver assistance system on driver behavior. In the first experiment, different visual assistance concepts are investigated. Innovative Bird's-Eye View concept is subjectively evaluated as the most suitable human-machine interface for the system, which information about upcoming deceleration situations and proposition of coasting actions result in estimated 4% of fuel reduction throughout a drive. In the second experiment, possible inaccuracies of presented information are considered. Results show, that drivers are not affected by partially missing situational data, as long as the information presented gives important situational cues for the comprehension of the upcoming situation. Also, no one has blindly followed advices of the system without having observed the development of driving situation in reality. The third experiment proved additional benefit of multimodal human-machine interface: haptic feedback via impulse of an active gas pedal, also known as force-feedback pedal, decreases reaction times and results in 7.5% reduction of estimated fuel consumption.

Acknowledgements

Dear reader,

This work you are about to read became possible only because of support, help, and productive cooperation of people, who were there for me during four years of my research at Lehrstuhl für Ergonomie, Technische Universität München.

At first, I would like to express particular appreciation for the scientific guidance I received from my professors: Prof. Klaus Bengler, Prof. i. R. Heiner Bubb, and Prof. Gudrun Klinker. Without their advices neither the idea of anticipatory advanced driver assistance system, nor presented and investigated concepts of its implementation would become the dissertational substance.

The realization process of the scientific ideas and advices was professionally directed by Mariana Just, whom on the first place I would like to thank for successful cooperation of people involved in this interdisciplinary research. She was able to negotiate and distribute necessary obligations between me and my colleagues from other university chairs: Simon Nestler (Fachgebiet für Augmented Reality), Markus Duschl (Fachgebiet für Augmented Reality), Florian Laquai (Lehrstuhl für Mensch-Maschine Kommunikation), and Kerstin Sommer (Lehrstuhl für Angewandte Psychologie, Uni Regensburg).

For the immense support in the experimental part of the presented work, I'm especially thankful to Christoph Rommerskirchen, Michael Bunk, Lluis Puig, and Hermann Hajek. Due to their help, it was possible to implement, conduct, and analyze the experiments on the highest level within the needed timeframe.

For the introduction to driver assistance systems and their ergonomic aspects before I decided to do the dissertational work, I am thanking Christian Lange, Martin Wohlfarter, and Marcus Tönnis. They made it happen, that among other research topics and university chairs I ended up being at Lehrstuhl für Ergonomie doing this interdisciplinary research.

During the work at Lehrstuhl für Ergonomie, I experienced friendly and respectful atmosphere, and for that I am grateful to my former colleagues. Especially to my close friend and again my colleague at the new working place Marina Plavsic, who was and is always there to sincerely share my happiness and to calm me down when I am facing difficulties. For the moral support I am also grateful to Ursula Mayer, Can Sandikcioglu, Vitaliy Voltarnist, and Rubin Sousa.

However, neither fulfilling research nor fascinating people would have happened in my life if not for my family. In the faces of my mother, my father, and my sister I receive unconditional basis full of love, non-judgment, pride for me, and any possible support for everything, what I am doing. This allows me to dare the things, and with one of the successful I am gladly sharing now with you.

Abbreviations

ADAS	Advanced Driver Assistance System
ACC	Active Cruise Control
AGP (FFP)	Active Gas Pedal, same as Force Feedback Pedal
CC	Cruise Control
C2C (V2V)	Car-to-Car Communication, same as Vehicle-to-Vehicle Communication
HMI	Human-Machine Interface
HUD	Head-Up Display
LED	Light Emitting Diode
SA	Situation Awareness
SRK	Skills-Rules-Knowledge
TMC	Traffic Message Chanel
TTC	Time-to-Collision

Used Notation

m	meter
min	minute
ms	millisecond
s	second
Ø	mean value
sd	standard deviation

CONTENT

1 INTRODUCTION

This chapter introduces the motivational background behind the presented research, describes its general objectives, and gives the overview of the dissertation structure.

Motivation of the work, presented in this dissertation, consists of both emerging industrial and scientific challenges. Nowadays, automotive industry is placing the issue of efficient and non-pollutant driving as one of the highest priority. Among numerous technological improvements of the conventional engine, the role of driver and his/her behavior while driving is acknowledged to possess high potential in reducing fuel consumption and harmful pollutants, i.e. increased efficiency.

In this dissertation, the focus is put on the efficient performance of deceleration maneuvers. The author exemplifies the usage of advanced driver assistance systems for this purpose and introduces the concept of anticipatory advanced driver assistance system as one of the means to support the driver in efficient driving strategy.

The objectives of this work regard the development of anticipatory advanced driver assistance system facilitating the performance of deceleration maneuvers and evaluation of the system's influence on driver behavior with regard to efficiency, comfort, and safety. At the end of this chapter, the overview of the dissertation structure is provided. The short outline of each chapter is given, revealing the flow and connections within the presented work.

Along with mentioned aspects, important terms and issues used later in the dissertation are defined in this chapter:

- *anticipation, anticipation in the road traffic, anticipatory driving, enhanced driver anticipation, and why these entities are important when defining efficient driver behavior and developing the system to support it;*
- *what are the efficient deceleration strategies and what is their potential in fuel reduction on the example of coasting/freewheeling phases;*
- *generalized criteria of efficiency, comfort, and safety while driving, and how they can be supported by advanced driver assistance system;*
- *definition of advanced driver assistance system via primary/secondary/tertiary driving task, navigation/guidance/stabilization level of primary driving task;*
- *definition of anticipatory advanced driver assistance system, and its contribution to "conventional" advanced driver assistance systems;*
- *sources obtaining traffic information used by (anticipatory) advanced driver assistance systems and their accuracy: definition of impreciseness, (partially) missed detection, and ghost targets.*

1.1 MOTIVATION

1.1.1 Ecological sustainability in automotive industry

Driving efficiency, namely the amount of consumed fuel and emitted pollutants, is currently one of the most important areas of research and development for automotive manufacturers around the world. The recent demand on ecologically sustainable behavior introduced new goals and challenges. Legislative restrictions, increasing ecological awareness of the consumers, and high prices on the fossil fuel market lead to automotive innovations amounting to reduced fuel consumption and hazardous emissions. As an example, according to Euro 5 and Euro 6 exhaust standards *(internet entry Euroactiv)*, the permissible limits of pollutants emitted by a car in 2015 are considerably lower than the ones allowed before. Also a shift in consumer preferences concerning important car features has been observed in the past few years *(Wyman, 2007)*: the ecological sustainability of the automobile has been placed fifth after the reliability, safety, cost-performance ratio, and general maintenance expenses.

Along with implications caused by emissions on the environment and legitimate targets, the market prices of fossil fuels play an important role in the industry's decision to accentuate research and innovation dedicated to the reduction of fuel consumption. Global oil reserve-to-production ratios are limited and their deficit is already predicted by various researches *(internet entry Beyond Petroleum,* and *internet entry Energy Information Administration, Official Energy Statistics from U.S. Government, International Energy Outlook 2008)*.

Responding to the mentioned concerns, the manufacturers reacted by forcing technological improvements of the conventional engine. Among other enhancements available on the automotive market, the most widely known are: variable compression which allows saving up to 30% of fuel compared to the conventional petroleum motor, hybrid concept – up to 20%, direct injection – 20%, and downsizing of the motor combined with turbocharging technology – 13% *(Alt, 2006)*.

Also the research of alternative energy sources becomes of increasing significance *(internet entry Electromobility$^+$)*. Electric vehicles operating on battery power would ensure pollutant-free driving, and independency from the availability/prices of fossil fuels. According to *Hanselka & Jöckel (2010)*, the customer, however, is ready to accept these innovations only when the costs, performance, comfort, reliability, and crash safety of electrical vehicles are comparable to present automobiles operating on conventional sources of energy. This is the limitation, which cannot be solved in a short term. The distance range of currently investigated electro mobiles with batteries, complying with weight and size restrictions, is short: up to 200 km, when driving with an average speed of 33.6 km/h without usage of low-beam headlights, wipers, seat heating, and climate control *(Küssel, 2010)*. When using climate control, especially during the winter for the heating, the range drops drastically to 90 km. This short operational range of electric vehicles implies often recharge of the battery, which is also not yet convenient: it make take up to several hours for a complete recharge *(Gray, 2011)*. The long-term solution to this problem could be wireless charging, but the needed infrastructure should be built *(internet entry Wireless Charging)*. Also recuperation, i.e. kinetic energy recovery system, partially transferring the braking energy into battery charge is important with respect to mentioned concern. Another issue limiting the usage of electric vehicles is the high cost of a battery. *Haselka & Jöckel (2010)* point out, that before an average consumer is ready to buy it, the price of it should be reduced in 3 times. Adding to this is the fact, that battery life is quite short, i.e. it should be changed several times during the life time of a vehicle. Therefore, as a short and middle term solution for the problem of environmental control and energy efficiency, one cannot ignore the vehicles with engine operating on petroleum or diesel.

Not only improvements of car mechanics and used sources of energy can help to reduce fuel consumption and pollution of the environment. Improved traffic flow can lead to avoidance of jams and stagnation of the vehicles, implicating not only increased driver's contentment with the journey, but also significant pollutant reduction. In project *Ecomove (2010),* traffic management and control are defined among other measures applied for advancing ecological sustainability. Adaptive balancing and control of the infrastructure are seen as the main tasks within traffic management activities, namely balancing traffic demand and network capacity by distributing traffic over a road network and facilitating it locally with traffic light control. On the motorway the restriction on allowed speeds and headways are taken into account as regulative measures, together with allowance for lane-change maneuvers.

Table 1.1: Automotive programs and their means dedicated to the reduction of fuel consumption and pollutant emissions

Automotive programs	**Means for reduction of fuel consumption**
Volkswagen AG: BlueMotion Technologies	
Daimler AG: TrueBlueSolutions	Vehicle technology
BMW AG: EfficientDynamics	
AUDI AG: Efficiency Program	
Nissan Automobil AG: Green Program 2010	Traffic flow management and control
Volvo: DRIVe	
Mazda Motor Corporation: SKYTECH	
Honda: EcoAssist	
Fiat S.p.A.: Eco-Drive	
Integrated project *Ecomove (2010)* – Cooperative Mobility Services and Services for Energy Efficiency	Support of efficient driver behavior
…	

The driving style is also emphasized as an important factor influencing fuel consumption. According to various sources, driving in compliance with the efficiency requirements can save up to 20-25% of fuel *(internet entry EcoDrive,* and *internet entry ADAC)*. Among others, *Honda (internet entry Honda),* and Fiat S.p.A. (*internet entry Fiat),* actively incorporate the driver into the process of efficient behavior by installing in-vehicle user interfaces providing an interactive feedback on the driving action with regard to the fuel consumption optimization. Table 1.1 provides the overview of the currently running programs and technologies applied by the automotive manufacturers to reduce fuel consumption and emitted pollutants.

1.1.2 Efficient driver behavior

The support of efficient driver behavior is put in the focus of this work. By **efficient driver behavior** is meant driver behavior, in the result of which driver reaches wanted driving state while maneuvering with the least possible fuel consumed. There are several common rules and advices, exercising which ensures efficient fuel consumption. Before these rules are presented, following operational terms used in their definition should be explaned:

- *Dahmen-Zimmer & Gründl (2007)* refer to **anticipation** as thoughtful presumption of future states and events, and **anticipation in the road traffic** as the ability to correctly predict future traffic situations and behavior of other traffic participants based on the previous knowledge and current perception.

- **Anticipatory driving,** also called foresighted driving, is the outcome of driver behavior in accordance to his/her anticipation in the road traffic (this definition is also adopted from *Dahmen-Zimmer & Gründl, 2007).*

- **Coasting** (also called engine braking) is the process of decelerating with the engaged clutch, exploiting motor torque during deceleration phases (definition adopted from *Reichart et al., 1998*). In this case, driver completely releases accelerator and does not depress any other pedals.

- **Freewheeling** is the process of coasting with the engine geared neutral or engine declutched (definition adopted from *Reichart et al., 1998*). Again, the brake pedal is not depressed.

1.1.2.1 Rules and advices regarding efficient fuel consumption

The summary of the rules/advices regarding efficient fuel consumption presented below is adopted from the dissertation of *Dorrer (2000).*

Rule 1. Operation of the engine in favorable to the fuel consumption range in order to reach maximum power from consumed fuel (for detailed explanation, see topics on brake specific fuel consumption and efficiency map for a typical port fuel-injected gasoline engine in *Kutz, 2008*):

- driving with low engine rev, i.e. in applicable cases, depending on the speed and driving situation, usage of higher gears is recommended;
- promptly accelerating with timely change to the higher gears;

- avoiding full load and highest speeds.

Rule 2. Energy optimized driving profile:

- anticipatory driving facilitating avoidance of unnecessary acceleration;
- anticipatory driving facilitating avoidance of unnecessary application of brakes and conscious usage of coasting/freewheeling during deceleration phases, i.e. usage of kinetic energy through coasting;
- once reached, stable maintenance of the desired speed until the need of its change emerges;
- avoidance of standstill with running motor.

Rule 3. Avoidance of jams and short trips.

Rule 4. Good maintenance of the automobile:

- regular checks of engine, gear box, air-conditioning system, etc.;
- correct tire pressure.

Accompanying advices. It is further advised not to overload the vehicle; to avoid additional unnecessary drag forces, e.g. not to keep windows opened; to limit the usage of electrical devices operating on the in-vehicle battery, as well as during the winter not to warm up the motor before driving.

While some of the advices given here lay solely in the responsibility of the driver or greatly depend on the driving experience, another can be followed to the sufficient extend only with the help of driver assistance systems. Thus, accompanying advices and Rule 4 are left for drivers and legislative restrictions to regulate. Following Rule 3 can be accompanied by the usage of navigation systems and Traffic Message Chanel (TMC) information. Operation of motor in favorable to the fuel consumption range (Rule 1) in general depends on the experience of drivers and their intentions. It should be mentioned, that this task is overtaken by the vehicle’s engine when driving with automatic transition. For the cars with manual transition some of the automobile manufactures introduce the visual feedback about which gear would be preferable for the current state of the engine with respect to fuel consumption. However, one should not oversee that in some of the driving situations, e.g. while overtaking, it is preferable to use lower gear to reach higher accelerations required for a rapid performance of the maneuver.

Rule 2, which regards energy optimized driving profile, provides the biggest potential for an in-vehicle system assisting the driver. While avoidance of standstill situations with running motor is facilitated by Start Stop functionality (as example see *internet entry BMW EfficientDynamics*), or, in its absence, left to the driver’s own performance, information provided in a due time about upcoming driving situation can greatly influence fuel consumption. According to *Reichart et al. (1998)*, driving strategy especially in deceleration situations “represents the type of driving strategy with the greatest possible potential for saving energy”.

1.1.2.2 Decrease of estimated fuel consumption in deceleration situations

According to the mentioned work of *Reichart et al. (1998)*, between 15% and 20% of fuel can be saved throughout the journey, when coasting a vehicle for the distances up to 1500 m. In this case, the longest coasting distance would correspond to a distance needed to reduce the driven speed from 150 km/h almost to a standstill state. Between 5% and 10% of fuel can be cut via performance up to 500 m long coasting phases. The longest (500 m) coasting phase is approximately the needed distance in driving situations requiring reduction of the driven speed from 100 km/h to 60 km/h.

Up to 30% of fuel is reduced when freewheeling a vehicle in almost all of the possible deceleration situations, in which longest freewheeling phase can reach up to 1500 m. By stretching this process to its limits, up to 40% of fuel cutoff could be expected *(Bertram, 1996)*. However, one should take into account that the experienced decelerations during freewheeling are significantly milder than the ones reached during engine braking. The customer acceptance of the system which proposes/assists freewheeling phases is questioned due to the required long distances for a reduction of a speed.

After careful consideration of presented motivational background behind supporting efficient driver behavior, it was decided to concentrate available time and resources on developing an assistance system, which helps the driver in efficient performance of deceleration maneuvers with accent on prolongation of coasting phases. Nevertheless, depending on the deceleration situation, it might be reasonable to incorporate phases of freewheeling for higher efficiency benefit. This question, however, is not investigated and analyzed within the scope of this dissertation.

1.1.3 Anticipatory advanced driver assistance system

With what means one is able to influence driver behavior? In the area of the presented research, it is done via advanced driver assistance systems (ADAS). To understand the essence of ADAS, one should be accustomed with the operational term “primary task of driving” and its three-level division.

The hierarchy of driving tasks, according to *Bubb (1993)*, consists of primary, secondary, and tertiary tasks.

- **Primary tasks** – these are all tasks necessary for the driver to keep the vehicle on the road and to proceed according to the planned driving course. While driving, primary tasks have to be continuously fulfilled by the driver: steering and depressing accelerator/clutch/brakes, shifting the gears, choosing an appropriate maneuver, navigating. These mentioned tasks occur on navigation, guidance (also known as maneuvering) and stabilization levels. Three-level model of driving task is developed, described, and used in the works of *Bernotat (1970), Donges (1978),* and *Michon (1985*). The definition of the three levels of the primary driving task provided below is adopted from the work of *Bernotat (1970)*.

On **navigation level**, such activities as planning the trip, namely choosing the appropriate route and time scheduling of the journey occurs. On **guidance, or maneuvering level**, driver has to decide on the appropriate speed and lateral position of the vehicle with respect to the current traffic conditions, including legitimate regulations and behavior of other traffic participants. On the **stabilization level**, driver operates accelerator, brake, and, in the case of manual transition, clutch pedals, as well as he/she steers the wheel. These mentioned activities on the three levels are the necessary activities to keep the vehicle in the lane and negotiate through a road network.

- **Secondary tasks** – tasks, required in a specific situation (wiping, dimming headlights, blinking).

- **Tertiary tasks –** tasks, fulfillment of which does not contribute directly to the proceeding of the vehicle throughout its driving course, e.g. operating an air-condition device or changing a radio station.

According the definition given to ADAS in project *RESPONSE 3 (2007),* **Advanced Driver Assistance System** is a driver assistance system, which supports the driver on the guidance level of primary driving task. As a result, outcome actions of a driver are of higher safety, comfort, and, possibly, efficiency, when comparing to unassisted driving *(Freymann, 2003,* and *Deutschle, 2005)*.

Within this dissertation, by “efficiency”, “comfort”, and “safety” is meant following:

- **Efficiency** is dependent on the estimated fuel consumption. Efficiency gain due to the assistance corresponds to lower fuel consumption during an assisted drive when comparing it to an unassisted one.

- **Comfort** is characterized by moderate deceleration values experienced during a deceleration situation. According to *Heißing (2008)* and *Farid et al. (2006)*, the limit of the subjectively perceived comfortable deceleration is $-3m/s^2$.

- **Safety** is the avoidance of collisions and extreme decelerations exceeding $-7m/s^2$ *(Farid et al., 2006)*, which drivers usually exercise in dangerous situations in order to avoid emerging collision.

According to *Freymann (2003),* some of the most widespread ADAS installed in vehicles of different automotive manufacturers are Active Cruise Control (ACC) and ACC Stop and Go, Heading Control (HC), Intelligent Brake Assistant (IBA), Parking Assistant (PA), Lane Change Assistant (LCA), etc. To detect relevant to the assistance situations, these systems use on-board sensors such as radar and LIDAR (Light Detection And Ranging) sensors, video- and infrared cameras *(Wisselmann et al., 2006).* Maximum longitudinal distance, at which long range radar sensors are able to detect relevant driving situation, e.g. used in ACC and ACC Stop and Go systems, is approximately 250 m *(internet entry Bosch GmbH, Fernbereichsradarsensor)*. One can recalculate this metric distance to the time distance, which is left before the situation is reached: when driving 100 km/h (28 m/s), it is 9 s (250 m divided by 28 m/s). This time distance is the operational time horizon of ADAS. As depicted in Figure 1.1, according to *RESPONSE 3 (2007)* the typical operational **time horizon of ADAS is between 10 seconds and 1 second**.

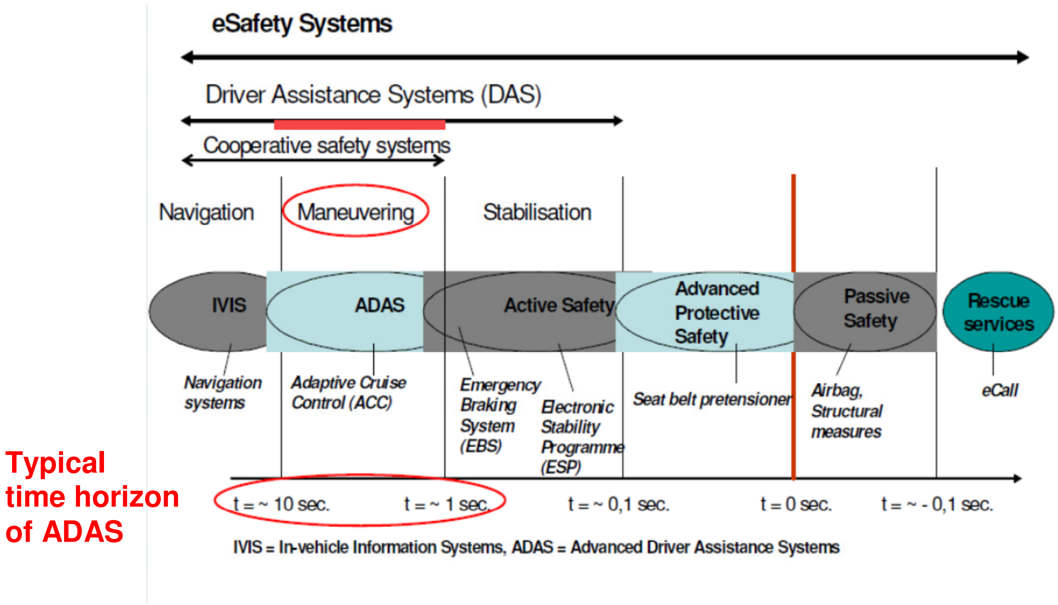


Figure 1.1: ADAS according to project RESPONSE 3 – development up to now (adopted from Schwarz, 2007)

This time horizon limits the functionality of ADAS to operating mainly in the current driving situation, without possibility to consider the immediately emerging one. Performance of complicated maneuvers, as well as further optimization of efficiency, comfort, and safety, requires more extensive prediction abilities of ADAS.

Emergency of new technologies in the sensor domain, such as vehicle-to-vehicle (V2V, or C2C from car-to-car) and vehicle-to-infrastructure (V2X, or C2X from car-to-infrastructure) communication *(Bogenberger et al., 2002,* and *Naab, 2004)* facilitates the implementation and development of so-called anticipatory ADAS, or foresighted ADAS (germ.: “vorausschauende”; *Kosch, 2004*, and *PReVAL, 2008)*. Figure 1.2 depicts new sources of traffic information, and **extended time horizon >10 s available for foresighted, or anticipatory, ADAS**. These assistances are mainly in the research phase now and not widely available on the market. Examples are intersection assistant *(Plavsic, 2010)* and traffic light assistant *(Thoma, 2008)*.

With this extended time horizon, anticipatory ADAS is enabled to provide information about an upcoming driving situation, which cannot be yet seen or precisely anticipated by the driver, but which emergence may require the driver to take the actions already at a present point in time in order to achieve possible benefits in safety, comfort, and efficiency. The main difference between anticipatory and conventional ADAS is that anticipation of the driver can be immensely enhanced. The driver receives the possibility to plan and perform his/her actions considering also the upcoming, possibly not yet visible, driving situation, and not only the one he/she sees.

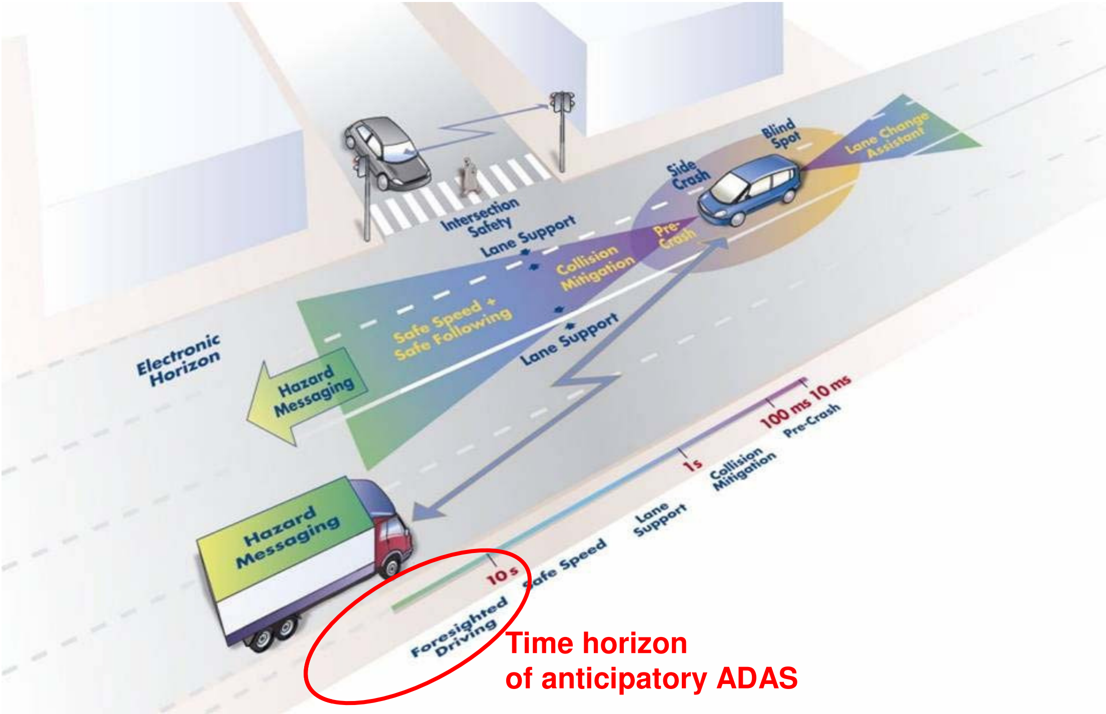


Figure 1.2: Anticipatory ADAS – development from now on (adopted from PReVENT, 2008)

The time course of driver's activities with and without anticipation-relevant assistance information is depicted in Figure 1.3 (adopted from *Nöcker et al., 2005*). As can be seen at Figure 1.3, information about the upcoming driving situation helps drivers to adopt their actions, initiates quicker decision making in comparison to unassisted driving, which results presumably in the choice and execution of more beneficial driving actions. Focus of anticipatory ADAS, introduced in this work, lays in helping the driver to condition and adapt actions according to upcoming deceleration situation to reach additional benefits in efficiency, comfort, and safety.

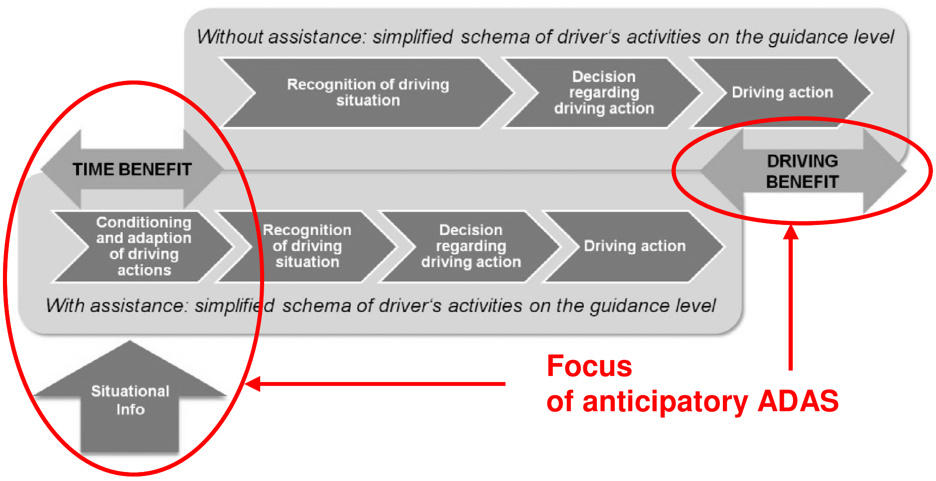


Figure 1.3: Time course of driver's activities with and without anticipation-relevant assistance information (adopted from Nöcker et al., 2005)

It is necessary, however, to consider in the development of anticipatory ADAS possible drawbacks of different information sources. Among others, works of *Wisselmann et al. (2006)*, *Laquai (2010)*, *Bengler (2010)* suggest, that the information about the driving situation acquired via available sensors is prone to certain inaccuracy, which necessarily should be taken into account during design and introduction phases of any driver assistance system. This inaccuracy greatly depends on the type of information source (e.g. radar or LIDAR sensors, infrared or video cameras, C2X). It is reflected by the source's update rate and delay in the received information, overall availability of the information (e.g. C2X and C2C are new technologies, and time is required until they are installed in all vehicles and infrastructure points), and on the technological physical limits (e.g. radar sensors cannot be used for the precise identification of the object's lateral position, video cameras – for longitudinal). The technique of data sensor fusion, i.e. usage of multiple sensors at the same time to benefit from their different advantages, can immensely increase the reliability of information about driving situation, but cannot completely eliminate the possibility of its inaccuracy *(ProFusion, 2006)*.

The types of information inaccuracy, relevant to the assisted driving situation, are defined in presented work as follows *(adopted from Ahrholdt, 2006)*:

- **Impreciseness** regards any numerical information about assisted driving situation, which does not completely correspond to the reality. It can be wrongly identified distances to the objects, their lateral locations, speed etc.
- **Missed detection** is the absence of any information about relevant objects, i.e. they are not detected. In the content of this work, the term **partially missed detection** is introduced. In this case, only some of the relevant objects from the group of them are not detected.
- **Ghost targets** are objects, which are recognized by the system, but do not exist in reality.

1.1.4 Application of innovative approach in the development of anticipatory advanced driver assistance system

How to design an anticipatory ADAS, which suites previously mentioned criteria of increasing efficiency, comfort, and safety in driving deceleration situations, considers possible drawbacks of information sources, and is highly appealing and valuable to the driver? The main contribution of this dissertation lays in the presentation and validation of the human-machine interface (HMI) of an anticipatory ADAS, operating on all three levels of Situation Awareness (SA) concept and Skills-Rule-Knowledge (SRK) behavioral theory (SA is developed in numerous works of Mika Endsley, SRK – by Jens Rasmussen). Detailed explanation of these two theories and their direct implications on HMI is provided in the next Chapter 2 “Development of HMI for Anticipatory ADAS”. Here only the general outline of how these processes are involved into the decision-making and performance of driving actions is provided, and expected influence of anticipatory ADAS upon them is presented.

1.1.4.1 Performance loop of primary driving task

The performance loop of primary driving task by the driver is presented by Figure 1.4. It is derived based on the works of *Donges (2009), Endsley (1995a), Rassmussen (1983),* and *Bernotat (1970).*

In the traffic environment, driver is operating a vehicle throughout the road network, residing at any given moment on a particular street with its traffic rules surrounded by other traffic participants. This process is identified as driving. In order to complete successfully the driving process, driver has goals to fulfill, which are defined in the terms of primary driving tasks.

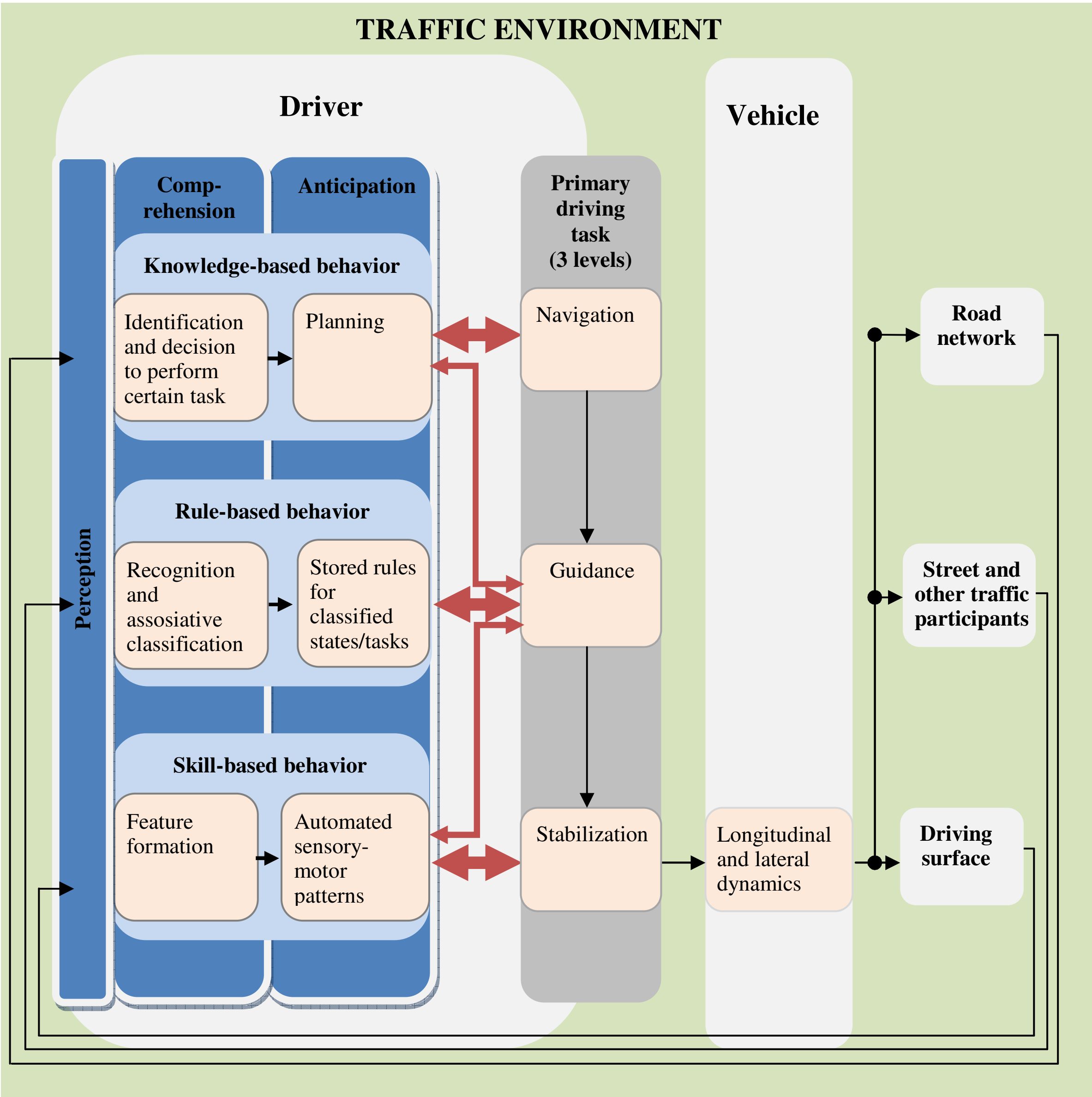


Figure 1.4: Performance of primary driving task – interrelation between driver, vehicle, and traffic environment with emphasis on driver's information processing and decision making mechanisms preceding driver actions

Before driver decides to undertake any action on the stabilization level of driving task, as the result of which the vehicle will change its longitudinal and possibly lateral positions, the driver has to identify his/her current tasks on guidance, and navigation levels. That is where the information processing and conscious decision making mechanisms of the driver start to be of importance. In this work, two theories related to information processing and decision making are paid a particular attention: Situational Awareness (SA) and Skills-Rules-Knowledge (SRK).

Lateral control over vehicle dynamics resembles in a lane position. Driver's primary instrument for controlling vehicle's lateral dynamics is a steering wheel. Loss of lateral control, or its incorrectness, may result in side (pre) crashes with other traffic participants and unintentional departure from the driven lane. Longitudinal control is executed when changing a speed via accelerator and brake pedal. Driver has to perform longitudinal and lateral control simultaneously, e.g. when choosing inappropriate speed, steering action might lead to unwanted lane departure. Mistakes in longitudinal control might lead to mistakes in lateral control, and vice versa. However, when appropriate, ADAS is classified as longitudinal, when it helps the driver to support the correct speed and distance to the preceding traffic participants *(internet entry Safe Sped and Safe Following)*, and as lateral, when assisting in keeping the lane and avoiding side (pre) crashes *(internet entry Lateral Support)*. Here the detailed explanation of lateral and longitudinal control is provided, because the focus of ADAS introduced in this work is the support of longitudinal control and resulting longitudinal dynamics of a vehicle (later emphasized in Figure 1.5).

Back to Figure 1.4, before steering or depressing accelerator or brake pedals (stabilization level), the driver has to decide on the maneuver, that he/she is willing to perform (guidance level). The maneuver can be dictated by the behavior of other traffic participants, obedience to the traffic rules present at driven segment of the road, or necessity to follow the planned route (later is the performance of driving task on navigation level).

SA defines three steps, which occur before the decision about particular action is taken. At first, the driver perceives the elements of the surrounding environment (Perception level). Afterwards the meaning of these elements in regard to driving task is established (Comprehension level). At the last level, Projection, or Anticipation, of different scenarios resulting from the possible applicable actions is made. As the result, the decision is made and the driving action is undertaken on stabilization level satisfying targeted goals on guidance and navigation levels of driving task.

SRK theory brings the stages of comprehension and anticipation into relation to the behavior, which is expected to be observed depending on perceived information. Perceived information which does not require extended comprehension or anticipation, e.g. the driver's feeling of friction between the wheels and surface of the road, results in almost immediate automated actions on stabilization level to keep the vehicle on the road. Such behavior is called skill-based. Presence of other traffic participants and traffic rules, however, requires more deep processes of comprehension and anticipation. In this case, the applicable rules and similar driving experiences start to play an important role, based on which driver decides for the change of speed and/or lateral position suitable for chosen maneuver (rule-based behavior). The most demanding in terms of comprehension and anticipation is knowledge-based type of behavior. On this level, driver has first to consciously identify the task and appropriate behavior, which cannot be directly deduced from previous experiences. On the knowledge-based level, before an action takes place the process of planning on how to perform identified task is required. For example, performance of the driving task on navigation level is a knowledge-based behavior.

Even though the commonly observed behavior on the stabilization level has the skill-based origin, on guidance – rule-based, and on navigation – knowledge-based, it is necessary to mention that in some situations the behavioral background on certain level of primary driving task can be that of a “less common” origin. On the guidance level of primary driving task, knowledge-based behavior starts to play role when planning an unforeseen or not routinely performed maneuver, e.g. turning on the unfamiliar intersection. Skill-based behavior is observed in performance of a maneuver, in which an expert driver unconsciously releases gas pedal once the braking lights of a vehicle in front are lit.

Other factors (not depicted in Figure 1.4), which influence information perception, processing, and decision in any situation, are driver’s practice and general state of health, his/her current emotional state, motivation, risk attitude, etc. These factors are not considered in detail within the scope of this dissertation. The focus is put on the enhancement of driver anticipation via influencing information processing mechanisms conceptualized in SA and SRK.

1.1.4.2 Place of anticipatory ADAS in the performance loop of primary driving task

Anticipatory ADAS is added in the introduced loop of interaction between driver, vehicle, and traffic environment as Figure 1.5 depicts. Anticipatory ADAS receives the information about the driven street and other traffic participants (information, most relevant to the guidance level of primary driving task), and presents it to the driver in order to enhance his/her anticipation. Figure 1.5 shows, that change in anticipation is a result of changed processes of perception and/or comprehension. The change of driver anticipation due to anticipatory ADAS influences the diving task on guidance level, e.g. driver might decide on a different maneuver when driving with ADAS. It is necessary to mention, that unlike conventional ADAS considering support of only rule- and skill-based behavior (see examples of such ADAS in Chapter 2.4.2 “Overview of HMI concepts in related research”), anticipatory ADAS considers all three types of behavior, which might occur on the guidance level. Planning on knowledge-based level must be supported by anticipatory ADAS. The author of this work claims that this is what constitutes anticipatory ADAS, and later investigates and validates this statement.

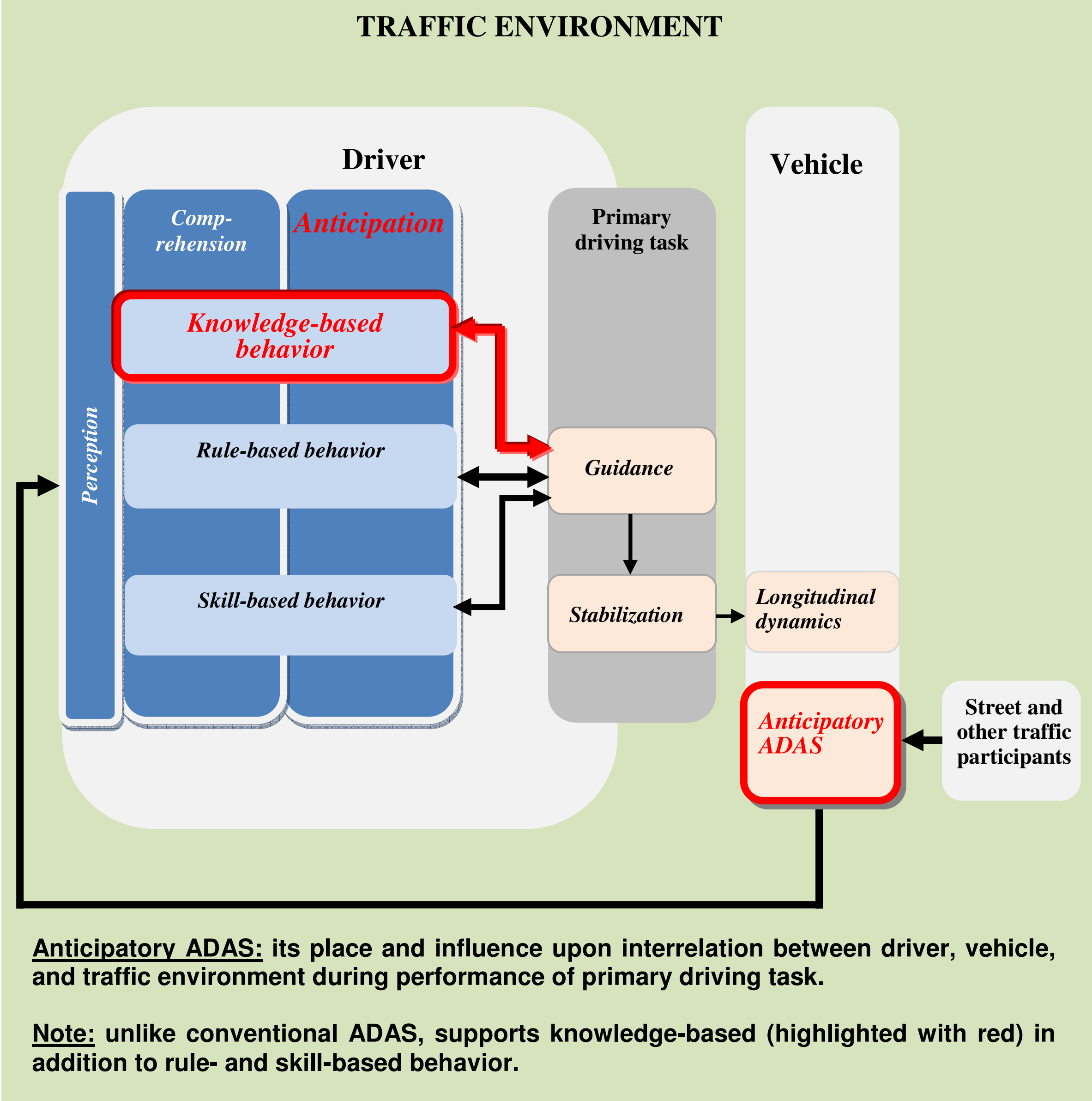


Figure 1.5: Anticipatory ADAS – its influence on interrelation between driver, vehicle, and traffic environment

Definitions of enhanced anticipation and anticipatory ADAS used throughout the scope of this work are following:

– **Anticipatory ADAS** is ADAS, which influences primary task of driving on guidance level by supporting the driver in his/her activities of planning (knowledge-based behavior), in activation of applicable rules and associated states/tasks (rule-based behavior), as well as possible sensory-motor patterns (skill-based behavior). New sources of information, via which it is possible to identify situations residing >10 s from the current time point, and, using this information, to influence planning of the driver, facilitate the functionality of anticipatory ADAS. High level goal of anticipatory ADAS is to increase efficiency, comfort, and safety.

– **Driver anticipation is enhanced** via anticipatory ADAS, if the action and resulting maneuver of the driver in particular situation leads to increased efficiency, comfort, and safety, when comparing to the maneuvering in the same situation without any assistance.

1.2 OBJECTIVES OF THE WORK

The summarized objectives of this work – goal/means/result – are presented in Figure 1.6.

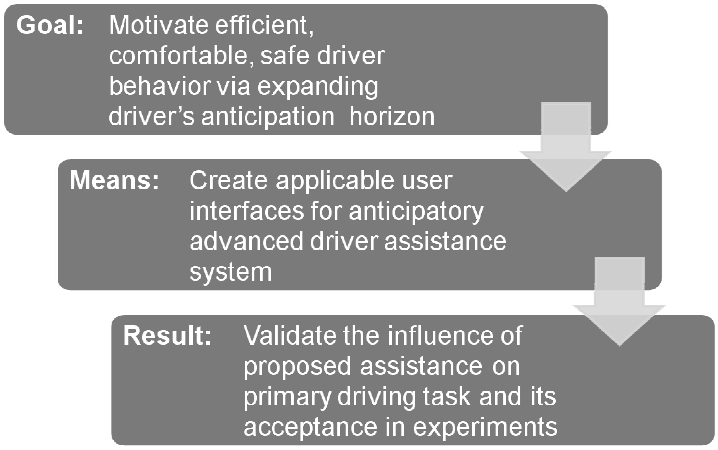


Figure 1.6: Objectives of the work

The main objective of this dissertation is to assist the driver in efficient, comfortable, and safe behavior by expanding the anticipation in deceleration situations, i.e. informing the driver about upcoming relevant driving situational details, and assisting in the appropriate action at the particular point in time via anticipatory ADAS. This is realized by developing and investigating anticipatory ADAS. The system's aim is to pursue the driver to extensively exploit the motor torque during deceleration phases instead of conventionally applying pressure on the brakes. The driver is advised by the system when the optimal coasting phase should be initiated, i.e. when to release the accelerator and to let the vehicle slow down using engine braking to the upcoming lower speed without pressing the brake pedal. If the driver does not immediately follow the initial advice of the system and therefore is not able to just coast the vehicle to lower target speeds, moderate braking is suggested at the appropriate point in time. In this case, possible sharp decelerations can be avoided.

After the aims of anticipatory ADAS are defined, the development of it considers creation of applicable human-machine interface and its validation. There are several main questions, which are answered by the results of three experiments performed within the presented investigation. They regard the benefits due to the usage of developed anticipatory ADAS. The results are based on the comparison of the performance of primary driving task with and without the proposed anticipatory ADAS:

– What is the subjective user acceptance of anticipatory ADAS with different HMIs?

– To what extent does the proposed assistance influence efficiency, comfort, and safety? In which deceleration situations is the most significant benefit?

- Do possible inaccuracies in the presented information about the upcoming situation lead to critical driving behavior, i.e. accidents? Does it influence the overall acceptance of the system advices?
- Does the visual concept of assistance cause potentially critical visual behavior?

1.3 OUTLINE OF THE THESIS

Below Table 1.2 presents the short description of each chapter's content. It also reveals the logical structure of the thesis, and connection between the chapters.

Table 1.2: Outline of the thesis

Chapter 1. INTRODUCTION
• Motivation behind the presented research: challenge of ecological sustainability and efficiency in the automotive industry, description of driving behavior minimizing fuel consumption, and scientific approach to assist it with the help of anticipatory ADAS. • Objectives of the dissertational work.
Chapter 2. DEVELOPMENT OF HMI FOR ANTICIPATORY ADAS
• Scientific background and derivation of general guidelines regarding human-machine interface (HMI) for anticipatory ADAS. • Application of derived guidelines and knowledge from related research in the development of HMI for anticipatory ADAS.
Chapter 3. EVALUATING ANTICIPATORY ADAS
• General aims of evaluation • Description of chosen driving situations and evaluation environment, in which anticipatory ADAS is investigated. • Description of chosen tools and methods to investigate introduced anticipatory ADAS. • Presentation of objective measurements regarding efficiency, comfort, safety, and visual behavior.
Chapter 4. FIRST EXPERIMENT: VISUAL HMI FOR ANTICIPATORY ADAS.
• Presentation of the purpose of the experiment, exact experimental design, description of test subject group. • Results regarding acceptance and influence on primary driving task of different visual HMIs for anticipatory ADAS.
Chapter 5. SECOND EXPERIMENT: INACCURACIES IN ANTICIPATORY ADAS INFORMATION

- Presentation of the purpose of the experiment, exact experimental design, description of test subject group.
- Results regarding acceptance and influence on primary driving task of visual HMI for anticipatory ADAS with consideration of possible inaccuracies in traffic information.

Chapter 6. THIRD EXPERIMENT: MULTIMODAL HMI FOR ANTICIPATORY ADAS

- Presentation of the purpose of the experiment, exact experimental design, description of test subject group.
- Results regarding acceptance and influence on primary driving task of multimodal HMI (visual and haptic modalities) for anticipatory ADAS.

Chapter 7. DISCUSSION AND CONCLUSION

2 DEVELOPMENT OF HMI FOR ANITIPATORY ADAS

Anticipation is part of the situation awareness (Endsley, 1995a), which is one of the information-processing models adapted in the automotive research. According to Sträter (2009), the added value of situation awareness concept lays in explicit proactive involvement of the human, namely in the theory's account on human ability to anticipate future states.

Organization of available information and its correct presentation according to the situation awareness demands can provide users with the deeper knowledge about the operational environment, and improve their anticipation and actions with respect to the set goals. Consideration of cognitive processes within situation awareness can vastly contribute to the process of HMI design of anticipatory ADAS.

The beginning of this chapter describes main processes related to and which constitute situation awareness of the operator. Afterwards the performance model of Skills-Rules-Knowledge Behavior is presented (Rasmussen, 1983), which is coupled with situation awareness stages and reveals the cognitive activities within each of them. Based on this background, the design principles for HMI supporting situation awareness and anticipation are given. After the derivation of general principles, the review of HMIs in related research is given, followed by concrete examples of HMI presented and evaluated within the scope of this dissertational work.

In this chapter, description of following concepts is provided:

- *situation awareness and its stages of perception, comprehension, and projection, respectively anticipation (Endsley, 1995a);*
- *basis of situation awareness: mental model, schema, active goals, top-down and bottom-up driven processes;*
- *information processing mechanisms of Skills-Rules-Knowledge Behavior model (Rasmussen, 1983);*
- *general design principles of HMI supporting SA and anticipation with account to presented theories;*
- *implementation of their timely constraints: time of anticipatory ADAS activation;*
- *implementation of their constraints regarding information content and form of presentation: Bird's-Eye-View visual HMI and Active Gas Pedal haptic HMI for anticipatory ADAS;*
- *"conventional" HMI not considering SA and SRK: Iconic visual HMI.*

2.1 ANTICIPATION WITHIN SITUATION AWARENESS CONCEPT

The term “Situation Awareness” is originated in the aviation industry. Nowadays, the concept of Situation Awareness (SA) is widely used in human factors science. There are numerous definitions of SA, among them definition from *Sarter & Woods (1991)*, who define SA as “accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of recurrent situation assessments”. *Dominguez (1994)* defines SA as "the continuous extraction of environmental information along with integration of this information with previous knowledge to form a coherent mental picture, and the end use of that mental picture in directing further perception and anticipating future need". The aim of SA according to *Moray (2005)* is to “keep the operator tightly coupled to the dynamics of the environment”. SA is part of cognitive process, which precedes the decision-making and resulting actions of the operator, according to the SA model presented in the work of *Endsley (1995a)*.

According to *Metz et al. (2008)*, the most commonly used SA definition is presented in the work of *Endsley (1988)*. She states that **SA is defined through "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"**, and identifies three levels, of which SA consists:

Level 1 - Perception. On this level, the perception of the elements of current situation occurs, which provides the insight to their status, attributes, and dynamics. On the guidance level of the driving task, these are the optical cues, which enable to keep the lane *(Gibson 1973, Donges 1975, Chatziastros 1999)*, the distances to other traffic participants and obstacles, their speeds and directions of the movement, traffic regulation signs.

Level 2 – Comprehension. After the separate elements of the environment are perceived, the comprehension process takes place. On this level, operators synthesize the perceived elements, and prioritize their importance and influence on the state, which they are striving to achieve, i.e. according to their active goal. While performing a driving maneuver, drivers identify the traffic participants, which are currently of the importance to its successful performance, consider the possible influence of the road conditions, etc.

Level 3 – Projection. This is the highest level of SA, on which the anticipation of following events takes place. This level precedes decision making, and allows choosing the most favorable course of actions to meet the operator’s current objective. At this state, drivers predict the movement of previously identified as relevant traffic participants, and incorporate the picture of their own possible actions accordingly to the anticipated timely development of the current situation.

As the result, SA “is knowing, what is going on around you”, or, expressed in scientific terms, SA is “operator’s internal model of the state of the environment” *(Endsley, 1995a)*.

In the complex environments, the amount of surrounding information to be perceived is vast, and under influence of dynamic nature there is limited available time before the decision and action have to be taken. Adding to this is the fact, that the working memory has limited capacity: the limit is 7±2 chunks that can be stored simultaneously, described in the work of *Miller (1956),* which under dynamic conditions can be even less, according to *Rassl (2004*). For the operator it is crucial to concentrate on the information, which is important and relevant to the correct action in the upcoming situation. Operator should not be distracted by information, which is irrelevant in regard to his/her activities and endangers the perception of cues of the highest priority.

Therefore, to be able to function within the time constraints in dynamic environments and overcome the limitations of working memory, the operator should direct attention to the relevant elements. Which elements can be of importance in particular situation, their form, function, and their interrelation are stored in mental models of the operator. *Johson-Laired (1993)* defines **mental models** as representations of past experiences used in a predictive way.

Mental model is generic: it is the representation of features and contextual events and states that enable the user to mentally try out actions before executing them. While driving, for instance, these could be the driving rules and their previous execution when crossing an intersection, overtaking, or passing through the construction site.

Mental model is considered to be a basis on which SA is formed. For a specific consolidation of actual elements of the surrounding, the operator uses the “filled” mental model with concrete pieces. This situation-dependent adaption of the mental model is called “schema”. *Barlett (1932)* state, that **schema** is an instance of mental model for a specific system. Mental models and their instances in form of schema not only influence the perception (i.e. to which elements the attention is directed), but also enhance comprehension, and provide mechanism for anticipation. For the dependencies and correlations between the upper mentioned components related to the process of SA, as well as its place in the system driver-vehicle in the traffic environment adopted from *Bubb (1993a-b)*, see Figure 2.1.

In Figure 2.1, the driving task is the reference input in the traffic environment, which the driver has to fulfill according to the pursued goals. Driving task involves current driving situation, i.e. necessity to turn, stop because of the traffic light, decrease/increase speed because of road curvature and road conditions, traffic regulations or presence and movement of traffic participants, etc. After the driver perceives the elements relevant to the driving task, comprehension and projection occur. Under the influence of resulting SA, the decision evolves about which actions to undertake, and they are realized using the steering wheel, accelerator, brake pedals, and, in the case of the vehicle with manual transition, clutch and gearshift box. The vehicle and its movement gives the feedback to the driver about the outcome of performed actions through its changed position in the traffic environment, displayed speed, engine sound, kinesthetic feeling of experienced longitudinal and lateral acceleration. At the same time the movement and changed position of the vehicle influences the driving task, which is to be fulfilled by the driver. This is called driver-vehicle system, which describes the course of events on the guidance level of driving task, and in which driver's SA is important in making a decision about resulting actions.

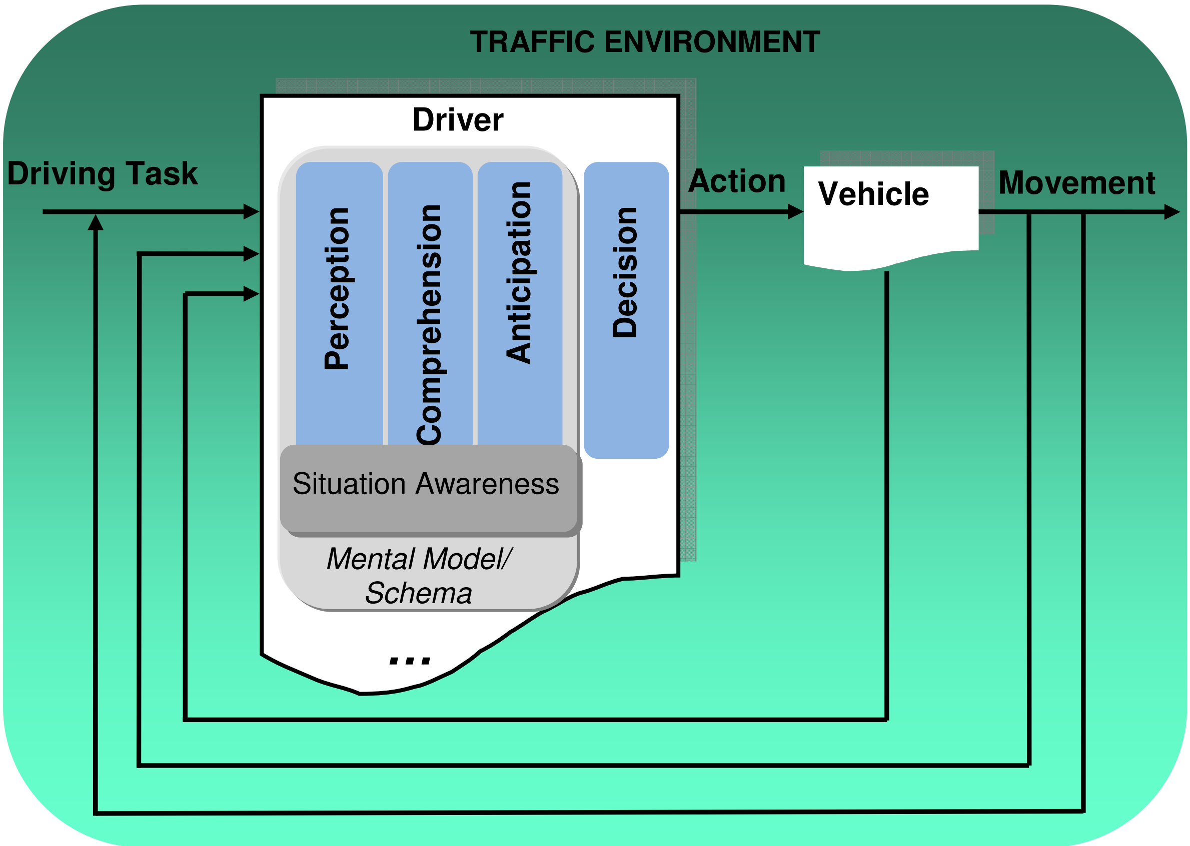


Figure 2.1: Driver-vehicle system and Situation Awareness concept (adopted from Bubb, 1993a-b)

What influences the formation of SA in this process, namely according to what one mental model is preferred over another in a particular situation? Here active goals, which are direct product of current driving tasks, of the operator play an important role. According to *Casson (1983),* they influence SA and are influenced by SA through goal-driven (also concept-driven or top-down), and data-driven (also bottom-up) processes.

In **goal-driven or top-down process** *(Goldstein, 2008)***,** the goal is explicitly formulated and effect of the actions is tested against it. Active goals can pre-shape attention while perceiving and awake basic structures of SA supporting comprehension and projection (anticipation), namely applicable mental models. For instance, the necessity to make a turn in order to reach the destination directs attention of the driver mainly onto relevant traffic participants.

However, the performance in the complex dynamic environments in majority of the cases depends not only on pursuing the explicit goals, but also on concurring to the accompanying demands of the operating environment. While performing a planned maneuver, the driver simultaneously has to keep the lane, safe distance to the lead vehicles, etc. This process, when the perceived environmental cues implicitly pose goals and tasks to reach them, is called **bottom-up, or data-driven** *(Goldstein, 2008)*. Data-driven process takes place under the circumstances, when the explicit statement of goal is not necessary, but rather the conditions of operating environment demand the activation of particular objectives.

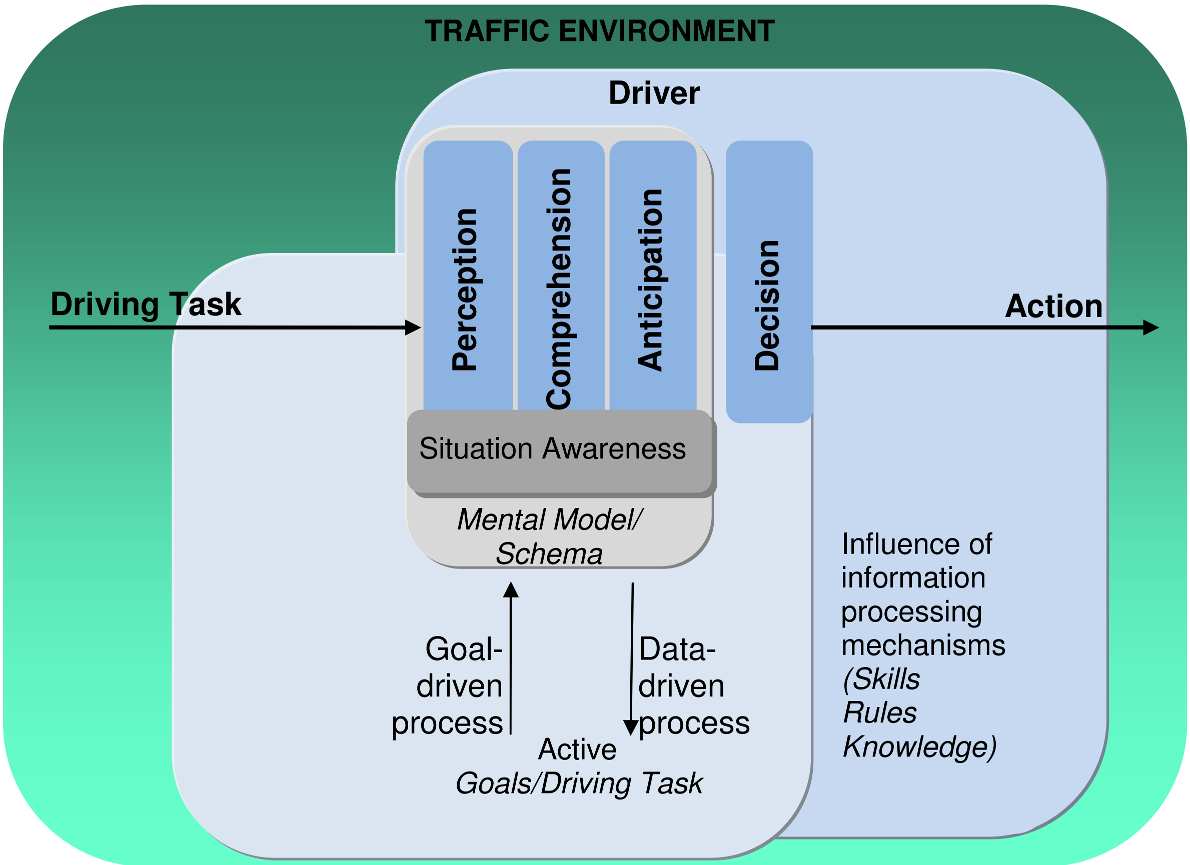


Figure 2.2: Influence of active goals and information processing mechanisms on SA, decision, and action of the driver (closer look at processes and components of driver SA from Figure 2.1)

The dynamic switch between goal- and data-driven processes is essential in the formation of correct SA enabling productive decisions and optimal actions. While driving, only the completion of both processes ensures safe and comfortable transportation from the departure to the destination point. According to *Taylor et al. (1996)*, the goal-driven processes are usually based on the knowledge of the operator, while data-driven – on skills and learned or empirically established rules. Figure 2.2 depicts the interrelation between active goals, information processing mechanisms, SA, decisions and actions.

In this work, the information processing mechanisms and resulting behavior are described using model of Skills-Rules-Knowledge Behavior developed by *Rasmussen (1983)*, which is one of the widely used driver information processing models according to *Bubb (1993b)*.

2.2 SKILLS-RULES-KNOWLEDGE BEHAVIOR

Rasmussen (1983) introduced the Skills-Rules-Knowledge (SRK) as the behavioral concept for the description of information processing mechanisms and following action performance. SRK provides the inside into the involvement of the human with the cognitive processes, which precede the execution of an action, and describes the attributes of the outcome actions, namely their degree of automaticity and the effort needed before the execution decision is made.

The cognitive processes, which have the skill-based background, lead to smooth, automated, and highly integrated patterns of behavior without high cognitive workload of the operator. In terms of time, the delay between perception and action for a skill-based behavior is the shortest. Keeping the lane and safe distance to the lead vehicles can in the majority of cases be considered as a skill-based driver behavior.

The skill-based behavior is being triggered by so-called signals perceived in the form, which couples perception with action and makes comprehension/anticipation as automated steps. The signals can be therefore directly interpreted in terms of action. Normally, when keeping the lane, the deviation between optimal imaginary trajectory and the actual position is tracked, and the steering eliminates the difference. Also, when reduction of the chosen distance to the lead vehicle is detected, the experienced driver automatically releases the accelerator and applies brakes without conscious reasoning. However, this same action can be rule-based for a novice driver.

The rule-based behavior is generally based on explicit know-how, which is either learned or derived during previous typical occasions. The rules followed by the actions can be reported. The most common description of the rule-based behavior is clausal: if A is observed, than B should be applied. However, with increased training and repetition of the same task, the rule-based actions can become skill-based.

The rule-based behavior poses higher cognitive workload when compared to the skill-based. The so-called signs trigger the rule-based behavior. According to *Rasmussen (1983)*, “Signs indicate a state in the environment with reference to certain conventions or acts. Signs are related to certain features in the environment and the connected conditions for action. Signs cannot be processed directly; they serve to activate stored patterns of behavior.” While driving, traffic lights and regulation signs most often awake rule-based behavior.

The most demanding in terms of workload are the knowledge-based processes. They usually demand the undivided attention of the operator: during unfamiliar situations, faced with an environment for which no explicit know-how and rules of control are available from previous encounters, the performance becomes dominantly goal-controlled and knowledge-based. Knowledge-based behavior is triggered by processing of symbols. Symbols represent the work domain in the form of an abstraction hierarchy to serve as an externalized mental model that supports knowledge-based problem solving. They consist of additional information, variables, relations, and properties that can be formally processed. To further explain the difference between signs and symbols, one might use the definition of *Cassirer (1944)*, in which the signs are the "physical world of being" and symbols are "part of the human world of meaning".

It should be noted, however, that even though skill-, rule-, and knowledge-based patterns lead to a different cognitive workload and differ in response time to the environment demands, they cannot be viewed as pure alternatives. Among others, *Klein (1989)* and *Kirlik (1989)* showed in their experiments, that operators prefer complying their actions according to their skills and learned/acquired rules, and, if the key information from the environment is not available to select the uniquely appropriate action, the knowledge-based procedure is activated. In order to avoid mistakes, maximize the benefit of performance, to correctly anticipate the future development of the situation, it is important that during the performance of a task operators rely on all three levels, interaction between which is shown in Figure 2.3. Interaction within SRK performance model is adopted from *Rasmussen (1983)*.

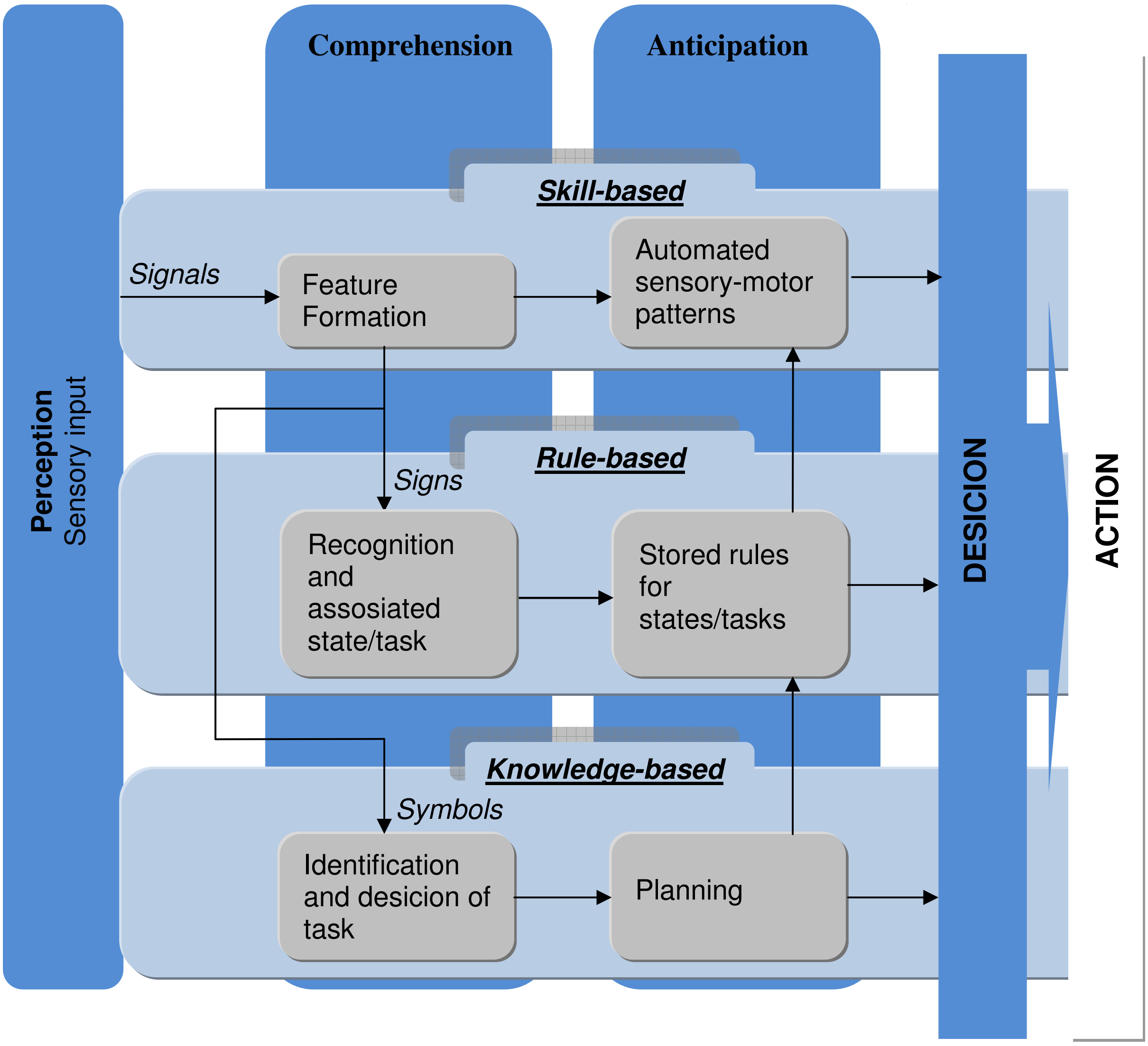


Figure 2.3: Interaction between SRK levels and their information processing mechanisms during human performance (adapted from Rasmussen, 1983)

Figure 2.3 shows, that the skill-based behavior goes along with conscious attempts of rule- or/and knowledge-based levels. The performers are acting on the skill level automatically (automated sensory-motor patterns). Signs, which evolve on the basis of the signals during a feature formation process, support the rule-based cognitive processes (recognition and definition of associated states/tasks and consequent awakening of the applicable stored rules). On the knowledge level, the identification and decision about a particular task bringing the system into the desired state takes place, followed by the plan of its execution. The planning process, nevertheless, influences also the set of chosen rules, which the operator applies while striving for the desired state. In their turn, the sub-set of activated rules can result in the skill-based automated motor patterns.

As example of interaction between SRK levels (Figure 2.3), reasoning and activities of the driver while approaching a speed limit sign are discussed. In this situation, once the driver becomes aware about upcoming speed limitation (either perceives from the environment or, if available, via assistance information), the rule-based level of behavioral control starts: recognition of this particular traffic regulation is performed and associated state (decreased driven speed) is defined. The procedural rules, which ensure achievement of associated state, would be to decrease the speed either via application of brakes, or coasting. If to assume, that the difference between driven and goal speed is high, and the distance before reaching speed limit sign is relatively small, the driver most probably would depress the brake pedal, and control the applied pressure on the skill-based level by observing the decrease of a speed and left distance. However, if the distance to the sign is long enough and immediate application of brakes is not necessary, the driver might get involved into the activities on the knowledge-based level. In order to choose satisfactory deceleration strategy, the driver should identify and decide upon the task: is he/she willing to coast a vehicle, or is it better to apply brakes? Are there any traffic participants, which might be disturbed by prolonged coasting phase? Afterwards the planning process takes place: when should the coasting phase begin? How long it will approximately last? Will the coasting distance suffice to decrease the speed, or when and where approximately application of brakes might become necessary? After the planning process is completed, the driver executes the chosen action and monitors its development: on the rule-based level he/she observes the decrease of the driven speed, and if the left distance is small and the speed should decrease more rapidly, driver decides to apply additional pressure on brakes. Again, pressure on the brake pedal is controlled on the skill-based level. This is the example, how all three levels of SRK might interact during a performance of a maneuver. The knowledge-based level provides the key possibility to anticipation, namely consists of planning process, which allows the driver to foresee several possibilities of maneuver performance, and to choose the most satisfactory one. On the rule-based level, driver applies causation dependencies: anticipation is here “semi-automated” and is the result of known rules and past experiences. In a feed forward manner, skill-level automated sensory-motor patterns are actuated.

In this work, the SRK processing mechanisms are ordered with the stages of SA. It is assumed that within the comprehension the feature formation is done, recognition and associated task/state is established, as well as identification of the needed task is performed. Anticipation involves planning, is supported by activated rules for accomplishment of the associated states and identified tasks. Anticipation also includes automated sensory-motor patterns, which are obtained either naturally, or via multiple repetition of certain activity.

In this work, the principles when designing HMI to support anticipation are based on introduced models of driver information processing mechanisms, SA and SRK.

2.3 GENERAL HMI GUIDELINES FOR ANTICIPATORY ADAS

There are four main questions to be answered during the process of any human-centered assistance development. *Schmidtke (1993)* brings into the focus assistance information content, form of its presentation, and place of its presentation. With regard to SA and SRK, also temporal aspects of assistance presentation have to be taken into account *(Endsley, 1995a)*.

- Information content: which information should be presented?
- Form of presentation: how this information should be communicated?
- Place of presentation: where this information should be presented?
- Time of presentation: when information should be presented?

In this subchapter, the general guidelines about information content, form and time of presentation are provided. These HMI guidelines consider presented SA and SRK mechanisms. In the following subchapters the concrete examples of their implementation are provided.

2.3.1 Information content and form

In the following, the guidelines regarding specifically information content and form of the assistance dedicated for the enhancement of the situational awareness, in particular anticipation, are provided. These suggestions are adopted from the work of *Endsley et al. (2003)* concerning designing principles of SA-enhancing interfaces.

Present comprehension- and projection-oriented information: direct presentation of higher-level SA needs (comprehension and projection) is recommended, rather than supplying only low-level data that operators must integrate and interpret manually. This relieves working memory from the additional load of incorporating disjoined information before comprehension and projection can be done. Instead of simply possessing the obvious facts from the environment, e.g. “the traffic light is red” or “you are on the secondary road”, the information content should present the additional value such as “you have to stop before passing the intersection”, or “start decelerating to let the vehicles on the main road pass". This can be viewed as the form of the projection to the future status based on the current conditions, which can increase the operator's benefits.

Present information in goal-oriented manner: goal-oriented information displays should be provided, organized so that the information needed for a particular goal is co-located and directly answers the major decisions associated with the goal. This facilitates the quick and optimal dynamic change between goal-driven and data-driven strategies. The system has to present the state and its projected implication located close to each other, so that the operator can perceive both pieces of information simultaneously.

Present information in a continuous manner: support for global SA is critical, providing an overview of the situation across the operator's goals at all times (with detailed information for goals of current interest) and enabling efficient and timely goal switching and projection. The system's state and detected situations of interest or their temporal absence should be at all times clearly understandable by the user from the presented information. However, the continuous awareness should avoid annoyance factor *(Norman, 2002)*.

Present important cues saliently: critical cues related to key features of schemata need to be determined and made salient in the interface design. In particular, those cues that indicate the presence of prototypical situations will be of prime importance and will facilitate goal switching in critical conditions. This is especially helpful for quick mobilization of appropriate mental models and schemata.

Do not present extraneous information: extraneous information not related to SA needs should be removed (while carefully ensuring that such information is not needed for broader SA needs). This is useful to further reduce the load on the working memory, and accentuate the attention of the operator on the relevant information.

Provide support for parallel processing: support for parallel processing, such as multi-modal displays, should be provided in data rich environments. According to *Hoffmann et al. (2009)*, following sensory channels are the most important for the automotive HMI presentation: visual, auditory, and haptic (including the tactic and kinesthetic-vestibular sub-channels). They have different information-rate capacity and perception time delay *(Johanssen et al., 1994,* and *Schmidt, 2000)*. Their combination can lead to faster and better SA formation, decision making, and resulting action.

The hierarchy of cognitive processing complexity, and how one should consider it in the useful interfaces, is the main point of the ecological interface design. According to *Vicente & Rasmussen (1992)*, the goal of this interface design is "to design interfaces that do not force cognitive control to a higher level than the demands of the task require, but that also provide the support for all three levels *(i.e. skill-, rule-, and knowledge-based cognitive processes)*." Therefore, while facilitating the lower levels of control, skill- and rule-based, the interface should present the information, which is needed by the knowledge-based process. In this way, operators are able to sufficiently control the process, and, when needed, to identify the error of the system's proposed action. However, one should always prove that operators do not rely solely on interface lower levels, i.e. following blindly the action, without considering information of higher cognitive levels.

Facilitate the most beneficial action: to provide the support to the skill-based behavior, one can use the signals. The signals should be connected with the action, and should be easily processed by the operator. In the automotive HMI domain, the signals can be represented by the change of color, audio ton, haptic feedback.

Facilitate the mobilization of stored rules: to support the rule-based behavior, it is advised to provide a consistent one-to-one mapping between work domain constraints and the cues or signs provided by the interface. Signs of the interface awakening the rule-based mental models and corresponding schemata should not be thought anew, they can be presented in the form of natural signs of the working environment.

Facilitate planning: reveal the problem space to serve as an externalized mental model that will support knowledge-based problem solving and planning. According to *Norman (2002)*, the interface should be based on the good conceptual model, exploit natural mappings, provide rich and necessary complex signs and symbols, which support interface's predictability. Compatibility to the natural perception of the operator, i.e. what can be implicitly understood without additional explanation, is essential in the presentation of signals, signs, and symbols.

2.3.2 Temporal aspects

Time, "both the perception of time and the temporal dynamics associated with events" *(Endsley, 1995a)*, is of great importance within the process of SA formation. There are following advices concerning these timing aspects in the presentation of assistance information derived in the work of *Cook et al. (2007)*.

Reaction time: before a particular action is undertaken by the operator, time is needed to perceive and comprehend the information, to anticipate the outcome of possible actions, and to make a decision regarding an appropriate action in current circumstances.

Temporal restriction: if the reaction time on certain events is a constraint in the current context, the design requiring high human efforts for its interpretation should be avoided. This is another way to justify the presentation of comprehension- and projection-oriented information.

Time to act and move: activities and movements require time in the dynamic environments. This fact must be considered and modeled.

Temporal perception: design must improve and support the understanding of temporal relations between actions in the environment.

Instant action capability: design should provide the user with the variety of applicable actions in the current situation.

Future action improvement: if and how the preconditions for the future actions may be reached.

2.3.3 Summary

Presentation of SA-enhancing information is a presentation of comprehension-/projection-oriented information, continuously available and organized in the goal-oriented manner, including salient cues and excluding extraneous data, supported by the means for parallel processing (multi-modal form of presentation is advised). It should communicate the applicable actions in current circumstances, guide towards the most beneficial action when needed, and reveal the temporal relations in the environment with respect to the actions of the operator. It should ensure the availability of time for the operator to perform a certain action, and should comply with the hierarchy of cognitive processing complexity, i.e. with increased complexity the available time before the decision and action is taken should also increase. The interface should possess signals, which allow the operator to link them directly to an action, provide signs in natural one-to-one mapping to the signs of the working domain, as well as overview of the conceptual model of the operating environment.

2.4 IMPLEMENTED HMI CONCEPTS FOR ANTICIPATORY ADAS

The rules, which are derived with respect to SA and SRK needs, are put in the focus of the HMI development for anticipatory ADAS in this work. Detailed description of activation time of the anticipatory ADAS complying with described temporal aspects is provided below. Also the overview and analysis of different HMI used in related research is done. Afterwards, accounting on established drawbacks and advantages, explanation of novel visual Bird's-Eye View HMI, and Iconic HMI are given. Bird's-Eye View concept complies with provided guidelines, and Iconic, as the alternative, does not and is similar to convenient visual HMI used in previous research. The implications of these concepts on driver acceptance and behavior are investigated in the experiments described in Chapters 4 and 5.

Explanation of haptic HMI realized via Active Gas Pedal (AGP) is provided. Multimodal HMI concept of anticipatory ADAS, consisting of AGP feedback and visual information about upcoming situation, is also tested, and the results of its influence on driver acceptance and behavior are presented in the Chapter 6.

2.4.1 Activation time of anticipatory ADAS

From the mentioned timing aspects in the Chapter 2.3 "General HMI Guidelines for Anticipatory ADAS", two are directly related to the activation time point: reaction time and time, needed to act and move (the rest of the advices are considered in the form of interface design , see Chapter 2.4.3 “Visual Bird’s-Eye View concept of anticipatory ADAS”).

Timely constraints regarding reaction times of the driver are dependent on human ability to perceive and comprehend available information about upcoming situation, to anticipate and make a decision before the action is undertaken. From the work of *Bergmeier (2009),* it is known that the mean time, which elapses after the visual warning is presented and before the driver notices it, depends on place and form of the warning and varies between 0.64 s (warning in the head-up display, HUD) and 1.27 s (warning in central information display, CID). In the same work, 1.03 s is taken for a time, needed to comprehend the provided information, anticipate future states and decide on the following action. Based on these facts, **2 s are chosen as the reaction time** of the driver between the information is displayed and action should take place: 1 s for the information to be seen after it is displayed (average between 0.64 s and 1.27 s, the place of presentation is chosen to be digital instrument cluster, therefore not as directly in the field of driver’s view as HUD, and not as far away as CID), and 1 s to comprehend, anticipate, and decide upon the action.

The second aspect considered for the time point of assistance activation is the time needed to act and move. In the case of presented anticipatory ADAS, which provides information about upcoming deceleration situation and supports efficient deceleration strategy, this is the time budget, which driver should have in order to perform a coasting phase to reach a required speed at a particular point of the course *(Popiv et al., 2009)*. In the development of presented anticipatory HMI, two cases of activation are considered.

In the case, when the deceleration situation is recognized by the system before the coasting phase from the driven to the upcoming lower target speed should begin (Figure 2.4, time point of system’s recognition of the relevant situation is $T_{situation\ detected}$), ADAS HMI provides the driver with the information about preferable start of coasting with account on the reaction time (2 s), $T_{start\ coasting}$. Following the advice of the system, the driver is optimizing efficiency criterion of his/her driving strategy.

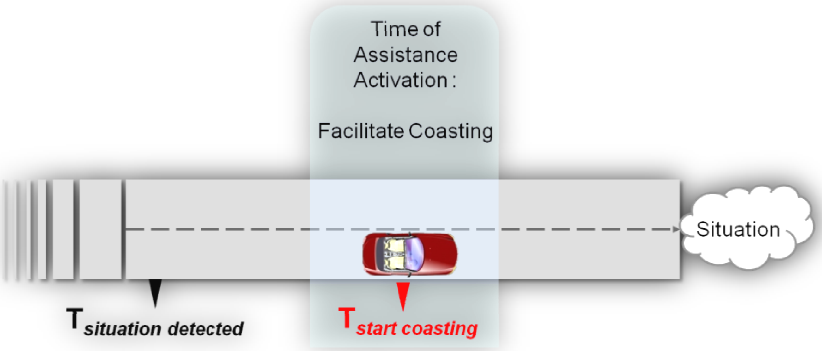


Figure 2.4: Efficiency consideration – time of assistance activation in the case of early recognition of the deceleration situation

In the second case, when the deceleration situation is recognized after the coasting phase should begin (Figure 2.5, $T_{situation\ detected}$ is after $T_{start\ coasting}$), the assistance immediately proposes to start moderate deceleration at the point in time $T_{situation\ detected}$. In this way, mainly comfort and safety criteria are addressed.

This later active state of the system can also occur in the case, when the driver does not react on the initial advice of the system to coast a vehicle, and in the evolved driving situation it is no longer possible to reduce the driven speed in a due time via pure coasting.

Again, it is important to mention, that presented in this work ADAS is anticipatory with extended horizon of situation detection. This implies that no cases are considered, in which deceleration situation is first recognized within the operational time horizon of collision avoidance/mitigation systems. All of the investigated deceleration situations are recognized and assistance is provided well before the system should directly assist the driver in collision avoidance maneuvers (>5 s according to *van der Horst, 1990a and 2007*).

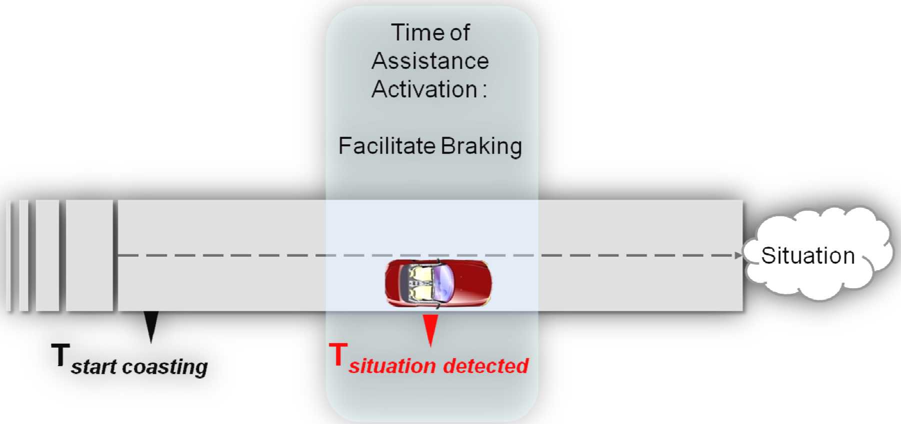


Figure 2.5: Comfort and safety consideration – time of assistance activation in the case, when the available time to the deceleration situation does not suffice to reduce the driven speed to the lower target speed via coasting

Durations and lengths of coasting phases, considered in the following investigation, can be found in Appendix A.

2.4.2 Overview of HMI concepts in related research

Before presenting HMI concepts for the anticipatory ADAS supporting deceleration phases developed within this work, overview and analysis of HMI for similar purposes used in previous studies is performed. Based on this information, HMI deficiencies and advantages used in former research are identified, and are considered in later presented novel concepts.

Overview and analysis of HMI in previous research consider following issues:

- HMI modalities and their place/form of presentation,
- compliance with HMI guidelines for anticipatory ADAS,
- driver acceptance of HMI,
- influence on efficiency.

HMI modalities used in the related experiments consist of visual information and haptic feedback presented to the driver. According to *Bubb (2001)*, the visual information provides the driver with understanding why some particular driving action is being advised, and haptic feedback ensures the quick appropriate action with regard to what should be done.

While form of visual information and the place of its representation differ depending on the research, haptic feedback is always provided with the help of Active Gas Pedal (AGP), also called accelerator Force Feedback Pedal (FFP). AGP is the accelerator pedal, which provides the force feedback on the foot of the driver. The feedback can be either continuous, or intermittent.

2.4.2.1 HMI with continuous AGP feedback

In the continuous case, according to the research of *Lange (2008)* and *Dorrer (2000)*, AGP feedback assists the driver in

- steadily keeping the wanted speed if no obstacles are recognized,
- reducing the driven speed and keeping the safety distance if e.g. the slower moving vehicle ahead is detected,
- and, in the case of efficiency optimized driving strategy, in performing coasting phases when approaching a relevant situation, e.g. lower speed limit zone.

This assistance is realized through the moderate resistance of the accelerator under the foot of the driver, which is felt when its optimum position according to the current driving situation is reached. At any point in time the driver is actively in the control loop over the primary task of driving (see more on the possible out-of-control loop problem in *Endsley et al., 1995b*), meaning the system is not overtaking explicitly any part of driving task. The driver can rest the foot against the resistance point to accept the advice of the system and follow when it is changing, or, with little additional force, overrun it and accelerate stronger in order to reach higher speeds. In this case, AGP is supporting anticipation of the driver via enhancing his/her skill-based behavior on the stabilization level. The resulting possible change of the driver behavior on the guidance level is triggered in the bottom-up manner.

In the dissertation of *Dorrer (2000)* the field experiment regarding acceptance and influence upon driver behavior of continuous AGP feedback is performed in real traffic conditions. HMI of the system enhancing the driving strategy consists in addition to AGP of LED indictors in the instrument cluster. Visual HMI overtakes the support of the rule-based behavior. Visual indicators in the instrument panel are showing the state of the system (on/off), allowed speed, upcoming speed, and the recognized slower lead vehicle when applicable.

16 test subjects with mean age of 33 years participated in the experiment. The test route is 37 km long, mainly located on rural roads, with 35 relevant deceleration situations, a vast majority of which are the imposed speed limit signs. The number of slower lead vehicles varies throughout the drives. The results show average reduction of estimated fuel consumption by 5.7% when driving with assistance. Individual gain when using the assistance varies greatly: maximal benefit in efficiency reached by some of the test subjects is 13%. However, the haptic feedback of the AGP is not accepted by two of the test subjects. The number of other participants (exact number is not provided) complains about the feeling of being slowed down by the system. The explanation provided by the conductor of the experiment concludes, that either it is due to the dominating character of AGP, or that some of the coasting phases required by the system are subjectively perceived as excessively long. It should be mentioned, that no temporal information about the development of the situation is provided to the driver. It can also be the reason, why the drivers perceive the advices of the system as too early to be followed in some of the deceleration situations.

The fixed-base simulator experiment of *Lange (2008)* also shows the potential reduction of fuel consumption when assisting the driver with continuous AGP feedback and visual information displayed in the head-up display (HUD). As in the previously described experiment, visual HMI takes into account only rule-based signs. Visual HMI information consists of the digital presentation of currently driven speed, traffic sign with currently allowed speed, which is changing to the upcoming lower speed sign framed in grey circle when the coasting phase should start.

The length of simulated driving course located on the rural road is 15 km, on which approximately 10 relevant deceleration situations occur, including slower lead vehicles and speed limitations. 29 test subjects took part in the experiment. 10.9% of the fuel is saved on average. This increased number compared to Dorrer's research can be explained by the absence in Lange's experiment of any urban road situations and low density of traffic. This allows the participants to follow all of the system's advices precisely.

In addition, experiment drives with only visual HMI are performed. During these drives no reduction in fuel is established. Again, no temporal aspects of the situation are explained to the driver, leaving without any support his/her planning activities. In this experiment, drivers ignore the advices of the system supporting only rule-based behavior and rely on their own anticipation and knowledge about the driving situation.

2.4.2.2 HMI with intermittent AGP feedback

In the case of intermittent assistance via AGP, the driver does not have the “always present” resistance point on the accelerator. Instead, driver feels the impulse of the gas pedal when the activation of the assistance takes place. This impulse can be provided in different forms: either vibration, or nonrecurring resistance. The researchers have the ability to adjust according to the needs of the system the duration and repetition of these impulses. Again, the AGP functionality enhances skill-based behavior. However, its influence on guidance level depending on the system’s purpose can be direct, and not forced from the stabilization level like in the case of continuous feedback. The intermittent AGP functionality has been tested for

- signalization to the driver on the stabilization level, when the change of the gear would be preferable *(Lange et al., 2010)* with regard to fuel consumption optimization,
- proposed as the warning on the guidance level when approaching a potentially critical situation which requires deceleration *(van der Horst et al., 1990b)*,
- and as identification to take the foot off the pedal to start the coasting phase on the guidance level in the deceleration situation *(Samper et al., 2001)*.

The later research is of the interest to the presented work. The experiment of *Samper et al. (2001)*, performed on the test grounds in Papenburg, Germany, with different modalities of HMI shows the following results: 6.8% of fuel is reduced with purely visual assistance, and 10.8% - with combination of intermittent AGP vibrations and visual information. There are two visual assistance concepts; each is displayed in the middle of instrument cluster. The first concept aims to support skill-based behavior and shows currently driven speed and upcoming lower speed when the coasting phase should begin. The second concept operates also on the rule-based level of behavior: represents in addition the reason of the deceleration phase, i.e. speed limit or slower lead vehicle. Both of these concepts are combined with vibrating impulse of AGP, which is signalizing the beginning of the coasting, and compared to the purely visual assistance based on the first concept and unassisted drives. Vibrating impulse of AGP is considered to aim at the guidance level of driving task, influencing in top-down manner the stabilization level.

28 test subjects took part in the experiment. Visual concept supporting higher levels of driver behavior is preferred to the simpler one. However, the most preferable is the multimodal concept. Multimodal HMI with additional information regarding deceleration reasons is evaluated as the most understandable, helpful, and self-explanatory.

During the drives assisted with multimodal HMI, the drivers are reacting considerably faster (within 0.7 s) compared to 2.5 s reaction times on visual information. This difference is subsequently reflected in the fuel reduction. However, similar to the results of *Dorrer (2000)* experiment, drivers are complaining about too long coasting phases. As the conclusion, the authors pointed out the necessity of further experiments to identify the balance between potential fuel reduction, duration and length of the coasting phases, as well as its user acceptance. Again, the absence of any information about temporal development of the situation is possible reason for the received feedback.

2.4.2.3 Summary and implications on HMI for anticipatory ADAS developed in this work

In the previous research regarding ADAS, which influences efficiency via supporting coasting phases in deceleration situations, two HMI modalities are considered: visual and haptic. Visual HMI concepts influence rule- and skill-based behavior on the guidance level of primary driving task. Anticipation of the knowledge-based behavior, namely planning, is not considered. Haptic modality realized via AGP supports skill-based behavior, which occurs either on the guidance, or on the stabilization level of primary task (intermittent vs. continuous feedback). It is depicted in Figure 2.6.

Even though in majority of the presented studies drivers follow the advices of the investigated systems and are able to reduce estimated fuel consumption depending on experiment conditions and driven course on average 5.7-10.9%, the acceptance of the system is limited. The author of this work argues that this is due to ignorance of the temporal aspects in HMI, which hinders the planning of the operator on the knowledge-based behavior.

According to *Benson (1997)*, "planning occurs in time, is ordered by time, and is experienced over time. (…) Temporal knowledge includes an understanding of the sequence, duration, frequency, and location of the events and actions". The deployment of situational awareness theory into the development of driver assistance system's HMI provides new possibility for the presentation of anticipation-relevant information. Thus, the crucial timing issues of the dynamically changing complex environments can be included. This is the focus of the assistance system developed and investigated within the scope of this work (for the comparison to Figure 2.6 see Figure 1.5 "Anticipatory ADAS – its influence on interrelation between driver, vehicle, and traffic environment"). Providing the driver with sufficient intelligent explanation about the upcoming situation including the timing aspects of its development has a strong potential in increasing the appeal, comprehension, and acceptance of an anticipatory ADAS.

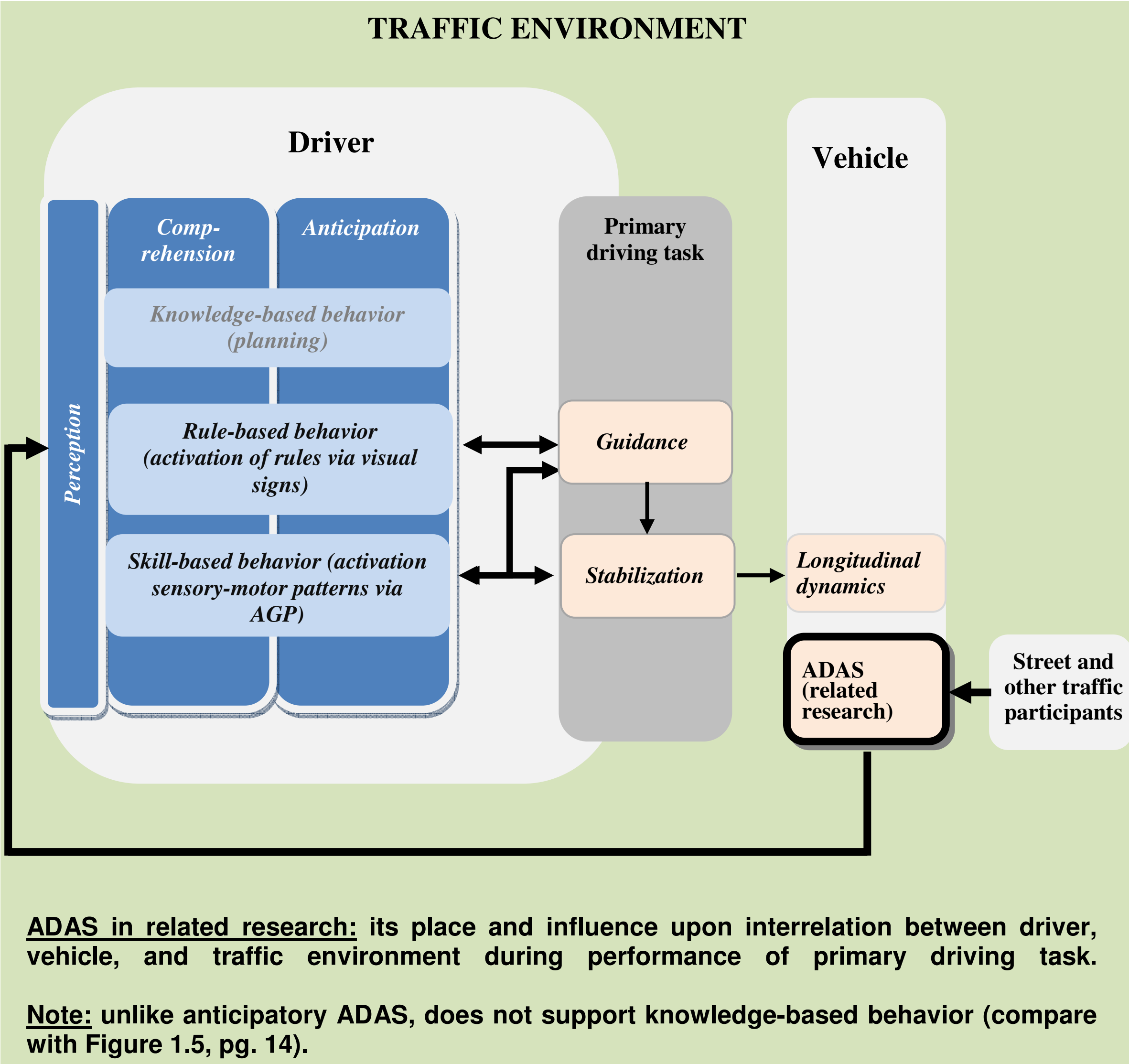


Figure 2.6: Related research – influence of ADAS on interrelation between driver, vehicle, and traffic environment

2.4.3 Visual Bird's Eye View HMI concept of anticipatory ADAS

The original idea of Bird's-Eye View concept is described in the work of *Nestler et al. (2009)*. As the name of the concept implies, HMI depicts from the point of bird's-eye view the virtual road, driven vehicle, and the deceleration situation when it emerges with its relevant participants, i.e. lead vehicles, and legitimate traffic signs.

This HMI possesses continuous characteristics: the presentation of the vehicle on the occupied lane is permanently displayed in the instrument cluster in the area between speedometer and tachometer (Figure 2.8). The deceleration situation is superimposed on the virtual road at the point of assistance activation, e.g. in Figure 2.7 the construction site and oncoming traffic are depicted, in Figure 2.9 – the traffic light with the stopped lead vehicle. The virtual road also schematically demonstrates the curvature (Figure 2.9), in order to further improve driver's comprehensibility and anticipation in the cases when the deceleration situation occurs in or behind the upcoming curve.

Figure 2.7: Example of Bird's-Eye View visual concept of anticipation-enhancing ADAS HMI in deceleration situations

Figure 2.8: Bird's-Eye View visual concept – no relevant situation detected

Figure 2.9: Bird's-Eye View visual concept – schematic depiction of road curvature

The legitimate traffic sign is also shown at the side of the virtual road to enhance the comprehensibility of the emerging situation. The information about the most beneficial action appears at the point of time of assistance activation: the green color of the vehicle suggests coasting in order to decrease speed (Figure 2.10). If pure coasting is not sufficient to reach the required lower speed, the color of driven vehicle becomes orange suggesting brake actuation (Figure 2.10). It is left to the driver to decide with which strength to brake. Overall, the idea of the concept is to enable the driver to understand the future driving situation, the most beneficial action at the particular point of time, and provide the feeling of the remaining time budget before the situation is reached.

Figure 2.10: Bird's-Eye View visual concept – action suggestion via change of color

The possible enhancements to the presentation of suggested action could be haptic feedback (described in the following subchapter "Haptic HMI of anticipatory ADAS"). As a visual alternative, one can consider the concept of *Thoma et al. (2008)*. Based on this concept, it is reasonable to display the difference between driven and optimal speed at a particular point of time via colored region in the speedometer. It would be left to the driver to minimize it either via coasting, or, if this difference region is rapidly increasing, via braking. Some of the other alternative concepts are also discussed in *Laquai et al. (2010)*.

In the Bird's-Eye View concept, general HMI guidelines for anticipatory ADAS are implemented. In Table 2.1 the explanation is given, of how each principle is considered within the presented design.

Table 2.1: Bird's-Eye View concept – implementation of anticipation-enhancing HMI principles

Principle	**Implementation**
Provide comprehension- and projection-oriented information	Emergence of the situation, upcoming lower goal speed, time and distance left until the situation is reached – these are the elements, which are considered to be relevant to comprehension and anticipation.
Organize information in goal-oriented manner	Everything is presented at the instrument cluster; driver does not have to search for parts of information to get the entire picture of the upcoming situation, and sees the causes and proposed actions simultaneously.
Display information in a continuous manner	This is realized via presence of the virtual road even when no relevant situation is detected. This allows the driver to have overview of the state of the system and its detected situations at any time throughout the entire journey.
Present important cues saliently and do not present extraneous information, facilitate mobilization of stored rules and planning	Traffic signs at the side of the virtual road (rule-based behavior), schematic depiction of the relevant traffic participants in the deceleration situation, when applicable – curvature of the road (rule-based and knowledge-based behavior) are chosen to be the important cues, which give the sufficient overview of the domain and support information processing on all the levels.
Support parallel processing	This is done via integration of the AGP haptic feedback.

Support temporal perception	The movement of the situation, which considers the remaining distance to it and driven speed, provides the overview of the time budget, which the driver has before he/she reaches the situation.
Action capability and its future improvement, facilitation of most beneficial action	Proposition of coasting or comfortable deceleration phases by moderately depressing the brake pedal are the actions (skill-based behavior), which comply with the efficiency, comfort, and safety criteria depending on the remaining time budget.
Consider time needed to act and move	This is done with consideration of reaction time and time, necessary to perform coasting or comfortable deceleration phases.

2.4.4 Visual Iconic HMI concept of anticipatory ADAS

In contrast to the Bird's-Eye View perspective used as the basis for the previously described concept, Iconic HMI is developed. Iconic HMI is based on a different concept, which follows implementation paradigm used in previously done research (see Figure 2.6): it does not provide the driver with the understanding of temporal development of the situation, is intermittent and not continuous, and aims to influence skill- and rule-based behavior, with a little consideration of enhancing planning, i.e. knowledge-based behavior. Therefore, it does not give the overview of the working domain and support for all levels of information processing mechanisms necessary for optimized anticipation of the driver.

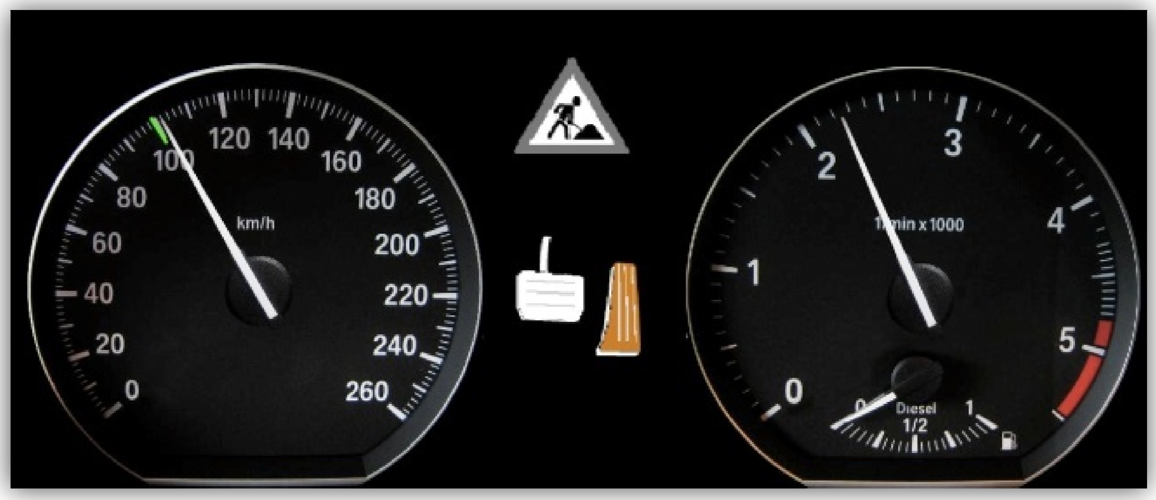


Figure 2.11: Example of Iconic visual concept of anticipation-enhancing ADAS HMI in deceleration situations

The icons of the traffic sign with brake/accelerator pedals appear only when the driver preferably should start the efficiency optimized action (Figure 2.11). The accelerator pedal is orange and starts to move when coasting is reasonable. The brake pedal moves if braking is necessary. No information about the remaining distance or time to the situation is provided (Figure 2.12).

Figure 2.12: Iconic visual concept – action suggestion via change of color and animation

2.4.5 Haptic HMI of anticipatory ADAS

As it is mentioned earlier, the multimodal displays have the possibility to further enhance SA and thus anticipation of the operators. In investigation presented in this work, based on the review of previous research, additional to the visual is chosen haptic modality.

AGP possesses intermittent character and gives the driver the haptic feedback generated by integrated electric motor *(internet entry Conti-Online)* at the time, when the assistance is activated. It is an impulse, the duration of which lasts for 0.3 s (Figure 2.13). The counterforce and the duration are chosen on the basis of opinions, which six experts have expressed during the AGP calibration phase preceding the experiments.

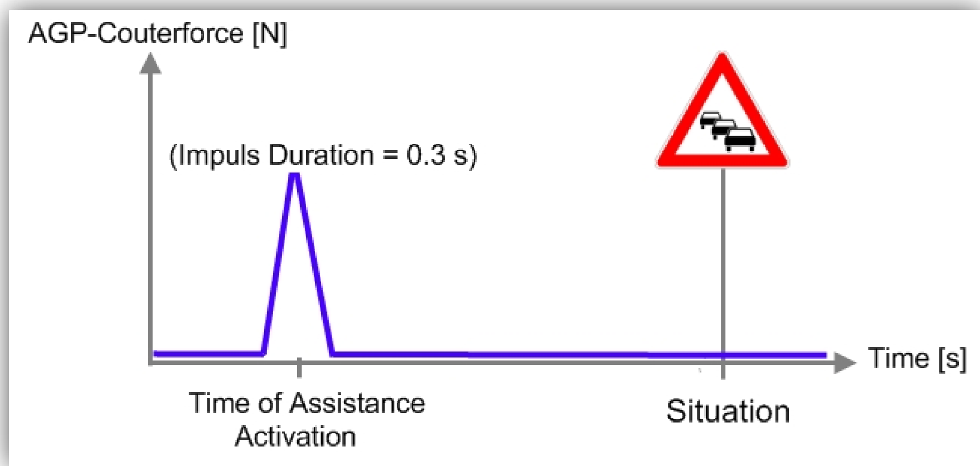


Figure 2.13: Time of assistance activation and AGP-counterforce

2.5 SUMMARY

HMI design for the anticipatory ADAS, dedicated to enhance anticipation of the driver and, due to it, improve efficiency in the deceleration situations, is based on the improving situation awareness and facilitating the underlying information-processing mechanisms of

SRK behavior. Unlike in the previous research, in which ADAS HMI supports only skill- and rule-based levels of behavior, Bird's-Eye View HMI reveals temporal development of the situation, assists in estimation of the available time until the situation is reached, as well as sequentially orders the driving events. Therefore, anticipation of the driver is supported also in the knowledge-based behavior, enabling the driver to plan his/her actions. The information is presented continuously and is organized in goal-oriented manner, providing the clear understanding of the causes triggering particular actions, supporting comprehension and projection rather than the perceptional level. The relevant salient cues, which evoke appropriate mental models, are chosen to be traffic signs, curvature of the road, and schematic presentation of the traffic participants involved into deceleration situation. Through it, also the rule-based behavior is supported. The skill-based behavior, namely the beginning of coasting or moderate braking, which is expected from the driver, is supported via color change in the displayed information. This visual concept can be combined with intermittent haptic AGP feedback, which can further improve skill-based reaction of the driver.

As the alternative to this concept, Iconic visual HMI concept is presented. It is similar with visual HMI, used in the previous research: it supports skill- and rule-based behavior, with no consideration of knowledge-based actions. Anticipation of the driver therefore is not supported to the complete extent. It is one of the investigation goals to examine the proposition, that HMI accounting on SA and SRK principles has better acceptance potential than the one, which considers only lower levels of SRK behavior. It is necessary to prove, if this additional information about temporal aspects of assisted situations really does bring additional benefits and improves the acceptance of HMI for anticipatory ADAS. After the setup of evaluation is presented in the Chapter 3 "Evaluating Anticipatory ADAS", the results of this comparison are described in the Chapter 4 "First Experiment: Visual HMI for Anticipatory ADAS".

3 EVALUATING ANTICIPATORY ADAS

This chapter addresses the general description of ADAS evaluation, namely the aims of the evaluation, experimental environment and definition of the scenarios at which the system's functionality is tested, collected measurements, and instruments used.

Investigated ADAS helps drivers to perform phases of deceleration in an efficient, comfort, and safe manner by enhancing their anticipation. One of the main aims of the evaluation is to explore the influence of this system on the driver behavior with respect to the changed efficiency, comfort, and safety. Subsequently, objective measurements collected and analyzed throughout the experiments regard efficiency as being dependent on the estimated fuel consumption, increased comfort is characterized by the reduced values of experienced decelerations, and safety – by the absence of extreme decelerations and collisions. Also the influence of visual HMI on visual behavior is taken into account, and in this chapter the description of considered visual behavior measurements is presented.

The hardware and software tools necessary for the experimental implementation and post-hoc evaluation of the gathered data are described. The simulated driving course used throughout the experiments is presented, in which the detailed description of investigated driving situations is provided.

After this information, which is relevant to all experiments presented within the scope of this dissertation, the separate explanation of each experiment and results of their analysis are provided in Chapters 4, 5, and 6.

3.1 SETUP OF EVALUATION

The user-centered approach is adopted in this work for the design of anticipatory ADAS. The design process of the product, the focus of which is end user, called user-centered or human-centered design, is the iterative process consisting of four stages *("ISO 9241-210 Human-centered design for interactive systems", 2010)*:

- specification of the context, in which the product is used: for the presented anticipatory ADAS, these are driving situations, involving deceleration phases;
- specification of the requirements, which must be achieved for the product to be successful: the driver is expected to accept anticipatory ADAS and follow advices of the system to benefit in efficiency, comfort, and safety;
- creation of the design solutions: Bird's-Eye View visual HMI concept (novel concept based on SA and SRK theories), Iconic visual HMI concept, haptic feedback via AGP;
- evaluation of the design.

According to the specification given in AIDE methodology *(AIDE Deliverable 2.1.4, 2008)*, evaluation is "the integral part of human-centered design". In the mentioned deliverable, it is stated that following points regarding evaluation are to be considered:

- definition of the aims of the evaluation (in *PReVENT SP Deliverable D16.1*, *2007,* these are specified as high level and experimental assessment objectives);
- description of the system, which is to be evaluated;
- definition of the scenarios and environment, in which system should be tested;
- definition of the test subject sample;
- definition of subjective and objective parameters and instruments to collect them;
- definition of the experimental design, development of experimental instructions both for participants and for experimenters, finalization of the experimental setup;
- performance of the experiment;
- analysis of the data;
- and production of summary indications about the system.

In this chapter, general aim of the evaluation is formulated and explained, short presentation of the different HMI concepts of anticipatory ADAS used in different parts of the evaluation is given (extended presenation of the concepts is in Chapter 2.4

"Implemented HMI Concept for Anticipatory ADAS"), and the description of evaluation environment and test scenarios is provided. Also objective parameters and instruments used to collect them are described.

In the following Chapters 4, 5, and 6, which present three experiments done within the scope of evaluation of anticipatory ADAS, the detailed description of each experimental purpose, design, test subject group, results of analysis, and summary indications are given.

3.2 EVALUATION AIMS

General aim of the evaluation is to check, if

(high level assessment objective) anticipatory ADAS expands driver's anticipation horizon during deceleration situations and this results in the increase of

- efficiency: reduction of estimated fuel consumption;
- comfort: reduction of strong decelerations;
- safety: avoidance of extreme decelerations and collisions in critical situations;

(experimental assessment objective) by presenting the oncoming situation and suggesting an action in order to motivate the driver to

- increase coasting durations;
- and avoid extreme decelerations and possible collisions by assisting in preferably preceding coasting/moderate-braking phase.

Along with this, the most suitable HMI concept for anticipatory ADAS should be selected. It regards the selection of visual interface, based on both subjective acceptance and proof, that with its usage visual behavior of the driver is not endangering the primary task of driving. It is also important to test the visual concept with respect to its durability to possible mistakes of the traffic information, as it is mentioned in the Chapter 1 "Introduction".

Multimodal HMI, consisting of visual and haptic modalities, should be analyzed with respect to additional benefits reached in high level assessment objectives.

3.3 SYSTEMS TO BE EVALUATED

Different ADAS concepts (visual Bird's-Eye View, Iconic, and multimodal consisting of visual and haptic modality, i.e. AGP) are developed, analyzed with respect to the mentioned aims, and compared against each other in three experiments.

Visual Bird's-Eye View concept is based on the guidelines, which are derived in Chapter 2.3 "General HMI Guidelines for Anticipatory ADAS". Iconic is a "conventional" visual concept similar to the ones used in previous researches, and is based on the presentation of proposed actions with simplified causal explanation without account on temporal development of the emerging situation. These two visual concepts are tested in the first experiment described in Chapter 4 “First Experiment: Visual HMI for Anticipatory ADAS”. In the second experiment, Chapter 6 ”Second Experiment: Inaccuracies in Assistance Information”, possible impreciseness of the data and partially missed detections in HMI are tested with respect to the driver acceptance and implications on efficiency, comfort, and safety.

Multimodal concept amplifies visual Bird’s-Eye View assistance with haptic feedback via AGP, and the results of its influence on driver behavior and acceptance are given in Chapter 6 “Third Experiment: Multimodal HMI for Anticipatory ADAS”, experiments.

3.4 TEST SCENARIOS AND EVALUATION ENVIRONMENT

The choice of test scenarios, in which the anticipatory ADAS is investigated, depends on following factors:

- consideration of existing and upcoming sources of traffic information: along with situations, which can be recognized via digital maps and long-range radar sensors, also deceleration situations, recognition of which is only possible due to emerging C2X communication are considered. This is done to show the potential of anticipatory ADAS in the new group of deceleration situations, which are not considered in previous investigations (see Chapter 2.4.2 “Overview of HMI concepts in related research”);

- place of situation occurrence: ADAS for increasing efficiency/comfort/ safety in previous investigations is mainly tested in the rural and highway situations. In this work, also some common urban deceleration situations are considered;

- and extent, to which anticipation of the driver can be enhanced via additional ADAS information: according to *van der Hulst et al. (1999)*, driver anticipation can be considerably improved (1) in the situations, which posses ambiguous situational cues (not yet visible relevant participants at the time point, when efficiency/comfort/safety oriented actions should begin), and (2) which are hard to be anticipated because of pre-shaped expectations, which may exist because of either very rare occurrence of such situations and no one is expecting them to happen, or because of insufficient driving experience.

  Also the situations, which are comparatively easy to anticipate, are considered: they are well visible at the time point, when efficiency/comfort/safety oriented actions should begin and posses neither unexpected character nor ambiguous cues.

The degree of situation anticipation is varied. In easily anticipatable situations, it is important to analyze if the advice is not perceived as annoying, which might lower the driver acceptance of proposed anticipatory ADAS. In the situations, which cannot be anticipated to the needed extent to perform an efficiency optimized action, it is investigated if the driver relies, follows and benefits from the advice of anticipatory ADAS.

Before starting an evaluation and implementing test scenarios, it is necessary to decide upon the environment, in which the testing takes place. According to *AIDE (AIDE Deliverable 2.1.1),* the testing can be done in laboratory environment, test track, and/or in real traffic. Laboratory environment provides the highest control of variables, allows precise repetition of driving conditions for each test subject, and, with the suitable software, enables the creation of any desirable test scenario. Unlike on the test track and especially in real traffic, dangerous driving scenarios can be implemented and system's effect on driver behavior investigated. However, one should be aware, that some of the driving measurements in their quantity may differ from those, which would be gathered under same conditions in real traffic. In virtual environment, drivers tend to underestimate the speed and overestimate the distances *(Brünger-Koch et al., 2006).* Longitudinal and lateral accelerations differ from those, experienced in real traffic conditions or on test tracks. Longitudinal decelerations, which are exercised by the test subjects in fixed-based simulator without kinesthetic feedback, are usually significantly lower, than those under dynamic conditions *(Siegler et al., 2001)*. However, according to *RESPONSE 3 "Annex to the Code of Practice for the design and evaluation of ADAS" (2006)*, "the first reaction might be similar to real driving", indicating similarity of time points at which possible actions like releasing accelerator or application of brakes occur.

Also keeping the lane *(Repa et al., 1983)* and curve negotiating *(Reymond et al., 2001)* is less precise in static test environment. These drawbacks of the fixed-base simulator can be to certain degree improved in moving-base (dynamic) driving simulators, but again, some of the mentioned issues remain *(Brünger-Koch et al., 2006)*. Therefore, if the focus of investigation lays in precise analysis of braking/accelerating and/or steering behavior, one should consider experiments either on the test track, or in real traffic.

With reliable data about longitudinal and lateral accelerations regarding their quantity and along with high control over variables and conditions, test tracks have major drawback when compared to laboratory environments: limited possibilities to implement complex test scenarios.

Experiments in real traffic provide the highest degree of realism; however, they exclude investigation of dangerous driving situations. At the same time, this is the testing environment with the weakest control over conditions and variables. Thus, the analysis of collected data and derivation of summary indications about the system is connected with the highest efforts when compared to the same evaluation processes, performed in laboratory or test track environments.

Given the experimental assessment objectives, requirements on test scenarios, available time and work resources, it is decided to perform the evaluation of anticipatory ADAS in fixed-base driving simulator located at the Institute of Ergonomics, Technische Universität München. It is assumed that the time point of accelerator release and brake application is similar to that under real driving conditions, and qualitative changes in efficiency/comfort/safety can be derived. Also multiple requirements on different test scenarios can be sufficiently fulfilled with reasonable costs only in the simulated conditions.

The field of the driver's front view in the presented investigation is 180°. The rear and side-mirror views are switched off during the experiment drives. The vehicle dynamics resembles BMW 3i motor with automatic transition. Estimation of fuel consumption and other driving relevant values are done for this engine (see Chapter 3.1.4 "Instruments, collected subjective and objective measurements").

Figure 3.1: Fix-Based Simulator at Lehrstuhl für Ergonomie, Technische Universität München

The landscape and driving course are simulated using SILAB software *(internet entry SILAB)*, which allows flexible and precise creation of the driving situations including the control over simulated traffic.

The description of investigated deceleration situations is provided below. Along with possible sources used to recognize the situation and anticipation complexity, following parameters are particularly important in the description of a situation with regard to the analysis: distance, at with the situation first becomes visible and therefore anticipatable *(visibility)*, and distance, at which the optimal coasting phase assuring best driving strategy regarding the efficiency criteria should be started *(optimal start of coasting)*. For the safety critical situation, also the distance, at which the moderate braking within the limits of comfort should take place, is considered *(optimal start of comfortable braking)*.

3.4.1 Construction site behind a right curve

This situation occurs on the two-lane rural road, where the permissible speed is 100 km/h if not explicitly changed by other speed limit signs. Test subject has to decelerate in front of the construction site, which is located on the driven lane in order to let the oncoming cars pass. The site is located 200 m after the end of a right curve with 700 m radius. This situation can be recognized to the sufficient extent for the proposed anticipatory ADAS only with the usage of C2C and C2X communication.

This situation is not easy anticipatable (oncoming traffic becomes visible much later after the efficiency optimized action should take place). Anticipatory ADAS aims to enhance planning of the test subject at the first place, and provide sufficient support for the rule- and skill-based behavior to increase efficiency/comfort/safety.

Visibility: 450-400 m before the construction site.
Optimal start of coasting: 500 m before the construction site (if driving 100 km/h).

Figure 3.2: Simulated deceleration situations – construction site behind a right curve

3.4.2 Construction site in a left curve

This is another rural road situation. The difference to the previously described situation is 500 m curve's radius, and the construction site is located directly in the curve. In this situation, like in "Construction site behind a right curve", anticipatory ADAS also strives to improve the process of planning.

Visibility: 280 m before construction site.

Optimal start of coasting: 500 m before construction site (if driving 100 km/h).

Figure 3.3: Simulated deceleration situations – construction site in a left curve

3.4.3 Speed limit on the rural road

Driver has to decrease the driven speed down to 70 km/h due to an incoming sharp curve in this situation. Numerous minor curves precede this situation, which make the emergence of this situation if not completely obvious, then expected. Such situations can be recognized at the needed distance either using digital maps, or C2X communication.

Visibility: at the distance of 200 m, the speed limit sign becomes recognizable. The exact speed limit can be read in the simulated conditions at the distance of 50 m before it is reached.

Optimal start of coasting: 400 m before the sign (if driving 100 km/h).

Figure 3.4: Simulated deceleration situations – speed limit on the rural road

In this situation, along with rule- and skill-based behavior, anticipatory ADAS supports the planning activity of the driver. Presumably, with early information about upcoming sign limit, the driver decides not to unnecessary accelerate between the curves, but rather coast the vehicle throughout this segment.

3.4.4 Town entrance

Driver has to decrease speed to 50 km/h when entering an urban area according to German traffic regulation rules. Even though this investigated situation is well visible at larger distances and is easy to anticipate, it is still unclear if the driver without assistance starts coasting early enough to perform an efficient deceleration maneuver. Like in “Speed limit on the rural road”, the information is obtained via digital maps or C2X communication.

Visibility: 600-500 m before the town entrance.

Optimal start of coasting: 650 m before the town entrance (if driving 100 km/h).

Figure 3.5: Simulated deceleration situations – town entrance

3.4.5 First and second slower preceding vehicles in the vicinity of prohibited overtaking

On the rural road, drivers are confronted twice with slower vehicles driving 80 km/h in the vicinity of prohibited overtaking. Even though both situations are well-visible, it is questionable if the drivers are able to perform deceleration maneuvers in an efficient manner without ADAS advice, and also if this advice is not perceived as annoying. Long-range radars are able to supply ADAS with the information about this situation.

Visibility: 260 m to the preceding vehicle.

Optimal start of coasting: 110 m (if driving 100 km/h) to the preceding vehicle.

Figure 3.6: Simulated deceleration situations - slower preceding vehicle in the vicinity of prohibited overtaking

3.4.6 Slower preceding vehicle and oncoming traffic

Drivers approach a vehicle driving 60 km/h on the rural road. They are allowed to overtake it after the opposite lane is free from the oncoming traffic. Oncoming traffic is not visible immediately, and the driver is likely to accelerate in the hope to overtake the slower preceding vehicle.

Visibility: 300 m to the preceding vehicle. The oncoming traffic is not immediately visible.

Optimal start of coasting: 200 m (from 100 km/h) to the preceding vehicle.

Figure 3.7: Simulated deceleration situations - slower preceding vehicle and oncoming traffic

With anticipatory ADAS, the driver possesses enough knowledge to plan efficiency optimized action, and decide to coast instead of accelerating. Information about oncoming traffic prohibiting immediate overtaking can be received with the help of C2C communication, and preceding slower vehicle – also with the long-range radar.

3.4.7 Parking car and oncoming traffic

Visibility: 200 m before the parking car.
Optimal start of coasting: 200 m before the parking car (if driving 50 km/h).

Figure 3.8: Simulated deceleration situations - parking car and oncoming traffic

The permissible speed limit is 50 km/h in the town. In this situation, driver has to decelerate because of a parking car occupying the driven lane. After the oncoming traffic on the opposite lane has passed, the driver can overtake the obstacle. Similar to “Slower preceding vehicle and oncoming traffic”, driver cannot see the oncoming traffic before he/she is 50 m from the parking car. To avoid unnecessary accelerations and abrupt braking, anticipatory ADAS provides the information about oncoming traffic and proposition to coast. Again, C2C communication is the source of relevant traffic information for the anticipatory ADAS.

3.4.8 First and second red traffic lights

The traffic lights are in the red phase. After some time, which considers the duration of optimal costing phase, they change to green. To maximize the efficiency via properly timed coasting phase, anticipatory ADAS proposes its start with account on information received via C2X communication.

Visibility: 250 m before the light.
Optimal start of coasting: 400 m before the light (if driving 50 km/h).

Figure 3.9: Simulated deceleration situations – red traffic light (longer coasting phase)

Visibility: 150 m before the light.
Optimal start of coasting: 230 m before the light (if driving 50 km/h).

Figure 3.10: Simulated deceleration situations – red traffic light (shorter coasting phase)

3.4.9 Speed limit on the highway

It is allowed to drive at any speed on German highways, if not explicitly expressed by additional speed regulation signs. In the situation, the allowed speed is set to 120 km/h on this particular segment of the simulated test course. Information about its emergence is like in "Speed limit on the rural road" and "Town entrance" can be received via C2X communication, or from the digital maps. As for the anticipation enhancement using anticipatory ADAS, it is almost impossible to plan and perform in time the efficiency optimized action without it.

Visibility: 400-350 m before the sign.
Optimal start of coasting: 750 m before the sign (if driving 150 km/h).

Figure 3.11: Simulated deceleration situations – speed limit on the highway

3.4.10 Stagnant traffic on the highway

Visibility: at the distance 300 m to the preceding vehicles.
Optimal start of coasting: at the distance 200 m to the preceding vehicles (if driving 100 km/h).

Figure 3.12: Simulated deceleration situations – stagnant traffic on the highway

The driver approaches a traffic congestion moving at 60 km/h on the highway. This situation is well visible. The permissible speed limit on this part of the simulated test course is 100 km/h. Long-range radars and C2C communication are the sources of information for anticipatory ADAS. However, like in “First and second preceding vehicles in the vicinity of prohibited overtaking", the driver is capable to anticipate the situation in a due time for an efficient deceleration. If and how the anticipatory ADAS improves driver behavior and influences acceptance of the proposed system, is to be investigated.

3.4.11 Highway jam

This is the only critical situation investigated in the experiment. Drivers are on the highway and drive with deliberately chosen speed. They approach a curve behind which the idle vehicles are located on all of the lanes. With the help of C2C communication, anticipatory ADAS can predict this situation and provide the driver with needed information. In this situation, safety criterion is of outmost importance. Anticipatory ADAS proposes moderate braking in order to avoid extreme decelerations, which are expected to be observed during unassisted drives: visibility conditions do not allow recognition of this situation without additional information, and the situation itself is not common and therefore expected by most of the drivers.

Visibility: 300 m before the jam.
Optimal start of coasting: >1,500 m before the jam (if driving 150 km/h).
Optimal start of comfortable braking less than -0.3g: 1,000 m (if driving 150 km/h).

Figure 3.13: Simulated test course – highway jam

3.5 INSTRUMENTS AND COLLECTED MEASUREMENTS

The main focus of the analysis is put on driving and visual behavioral effects caused by the anticipatory ADAS, and subjective acceptance of this assistance. Dependent measures, which are gathered during experiments, both include subjective and objective data. Subjective data are related to the driver acceptance and his/her impression of the proposed assistance, and objective – to the efficiency, comfort, and safety. Also visual distraction due to proposed visual concepts is considered.

Subjective measurements regard likability, helpfulness, wish for an investigated system, etc. In the experiment with multimodal HMI, the negative impact of perceived AGP dominance is taken into account. The exact questions answered by test subjects are provided in Chapters 4, 5, and 6 – they differ in each experiment, and therefore are not presented in this chapter, in which only common measurements for the entire investigation are described.

Driving data and relevant situational data (see next Chapter 3.5.1 "Driver behavior measurements") are recorded at 60 Hz within SILAB framework. To ensure plausibility of the results regarding efficiency, the work of *Müller (2010)* proves that qualitative changes of fuel consumption during driving a test cycle in the simulator are the same, as observed for the real engine. Exact quantities of fuel consumption do differ to those of the real vehicle, and therefore are omitted in the presentation of the results in this work.

Visual data (see Chapter 3.5.1 "Visual behavior measurements") are collected at 25 Hz using DIKABLIS software *(internet entry Ergoneers).*

Analysis of dependent measurements is done for the entire drive, and separately for segments of the experiment course containing deceleration situations. In following, this is referred to as situation-oriented analysis. Any analyzed situation segment starts where the optimal coasting phase should begin when driving the imposed speed plus 100 m (for the situations occurring on rural road), or plus 200 m for highway situations in order to take into account faster driving test subjects, and ends when the situation is bypassed. As it is mentioned before, the optimal coasting phase is the coasting phase, during which the driver decreases to the upcoming lower speed in a due time driven by releasing accelerator and without depressing brake pedal.

The descriptive analysis of driving data is done with the help of MATLAB and Excel. The analysis of visual data is performed using D-Lab and DIKABLIS Analysis tools *(internet entry Ergoneers)*. Inferential analysis is done using SPSS software, according the principles explained in *Bortz (2005)* and *Bortz et al. (2006).*

3.5.1 Driver behavior measurements

Driving behavior measurements are related to anticipation horizon of drivers and its evolution, change of it and resulting actions with the presence of anticipatory ADAS, and observed effects on efficiency, comfort, and safety. Below the definition of these measurements and their exact description is provided.

3.5.1.1 Driver anticipation horizon and resulting actions

In this work, anticipation horizon at any given moment is described by following entities: “traffic situation”, “driving situation”, “driver situation”, (thee terms are adopted from *Reichart, 2001*), and “driver behavior” (adopted from *Fastenmeier, 1995*).

Traffic situation (“Verkehrssituation”) is an objectively present consolation of traffic participants and relevant influencing parameters of the traffic surroundings. In this work, if not indicated otherwise, the term “situation” refers to the traffic situation. Traffic situations considered in following investigations are described in Chapter 3.4 “Test Scenarios and Evaluation Environment”. Complete or ideal anticipation would be when a traffic situation can be perceived and properly comprehended by the driver in a due time to perform efficient, comfortable, and safe maneuver.

Driving situation (“Fahrsituation”) is that part of traffic situation, which can be objectively seen/perceived by the driver. Due to objective limitations, i.e. visibility, the driver is not always able at once to perceive and properly comprehend the complete traffic situation, and is exposed to the part of it – driving situation. Potential or possible anticipation is based on the assumption, that almost immediately after the relevant elements of traffic situation become visible, driver perceives and comprehends them, plans and performs his/her actions accordingly. The point of analysis operationalizing driving situation and potential anticipation is chosen when all key elements of traffic situation first become visible**, SitVis**. These key elements depending on the situation are traffic signs or lights, preceding or/and oncoming vehicles.

Driver situation (“Fahrersituation”) is the subjective representation of the situation established by the driver after perception. Real anticipation of the driver is based on it. In following investigations, it is assumed that once the driver sees the key elements of the situation, time point **SitSeen**, he/she establishes the anticipation about upcoming events.

Anticipatory ADAS strives to improve the real anticipation of the driver, which is at least objectively limited by the potential anticipation, and to approximate it to the complete one. In presented investigations, the outcome of this attempt, implications of enhanced anticipation on efficiency/comfort/safety, is measured via performance measures of driver behavior (for other techniques measuring SA and anticipation, their drawbacks and advantages, see *Endsley, 1995c* and *Endsley, 2000*).

Driver behavior (“Fahrerverhalten”) means the actions of the driver related to primary task of driving, which are exercised in order to complete the current driving task. In this work, the more efficient/comfortable/safe driver behavior in considered deceleration situations is observed when driving with anticipatory ADAS, the more successful is the attempt to enhance the anticipation. To analyze driver behavior in this respect, following analysis points are chosen:

- Optimal start of coasting, **CoastOpt** – point in time, when the start of vehicle coasting is optimal in terms of an efficiency criterion. The needed distance and the proper point in time for CoastOpt depending on driven and goal speeds are calculated for the vehicle dynamics model used in the fixed-base simulator at Lehrstuhl für Ergonomie, which resembles one of the BMW 3i motors with automatic transition.

- Real coasting, **CoastReal** – point in time, when the driver actually releases the accelerator and starts coasting. The smaller the distance between CoastReal and CoastOpt is, the more efficient is the driver behavior.

- Real braking, **BrakeReal** – point in time, when the driver depresses the brake pedal. Here the comfort and safety are of the main concern: is distance to the situation at the point BrakeReal smaller than the distance needed to brake on the border of comfort? If yes, it means that the driver performs uncomfortable and potentially unsafe deceleration maneuver.

The distance needed to brake on the border of comfort (with -0.3g) is calculated as follows:

$$\begin{cases} d_{border\_comfort} = v_{driven} \cdot t + \frac{1}{2} a t^2 \\ v_{goal} = v_{driven} + at \end{cases} \leftrightarrow \begin{cases} d_{border\_comfort} = \frac{1}{2}\left(\frac{v_{goal}^2 - v_{driven}^2}{a}\right) \\ t = \frac{v_{goal} - v_{driven}}{a} \end{cases}$$, where

$d_{border\_comfort}$ – distance needed to brake on the border of comfort, in m; v_{driven} – driven speed, in m/s; v_{goal} – goal speed, in m/s; a – acceleration, put to -0.3g; t – time, in s, needed to reach v_{goal} from v_{driven} when accelerating at a.

Characteristic distances, which are relevant to each of the analyzed points, are metric and time distances to the deceleration situation.

Metric measurement is distance, **DIST, in m,** to the deceleration situation. The results are presented using mean (denoted as Ø) and standard deviation (sd) values, calculated based on data of all test subjects.

Time measurement is Time-To-Collision, **TTC, in s,** which corresponds to the remaining time budget before the situation is reached when the driven speed is not changed. The results are presented using Ø and sd values, calculated based on data of all test subjects.

TTC is calculated for a single subject at a particular analysis point as

$$TTC[s] = \frac{d_{obstacle}[m]}{v_{driven}[m/s] - v_{obstacle}[m/s]}$$

where $d_{obstacle}$ – distance between the driven vehicle and the obstacle at the analysis time point; v_{driven} – speed of the driven vehicle; $v_{obstacle}$ – speed of the obstacle, in case of a static object i.e. construction site or speed limit sign is equaled to 0 m/s. In this later case TTC can be considered as the time headway (Cherri et al., 2005), or as time distance to the situation. More TTC-related information can be found in (van der Horst, 1990).

In the first experiment to show the potential of anticipatory ADAS, Chapter 4 “First Experiment: Visual HMI for Anticipatory ADAS”, a detailed analysis of anticipation horizon and resulting actions when driving without and with assistance is presented. However, in some of the considered situations SitSeen is omitted, because of the discrepancy between simulated and real traffic conditions. Based on the investigations of *Färber (1986), Reichart (2000),* and *Farid (2008)*, following situations are chosen for the complete analysis of anticipation horizon: construction sites behind right and left curves, town entrance, slower preceding vehicle and oncoming traffic, parking car, stagnant traffic on highway, and highway jam. In other situations, due to obvious difference in their perception between simulated and real conditions, SitSeen is excluded from the analysis.

The analysis of driver anticipation horizon and resulting actions is also performed in the second (Chapter 5 “Second Experiment: Inaccuracies in Assistance Information”) and third (Chapter 6 “Third Experiment: Multimodal HMI for Anticipatory ADAS”). If the difference to the results of the first experiment is observed, they are presented.

Below dependent measurements are described, which reflect the global implications of driver behavior on efficiency/comfort/safety. In the dissertation, these measurements are presented for each of the three experiments.

3.5.1.2 Efficiency, comfort, and safety

To see the global effect of the system on the efficiency (resulting influence of proximity between CoastOpt and CoastReal), fuel consumption is estimated when driving with and without the anticipatory ADAS.

Estimated fuel consumption, **$b_{e\%}$, in %** – calculated for the vehicle dynamics model in the fixed-base simulator at the Lehrstuhl für Ergonomie, which resembles a BMW engine with automatic transition. The value of the estimated fuel consumption is given in percents to emphasize the tendency of its change while driving with assistance compared to the baseline condition (i.e. unassisted drive); 100% corresponds to the estimated fuel consumption in the baseline drives. The results are presented using Ø and sd values, calculated based on data of all test subjects.

For the comfort criterion, the minimal reached decelerations during braking phases are taken into account. If the decelerations are lower than -0.3g or the braking maneuver starts later than needed to brake on the border of comfort, it is assumed that the comfort criterion is not fulfilled. The expectancy is, that if during the unassisted drives these decelerations occur, then with assistance they will be significantly milder.

Minimal deceleration, **a_{min}, in m/s²** – values of minimal decelerations experienced during the deceleration phase. The results are presented using Ø and sd values, calculated based on data of all test subjects.

Safety criterion accounts also on the minimal decelerations a_{min} lower than $-7 m/s^2$, and number of collisions, **$N_{collision}$**, which are the result of late reaction and insufficient decrease of driven speed. This part of analysis is especially important for the situation “Highway jam”.

3.5.2 Visual behavior measurements

For the measurement and analysis of driver’s visual behaviour the guidelines from *ISO 15007 “Road vehicles – Measurement of driver visual behaviour with respect to transport information and control systems”* are taken into account (*ISO 15007-1:2002* deals with definitions and parameters, *ISO 15007-2:2002* – with equipment and procedures).

According to these norms, the following measurements are considered in the presented investigation:

Number of glances – number of glances to a visual target* during a defined condition†. In the results, this measure is not provided directly, but used for calculation of mean glance duration and glance frequency.

Glance duration – time, in s, from the moment the direction of the gaze moves towards a visual target to the moment it moves away from it. In the results, this measure is not provided directly, but used for calculation of total glance duration.

Total glance duration – time, in s, which is the summation of all glance durations to the visual target during a condition (in presented investigation – during the analyzed situational segments). Calculated as ∑ (glance duration1, glance duration2, ..., glance durationN) for a single subject. Used for calculation of mean glance duration and percentage time.

* Visual target is the digital instrument cluster in presented investigation

† Defined condition is either entire drive, or analyzed situational segment. The valid condition is specified before every presentation of results in the experiment chapters.

Mean glance duration – mean duration, in s, of the single glance, which a test subject directs towards the visual target during a condition. Calculated as (total glance duration directed to a visual target during a condition)/(number of glances to a visual target during a condition). The results are presented using Ø and sd values, calculated based on data of all test subjects, i.e. for each test subject the mean glance duration during a condition is computed, afterwards mean and standard deviation of these values are emitted.

Percentage time – percentage of time, in %, spent looking at the visual target during a condition. Calculated as (total glance time directed to the visual target during a condition)/(duration of the condition)*100%. The results are presented using Ø and sd values, calculated based on data of all test subjects.

Glance frequency – number of glances to a target within a defined time period, or during a defined condition, where each glance is separated by at least one glance to a different target. Calculated as (number of glances to a visual target during a condition)/(duration of the condition), unit is 1/s. The results are presented using Ø and sd values, calculated based on data of all test subjects.

Maximum glance duration – the longest glance duration, in s, to a visual target during a condition. Calculated as max(glance duration1, glance duration2, …, glance durationN) for a single test subject. The results are presented using Ø and sd values, calculated based on data of all test subjects.

Also the distribution of the glances directed on the visual target is considered in the analysis.

Additionally, to establish how long is needed for the driver to see the displayed information, variable **time needed to perceive visual HMI information, in s,** is introduced. This is the time, which elapses between the time point, at which the information regarding upcoming situation is displayed, and until the driver first looks at the instrument cluster.

Visual behavior is investigated in order to establish the distraction degree from the primary task of driving caused by the proposed assistance. The values are compared to those from related experiments, which provide the information of which values can be considered as non-critical.

3.6 SUMMARY

This chapter states the aims of evaluation consisting of three experiments, which are presented in subsequent chapters. The general aim is to investigate the influence on efficiency/comfort/safety of anticipatory ADAS, ensure its safety with respect to visual behavior, and to choose the most suitable HMI for the system. It is explained why a particular evaluation environment (fix-based simulator) and test scenarios are chosen.

Analysis measurements, chosen for derivation of summary indications about the system and for validation of the experimental aims, are reliable in the fix-based simulator. Moreover, the extended requirements on test scenarios, including consideration of different traffic information sources, different types of roads, and different degree of the possibility to anticipate a situation, also influenced the choice of the evaluation environment.

Dependent measurements, related to driver and visual behavior, are defined and explained within this chapter. They are used in the following experiments to validate the anticipatory ADAS.

4 FIRST EXPERIMENT: VISUAL HMI FOR ANTICIPATORY ADAS

In this experiment, two types of visual HMI of the anticipatory ADAS are tested. One of them is based on the Bird's-Eye View presentation of upcoming deceleration situation (Chapter 2.4.3 "Visual Bird's-Eye View HMI concept of anticipatory ADAS"), another –on the Iconic (Chapter 2.4.4 "Visual Iconic HMI concept of anticipatory ADAS").

Driver subjective acceptance and preferences regarding introduced visual concepts are investigated. Also the influence of assistance system on driver behavior, resulting fuel consumption and efficiency, beginning of braking and comfort, number of collisions and safety is addressed. Visual behavior observed during the experiment drives with introduced HMI concepts is discussed in detail.

Bird's-Eye View visual HMI concept, which proved to be most suitable visual HMI for anticipatory driver assistance system according to the presented analysis, is adopted for the following experiments described in Chapter 5 "Second Experiment: Inaccuracies in Assistance Information" and Chapter 6 "Third Experiment: Multimodal HMI for Anticipatory Driver Assistance System".

4.1 PURPOSE OF FIRST EXPERIMENT

This experiment is the primary investigation of the anticipatory ADAS in regard to its form of visual presentation and triggered visual behavior of the drivers, its influence on driving behavior and subsequently implications on efficiency/comfort/safety criteria.

The scope of this investigation consists of multiple issues, divided in three categories:

- **subjective acceptance** of the proposed visual HMI for the anticipatory driver assistance system,
- **influence on visual behavior** of the proposed visual HMI,
- assistance's **implications on driver behavior**, and, correspondingly, on estimated fuel consumption and number of collisions in safety critical situation.

Based on the results addressing these issues, the preferred visual HMI concept for the anticipatory driver assistance system is chosen, as well as its potential benefit in efficiency and safety while driving are demonstrated.

In the following, goals of the experiment are ordered with respect to these three categories.

Regarding subjective acceptance, following questions are put in the focus of the experiment: does the driver feel the benefit due to the proposed assistance system? What HMI concept (Bird's-Eye View or Iconic) does he/she prefer? Issues of likability, understandability, helpfulness, and increased feeling of safety are analyzed to answer these questions. Also HMI preferences from the two proposed concepts are taken into account.

Investigation of influence on visual behavior is important to determine the degree, to which the driver might be distracted due to visual HMI from the primary task of driving. The descriptive results of visual behavior measurements are compared to advised limit values taken from the research on this topic (see Chapter 3.5.2 "Visual behavior measurements"). Based on this comparison, conclusions about potential visual distraction of presented HMI concepts are drawn.

Implications on driver behavior of the anticipatory driver assistance system are also analyzed in great detail. At first, analysis of driver anticipation horizon is performed; afterwards the benefits while driving with assistance regarding efficiency and safety are derived. Following hypothesis pairs (alternative H1 and null hypotheses H0) are proved during this analysis (significance level is 0.05):

Earlier_Coasting/H1: $DIST_{CoastReal}$_unassisted ≠ $DIST_{CoastReal}$ _assisted. Driving with the proposed assistance systems is characterized by different beginning of the coasting phases in investigated deceleration situations when compared to unassisted driving.

Earlier_Coasting/H0: $DIST_{CoastReal_}$unassisted = $DIST_{CoastReal}$ _assisted. Driving with the proposed assistance systems does not lead to different beginning of the coasting phases in investigated deceleration situations when compared to unassisted driving.

Efficiency_Benefit/H1: $b_{e\%_}$unassisted ≠ $b_{e\%_}$assisted. Driving with the proposed assistance systems differs in efficiency compared to unassisted driving.

Efficiency_Benefit/H0: $b_{e\%_}$unassisted = $b_{e\%_}$assisted. Driving with the proposed assistance systems does not have any influence on efficiency compared to unassisted driving.

Safety criterion is investigated in the safety critical situation “Highway jam”, and proves following hypotheses:

Safety_Benefit_Deceleration/H1: $a_{min_}$unassisted ≠ $a_{min_}$assisted. Driving with the proposed assistance systems results in different decelerations in the safety critical situation, in which without the assistance drivers must exercise the emergency braking.

Safety_Benefit_Deceleration/H0: $a_{min_}$unassisted = $a_{min_}$assisted. Driving with the proposed assistance systems does not influence decelerations in the safety critical situation.

Safety_Benefit_Collision/H1: $N_{collision_}$unassisted ≠ $N_{collision_}$assisted. Driving with the proposed assistance systems helps to avoid collisions in the safety critical situation.

Safety_Benefit_Collision/H0: $N_{collision_}$unassisted = $N_{collision_}$assisted.. Driving with the proposed assistance systems does not help to avoid collisions in the safety critical situation.

4.2 SETUP OF FIRST EXPERIMENT

The hardware and software tools used for the setup and analysis of the experiment, as well as simulated deceleration situations are described in Chapter 3 “Evaluating Anticipatory ADAS”. All thirteen situations (see Chapter 3.4 “Test scenarios and evaluation environment”) are incorporated into simulated test course for this experiment. The resulting length of the test drive is 27.5 km, consisting of the highway, rural, and urban segments.

26 test subjects with average age of 34 years took part in the experiment (see Chapter 4.3 “Test Subjects”). The general information about the age of a test subject, his/her driving experience, etc., is collected using demographic questionnaire (Appendix B.1). Afterwards each test subject has to complete introductory drive (20 min) in order to get used to the driving environment, i.e. braking, steering, accelerating, and perceiving speed and distance in the static simulator. During this drive, no assistance is displayed: only speedometer and tachometer are presented in instrument cluster.

Afterwards the explanation of both investigated HMI concepts, Bird's-Eye View and Iconic, is provided. Two short drives (so-called first-contact drives, 5 min each) with both visual HMI concepts are performed. During these drives, test subjects are confronted with three deceleration situations assisted by mentioned HMIs in order to get the feeling of system's functionality. None of these example situations occurred later during the analyzed drives to omit the recognition effects. So far no driving, visual, or related to the system's subjective acceptance data are collected.

After this first phase, the main experiment drives are performed. Three drives occur. One of these drives is a reference drive without any assistance, latter referred to as **Baseline** drive, or Baseline condition. Two other drives are assisted with Bird's-Eye View and Iconic HMI, correspondingly later referred to as **Bird's-Eye View** and **Iconic** drives or conditions. Between them, subjective data regarding system's acceptance are collected using questionnaires (Appendix B.2 and B.3). Also synchronized driving and visual measurements are recorded for further analysis. After the completion of the experiment drives, final questions are asked regarding HMI preferences and their final subjective evaluation (Appendix B.4).

The order of the three drives is permuted for each test subject in order to diminish the effect of familiarization in the within-subject design of the experiment. This prevents some irrelevant to the tested condition factors to influence results of general analysis, e.g. test subjects might act more confident in the third drive than in the first not because of certain condition, but because they have already driven for 40 min. If the third drive is performed by all test subjects under the same tested condition, results might be better because of familiarization and not due to the condition. In permuted design, these inaccuracies are eliminated. Overview of the experimental design is presented in Figure 4.1.

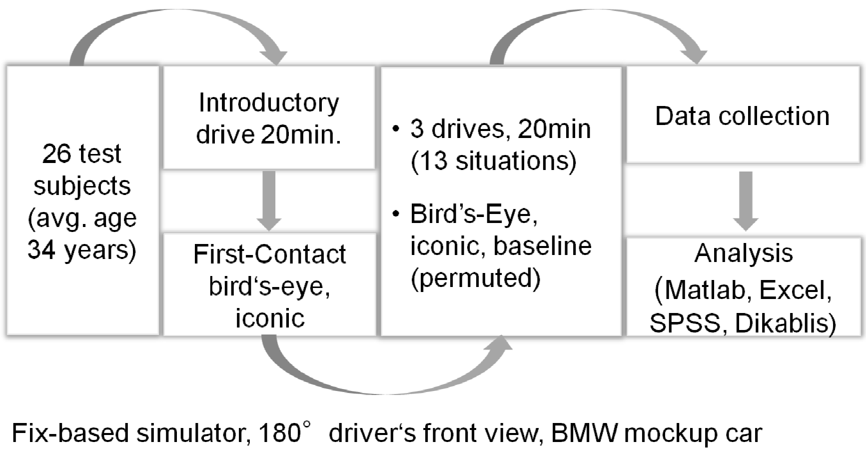


Figure 4.1: Visual assistance for anticipatory driving – overview of the experimental design

In following sub-chapters, the detailed description of test subject group, analysis approach, and results are provided.

4.3 TEST SUBJECTS

26 test subjects (17 male and 9 female) took part in the experiment. All of them hold valid category B European driver's licenses. The average age of the test subjects is 34 years (standard deviation is 13.6 years), the age ranges from 23 to 64 years. The driving experience varies: seven participants drive less than 10,000 km per year, eleven – between 10,000 and 20,000, and eight – more than 20,000 km per year.

4.4 ANALYSIS APPROACH

Subjective acceptance is evaluated using questionnaires. Test subjects agree/disagree with statements "I like the concept very much", "The concept increases the feeling of safety", "The concept is easily understandable", and "The concept makes it easy to adjust to the situation". Agreement or disagreement is expressed by choosing one of five possible grades: "not at all" (assigned grade is -2), "no" (grade -1), "on average" (grade 0), "yes" (grade 1), and "absolutely" (grade 2). The degree of likability, increased feeling of safety due to a concept, understandability, and helpfulness in adjusting to the situation, are thereafter derived based on descriptive values of the received grades. The differences between the introduced concepts are proved using Wilcoxon matched-pairs signed-rank test. The significance level is 0.05.

In the final questionnaire each test subject has to give an answer to the question, "If you had to arrange the vehicle according to your wishes, would you include the anticipatory driver assistance system?". The answer ranges from "not at all" (-2) to "absolutely" (2). This question is followed by the proposition to grade each HMI concept, Bird's-Eye View and Iconic, according to its suitability as the basis for HMI of the anticipatory driver assistance system ("If my vehicle had the anticipatory driver assistance system, my wish for the following concept would be…"). The possible grades are "not at all" (-2), "probably" (-1), "on average" (0), "willingly" (1), "absolutely" (2). The differences between the grades given to both concepts are analyzed with Wilcoxon matched-pairs signed-rank test, significance level is 0.05.

At the end of subjective evaluation, test subjects choose one of the two investigated visual concepts as the most preferable. The number of test subjects, who prefer Bird's-Eye View concept over Iconic and vice versa, is given in the result section.

Driving behavior measurements are described in Chapter 3.5.1 "Driver behavior measurements". In this work, results of the analysis regarding driver anticipation and resulting actions, efficiency, and safety are presented. Results regarding a_{min} for comfort criterion are omitted due to confirmation of the possibility, that experienced decelerations in static simulator are much stronger than one would expect, and are not comparable within different conditions. More often than not, the analysis reveals that test subjects brake unreasonably strong in all of the conditions, with the comment "I didn't feel my vehicle to decelerate, so I depressed brakes harder". Apparently, kinesthetic feedback is necessary to judge the strength of deceleration.

Measurements of visual behavior are described in detail in Chapter 4.2.2 "Visual behavior measurements.

Descriptive values for most of the driver and visual behavior measurements are presented by mean values, denoted as **Ø**, and standard deviation, **sd**. These are also represented in bar diagrams. Statistical analysis is done via the one-way repeated-measures analysis of variance (ANOVA) with post hoc comparisons using Bonferroni corrections after the normal distribution of values is proved. The significant differences between conditions are marked with the arrow line above the corresponding bars in the provided diagrams, the significance level is 0.05.

4.5 RESULTS OF QUESTIONNAIRES

Subjective evaluation, presented in this thesis, concerns following issues:

- likability and understandability of the concepts, feeling of safety that they provide, helpfulness in driver's adjustment to the situation;
- general wish for a system, enhancing driver's anticipation regarding upcoming deceleration situations to increase efficiency, comfort, and safety;
- wish for a system, based on the investigated (Bird's-Eye View and Iconic) concepts, and preferences of one concept over another.

Diagram 4.1 presents analysis results of likability, understandability, etc. for both Icon and Bird's-Eye View HMI concepts. As it can be seen, Bird's-Eye View concept is on average evaluated better than Iconic (values in Diagram 4.1 represent average grades from -2 to +2, given to the concepts for their properties). Wilcoxon matched-pairs signed-rank test proves significantly better results in the case of Bird's-Eye View concept for likability and understandability. Both concepts provide drivers with increased feeling of safety, and are helpful in adjusting to the situation. Regarding these two criteria no significant differences between the concepts are detected.

General wish for a system, which enhances anticipation by presenting oncoming situation and suggesting an optimized action, is high (see Diagram 4.2): 19 test subjects explicitly express their wish for it, four have an average wish, and three cannot answer the question.

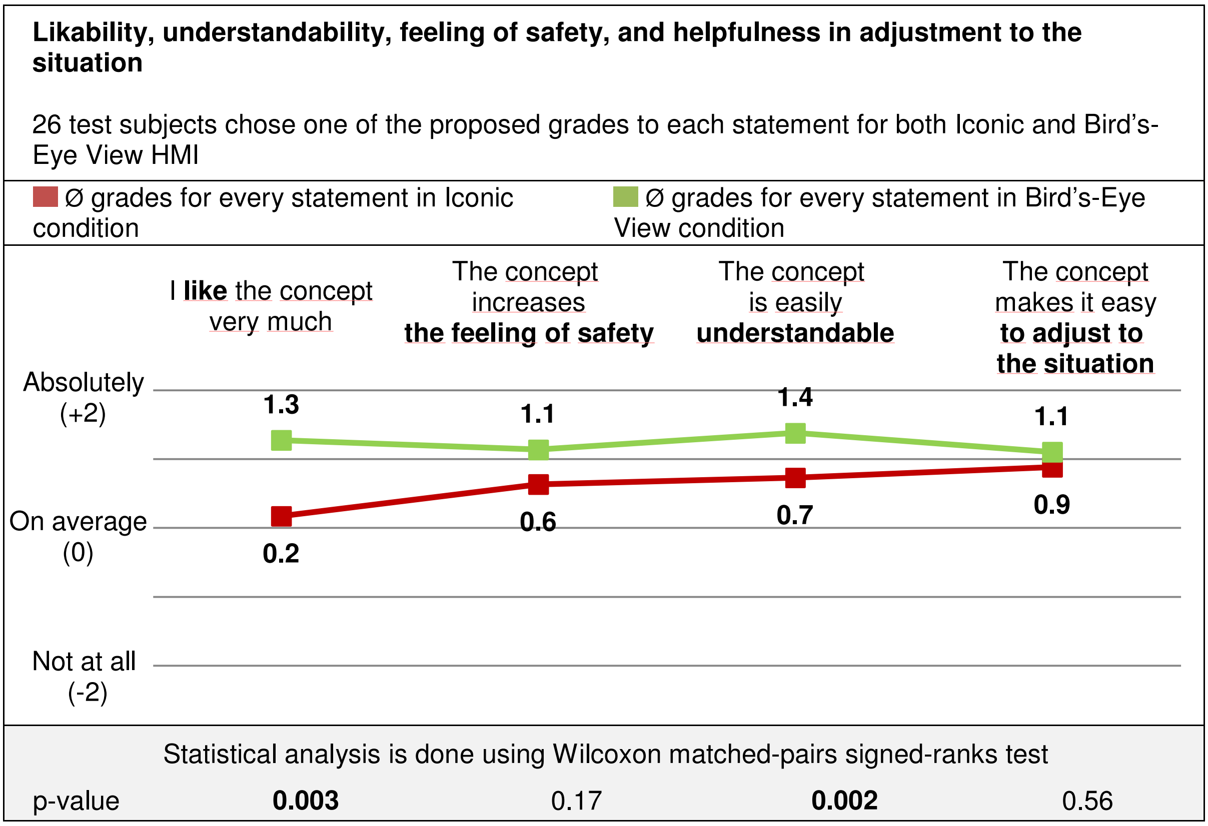


Diagram 4.1: Results of questionnaires – likability, understandability, feeling of safety, adjustment to the situation (Bird's-Eye View and Iconic HMI)

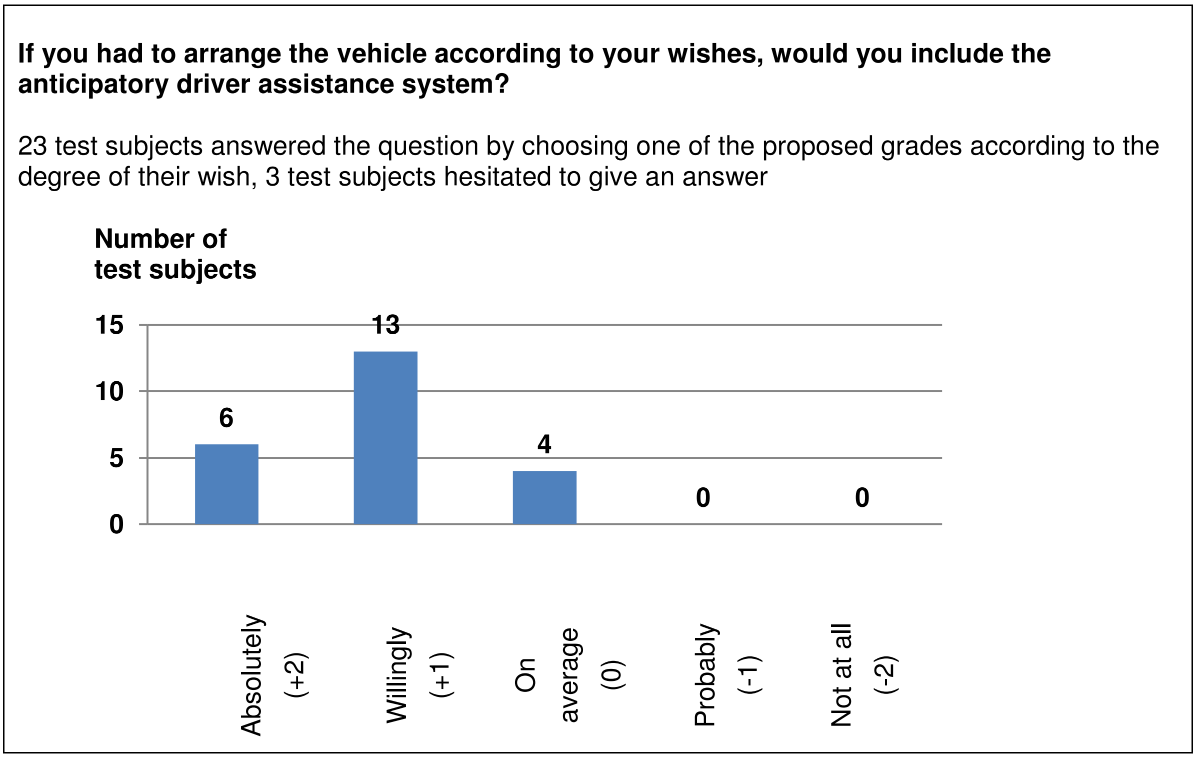


Diagram 4.2: Results of questionnaires – general wish for the anticipatory driver assistance system

When afterwards asked to grade each of the concepts as the basis for such assistance system, it becomes clear, that the preference of the test subjects is Bird's-Eye View HMI (Diagram 4.3). It is found to be more suitable visual HMI of the anticipatory ADAS in comparison to Iconic concept (Wilcoxon matched-pairs signed-rank test, $p < 0.002$). When asked directly, which concept would one prefer over another, the definite winner is Bird's-Eye View (22 votes) against Iconic (3 votes). One test subject hesitated to give an answer to the question.

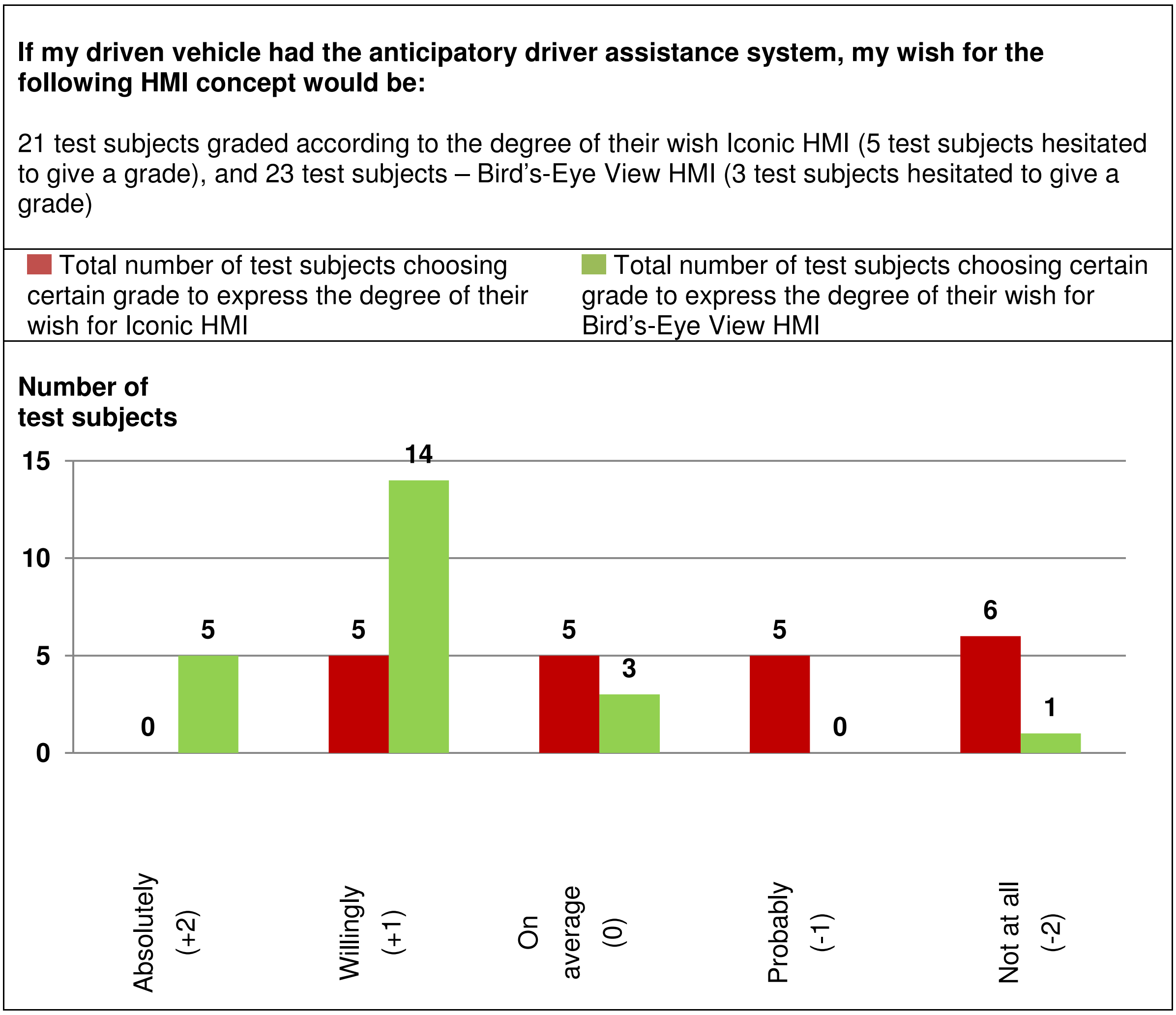


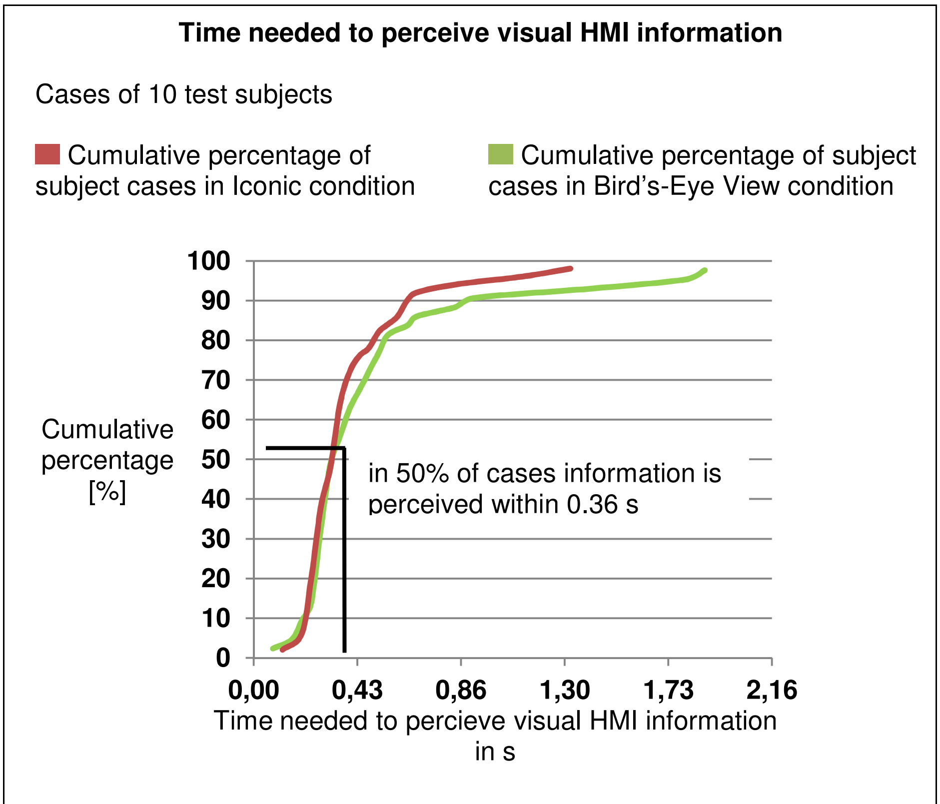
Diagram 4.3: Results of questionnaires – wish for the anticipatory driver assistance system based on Bird's-Eye View and Iconic concepts

Additional results concerning subjective acceptance of proposed concepts can be found in the work of *Duschl (2010)*.

4.6 RESULTS OF VISUAL BEHAVIOR

The analysis of the driver visual behavior regarding time needed to perceive visual HMI information shows that the presented information is not overseen. In 50% of the cases the displayed information is noticed within 0.36 s both in the case of Iconic and Bird's-eye view

HMI. Diagram 4.4 provides the corresponding Pareto chart, the data of which corresponds to visual behavior of ten randomly chosen test subjects. However, the results of the third (above 50% and below 75%) and fourth (above 75% and below 95%) quarters of all the analyzed cases show, that Iconic assistance presentation is noticed faster, than Bird's-Eye View. As a result, in 95% of the cases drivers see the representation of the upcoming driving situation within 1.12 s (Iconic) and 1.80 s (Bird's-Eye View) after it appears in the instrument cluster. Relatively lower numbers in the case of Iconic HMI in comparison to Bird's-Eye View can be explained by the intermittent character of the visual assistance: sudden appearance of the signs on the black area between speedometer and tachometer is noticed faster, than the additional information superimposed on the virtual road. This corresponds with findings of *Bergmeier (2008)*, which state that blinking information in in-vehicle displays directs attention of the driver faster, than non-blinking. Nevertheless, with both assistance HMIs, information is generally perceived within less than 2 s [‡] after it is displayed by the system.



	Assistance information is perceived in 25%, 50%, 75%, and 95% of the subject cases within following time, in s			
	25%	50%	75%	95%
Iconic	0.28	0.36	0.44	1.12
Bird's-Eye View	0.28	0.36	0.52	1.80

Diagram 4.4: Results of visual behavior – cumulative percentage of subject cases regarding time needed to perceive visual HMI information

[‡] 2 s are chosen as the reaction time needed to perceive and act according to the advice of the system (see Chapter 2.4.1 "Activation time of anticipation ADAS").

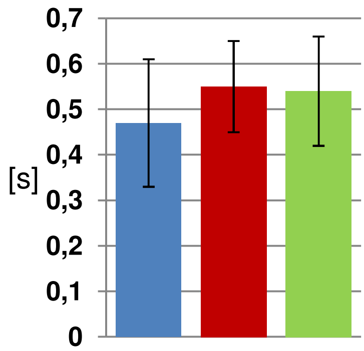
The driver directs his/her glances towards instrument cluster throughout a drive with mean duration of 0.47 s (Baseline), 0.54 s (Bird's-Eye View), and 0.55 s (Iconic). Corresponding values of mean durations in different conditions and their standard deviations are depicted at Diagram 4.5, on the left. Statistical analysis reveals the significant influence of assistance information on the mean glance duration: F(2;68) = 3.13, p = 0.04. Post hoc comparison does not detect any significant differences between assisted and baseline drives, however. The quantity of the observed values (0.54 - 0.55 s) during the assisted drives can be by far considered as normal and not endangering the task of driving. Such duration of the glance can be compared to a glance directed towards the rear-view mirror *(Green, 1995)*.

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected <u>when driving the entire course</u> in following conditions:

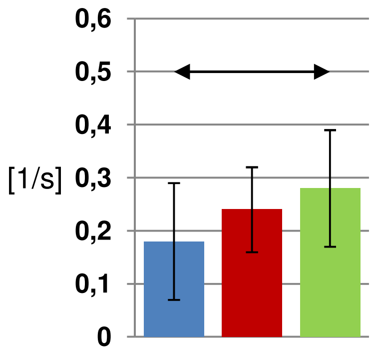
■ Baseline ■ Iconic ■ Bird's-Eye View

◄──► *signifies that p<0.05, ANOVA with post hoc comparisons using Bonferroni corrections*

Mean glance duration directed at instrument cluster, in s



Frequency of glances directed at instrument cluster, in 1/s



	in s, Ø±sd	in 1/s, Ø±sd
Baseline	0.47±0.14	0.18±0.11
Iconic	0.55±0.10	0.24±0.08
Bird's-Eye	0.54±0.12	0.28±0.11

Diagram 4.5: Results of visual behavior – mean glance duration and glance frequency, analysis of the entire driving course

The glance frequency (Diagram 4.5, on the right), frequency of glances directed at the instrument cluster, significantly increases with assistance: F(2,68)=5.28, p=0.007. Post hoc comparison of Baseline and Bird's-Eye View assisted drives proves the significant difference between these two conditions: p=0.005. Increased frequency is explained by increased number of shorter glances (see Diagrams 4.7, 4.8, 4.9). Nevertheless, the mean values of glance frequency caused by Bird's-Eye View HMI, 0.28 times per second, do not exceed the safety tolerant glance frequency at the instrument cluster of 0.35 times per second recommended for the in-vehicle displays in the work of *Hada (1994)*.

Significant increase is observed in the percentage of time spent looking away from the road (road-blind time), caused by gazes directed at the instrument cluster during assisted drives: F(2;68)=12.72, p<0.001 (Diagram 4.6, on the left). The differences are significant: in Baseline vs. Iconic HMI drives comparison p<0.002, and Baseline vs. Bird's-Eye View HMI p<0.001. In the findings of *Hada (1994)*, 32% is found to be the safety tolerant mean road-blind time due to the glances on in-vehicle displays. This value is by far not reached in any of the assisted drives: in the case of Iconic HMI it amounts on average to 12.75%, and Bird's-Eye View – to 14.28%. It should be also mentioned, that higher percentage of time, spent looking in the direction of instrument cluster with both visual concepts of assistance, does not result in any critical driving situation throughout the experiment drives. Remaining percentage of the glance time dedicated to the road scenery is sufficient to control the evolving driving situation and avoid any abrupt maneuvers *(Serafin, 1994)*.

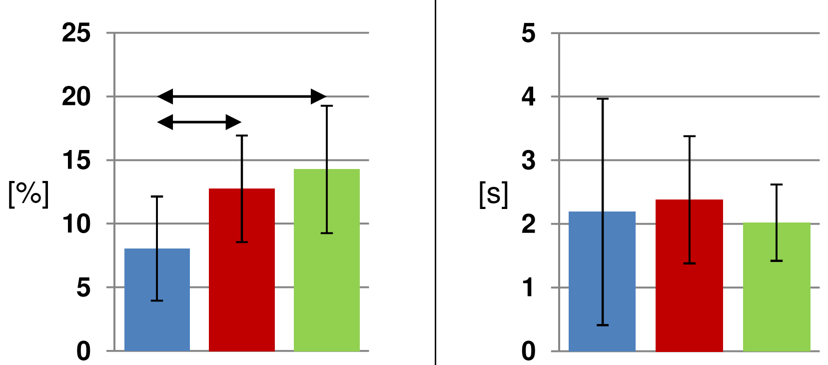
Maximum glance duration (Diagram 4.6, on the right) is not affected by the assistance: F(2;68)=0.48, p=0.62.

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected <u>when driving the entire course</u> in following conditions:

Baseline | Iconic | Bird's-Eye View

⟷ *signifies that p<0.05, ANOVA with post hoc comparisons using Bonferroni corrections*

Percentage of time spent looking at instrument cluster, in %	Maximum glance duration of the glances, directed at instrument cluster, in s



	in %, Ø±sd	in s, Ø±sd
Baseline	8.06±4.09	2.19±1.78
Iconic	12.75±4.18	2.38±1.00
Bird's-Eye	14.28±5.00	2.02±0.60

Diagram 4.6: Results of visual behavior – percentage of time spent looking at the instrument cluster and maximum glance duration, analysis of the entire driving course

For better insight into the provided values, the total glance distribution is provided in Diagram 4.7 (Baseline – on average 190.5 glances on the instrument cluster per drive of a test subject), Diagram 5.8 (drives, assisted via Bird's-eye View HMI – on average 309.5 glances per drive), and Diagram 5.9 (drives, assisted via Iconic HMI – on average 238.5 glances per drive).

Frequency distribution of single glance durations directed at instrument cluster, in %, and cumulative percentage of their cases

Cases of 26 test subjects, collected when driving the entire course in baseline condition

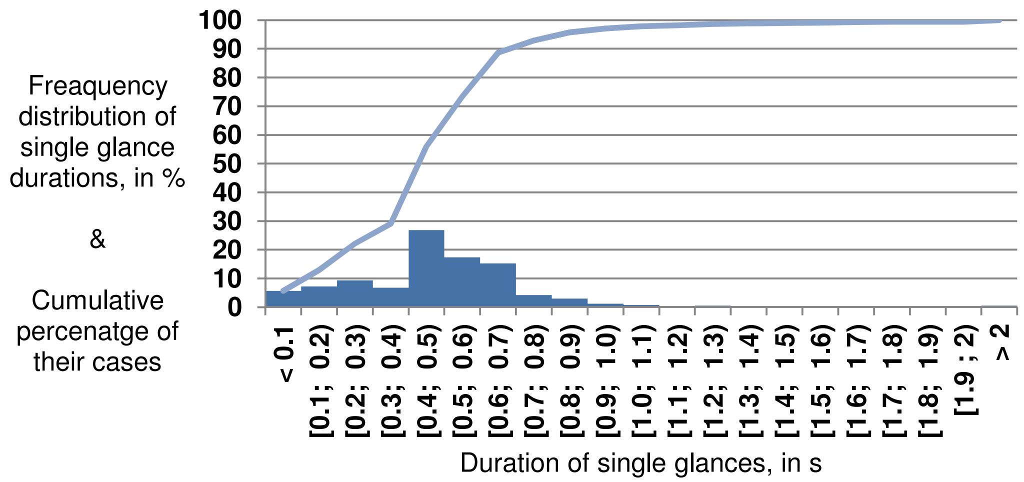


Diagram 4.7: Visual behavior – glance distribution in Baseline drives, analysis of the complete drive

Obviously, significantly increased frequency of glances directed towards the instrument cluster in Bird's-Eye View condition in comparison to Baseline (see Diagram 4.5) is a result of higher number of glances at the instrument cluster. However, as it can be seen from Diagram 4.8, most of them are short glances controlling the state of the assistance, and do not cause massive visual distraction. Due to them, significantly increased total percentage of the time dedicated to the visual target is also explained.

In the case of Iconic condition (Diagram 4.9), the number of glances increases relatively moderately compared to Baseline. However, some of the glances become longer – 5% of them are longer than 1.2 s, compared to the Bird's-Eye View condition – 1.08 s, and Baseline – 0.88 s. Also the median value, corresponding to 50% of the single glance durations, is larger in Iconic case: 0.52 s vs. 0.48 s for both Bird's-Eye View and Baseline conditions.

It should be noted, that "2 s - Rule" *(Noy, 1999)*, implying that in-vehicle displays should not cause longer glances than 2 s in 85% of the cases, is not violated in all conditions.

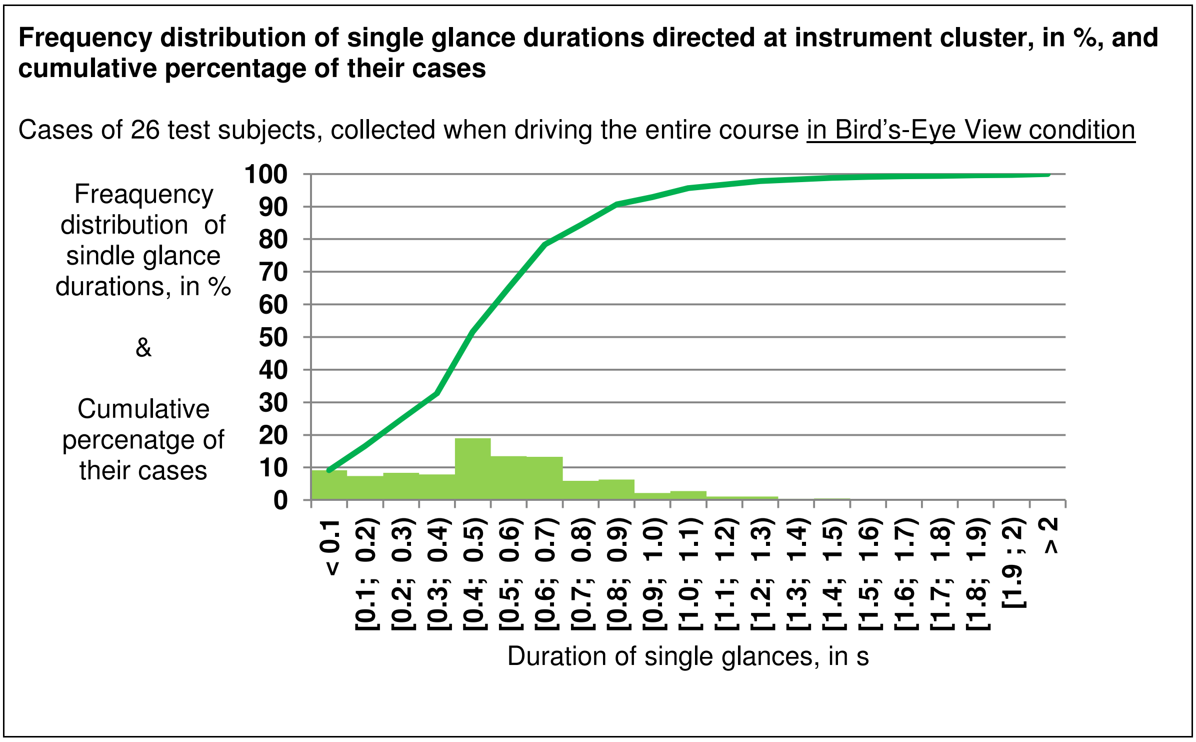


Diagram 4.8: Visual behavior – glance distribution in Bird's-Eye View assisted drives, analysis of the entire drive

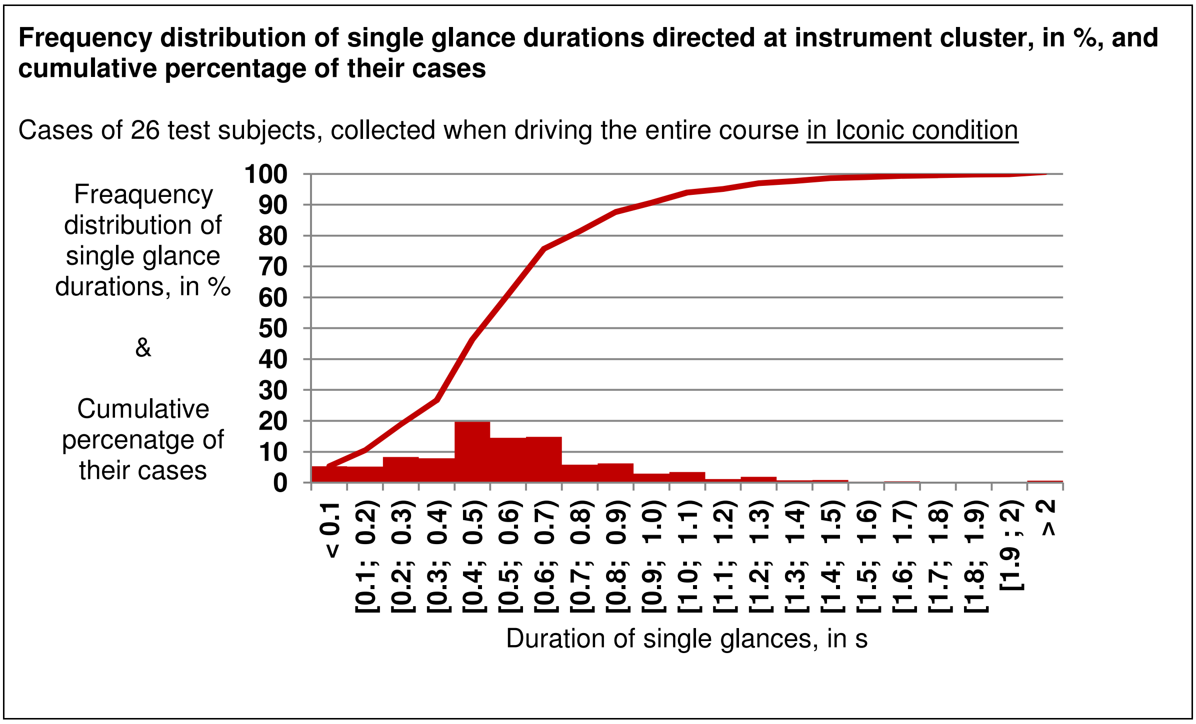


Diagram 4.9: Results of visual behavior – glance distribution in Iconic assisted drives, analysis of the entire drive

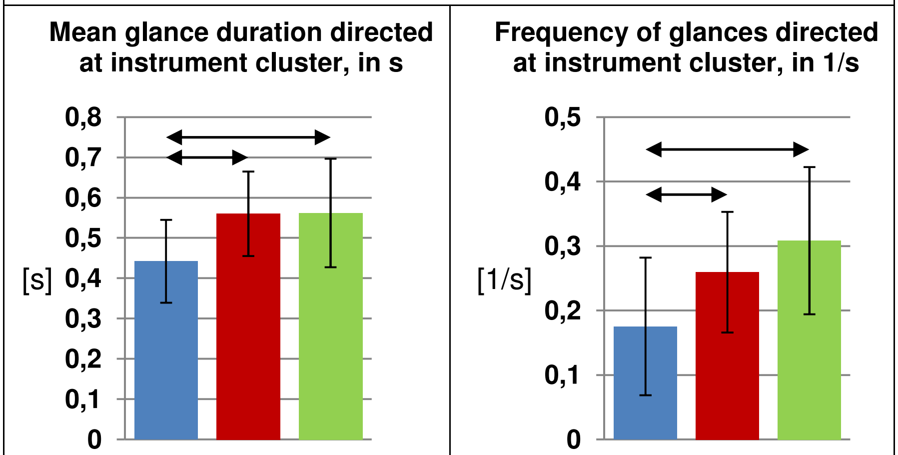
To be able to forecast the effects of increased density of assisted situations on visual behavior, analysis of the situational segments, during which the assistance is activated, is done (see detailed results of visual behavior on each situational segment in the work of

Bruckmaier, 2010). The compound values of the visual analysis performed for these situational segments are provided in Diagrams 4.10 and 4.11.

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected when driving through 13 investigated situations in following conditions:

Baseline Iconic Bird's-Eye View

⟷ *signifies that p<0.05, ANOVA with post hoc comparisons using Bonferroni corrections*



	in s, Ø±sd	in 1/s, Ø±sd
Baseline	0.44±0.10	0.18±0.11
Iconic	0.56±0.14	0.26±0.09
Bird's-Eye	0.56±0.10	0.31±0.11

Diagram 4.10: Results of visual behavior – mean glance duration and glance frequency, compound analysis of separate situations

During activation of the assistance system, mean duration of glances directed towards the instrument panel (Diagram 4.10, on the left) significantly increases compared to Baseline condition: $F(2;74)=9.24$, $p<0.001$. Post hoc analysis reveals significant differences between both Iconic and Baseline ($p<0.001$), Bird's-eye View and Baseline ($p<0.001$). The quantity of the values (on average 0.56 s), however, can be considered as not endangering. Glance frequency (Diagram 4.10, on the right) is also influenced by the assistance: $F(2;74)=10.61$, $p<0.001$, significant differences ($p<0.001$) in post hoc comparisons both between Iconic and Baseline, Bird's-Eye View and Baseline conditions. The safety tolerant value of mean 0.35 times per second is not exceeded in any of the conditions.

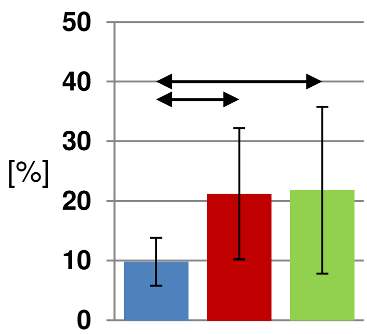
Maximum glance duration (Diagram 4.11, on the right) does not significantly differ in tested conditions: $F(2;72)=1.21$, $p=0.3$. Total percentage of time (Diagram 4.11, on the right), spend looking on the instrument panel during activation of the system, increases: $F(2;74)=22.71$, $p<0.001$, post hoc Iconic vs. Baseline and Bird's-Eye View vs. Baseline conditions – $p<0.001$. 32% used as the permissible limit is not reached by mean values in any of the cases: in the case of Iconic HMI on average 21.2% of glance time is directed towards the instrument cluster, in the case of Bird's-Eye View – 21.8%. However, these numbers might decrease with the long-term usage of a system similar to the findings of *Wohlfarter, 2005*.

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected <u>when driving through 13 investigated situations</u> in following conditions:

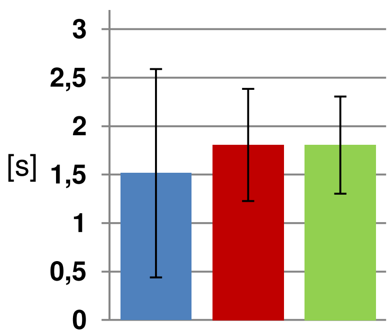
Baseline   Iconic   Bird's-Eye View

⟷ *signifies that p<0.05, ANOVA with post hoc comparisons using Bonferroni corrections*

Percentage of time spent looking at instrument cluster, in %



Maximum glance duration of the glances, directed at instrument cluster, in s



	in %, Ø±sd	**in s, Ø±sd**
Baseline	8.06±4.09	2.19±1.78
Iconic	21.2±11	2.3±1.00
Bird's-Eye	21.8±14	2.02±0.60

Diagram 4.11: Results of visual behavior – percentage of time spent looking at the instrument cluster and maximum glance duration, compound analysis of separate situation

4.7 RESULTS OF DRIVER BEHAVIOR

In this chapter, results regarding driver behavior are provided. At first, efficiency benefit reached via usage of the anticipatory ADAS throughout the entire drive is explained. Afterwards the detailed analysis of separate situations is given. It includes a description of the evolution of anticipation horizon in some of the investigated situations under Baseline condition, and benefits in efficiency and safety reached via its extension by the anticipatory driver assistance system.

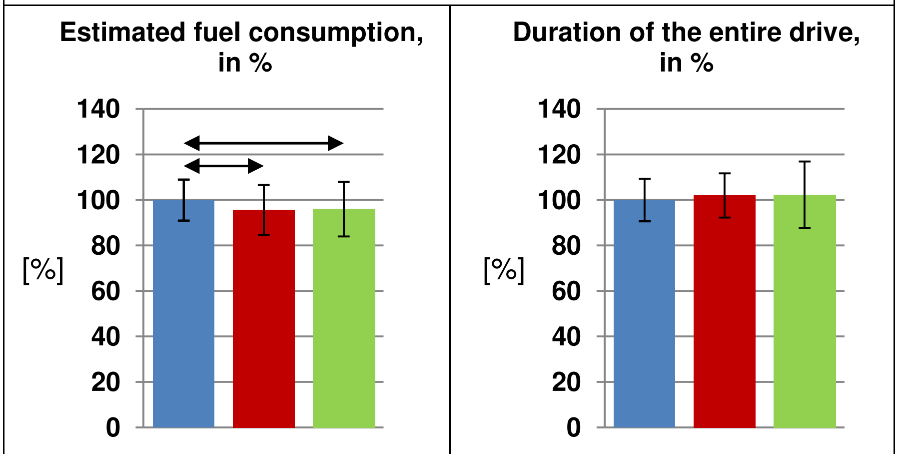
4.7.1 Entire drive

Assistance has a significant influence on the estimated fuel consumption determined for the entire course: $F(2;75)=9.203$, $p<0.01$. When driving with Iconic or Bird's-Eye View assistance, the test subjects save on average 4% of the estimated fuel (post hoc comparison Iconic vs. Baseline: $p=0.001$, and Bird's-Eye View vs. Baseline: $p=0.022$). The duration of the assisted drives increases on 2%: $F(2;75)=3.21$, $p=0.058$. The descriptive values are given in Diagram 4.12.

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected when driving the entire course in following conditions:

Baseline — Iconic — Bird's-Eye View

←→ *signifies that p<0.05, ANOVA with post hoc comparisons using Bonferroni corrections*



	in %, Ø±sd	in %, Ø±sd
Baseline	100±9	100±9.3
Iconic	95.6±11	102±9.7
Bird's-Eye	96±12	102.4±14.6

Diagram 4.12: Results of driver behavior – estimated fuel consumption and duration of the drives

The observed average reduction of estimated fuel consumption during assisted drives is explained by the fact, that in some of the thirteen investigated situations test subjects with the help of received assistance information are able to prolong coasting phases. This subsequently leads to lower estimated fuel consumption.

In the following, the detailed analysis of driver behavior, increased efficiency, and safety in separate situations is provided. For the majority of the situations, the evolution of driver anticipation horizon and resulting driving actions in Baseline condition are analyzed in detail. This is done to establish the potential for the anticipatory ADAS of increase in efficiency, comfort, and safety. Afterwards the driving actions in Baseline are compared to the ones occurring in Bird's-Eye View and Iconic conditions. Efficiency, comfort, and safety benefits, if observed, are explained.

It should be mentioned, that analysis of Baseline drives with respect to the perception is justified by the fact that the visibility of the simulated environment is comparable to the real life conditions in majority of the situations. Namely, the analyzed situations become recognizable in the simulated world at the same distance, as it would be the case in reality. If, in some of the situations, simulated environment and visibility cannot be compared to the real life conditions (e.g. involving traffic lights or signs), the detailed analysis of evolution of natural anticipation horizon is omitted.

4.7.2 Construction site behind a right curve

Evolution of driver anticipation horizon and resulting driver behavior in Baseline: Table 4.1 presents the description of evolution of anticipation horizon of drivers and their resulting behavior. The descriptive values, metric distances (DIST) and time distances (TTC) which are left from particular point of course (CoastOpt, SitVis, CoastReal, SitSeen, BrakeReal) to the situation itself (construction site), are provided.

At time point CoastOpt, when the coasting phase with the optimal efficiency consideration should begin, the situation is not yet visible. Therefore, it is impossible for a driver to start this efficiency-optimized action without additional information. Even when the situation becomes visible for the first time, drivers do not see it immediately. This is explained by the preceding right curve before the construction site, which drivers first have to negotiate and therefore spend more time than usual looking on the road in a near field *(Serafin, 1994,* and *Schweigert, 2003)*. Approximately in the beginning of the curve drivers release the accelerator and start coasting. At this time point, it is almost 200 m after CoastOpt.

Table 4.1: "Construction site behind a right curve" – evolution of driving and driver situations with resulting driver behavior during unassisted drives

ANALYSIS POINT	DIST/TTC (Ø±SD)	DRIVING SIT.	DRIVER SIT.	PERFORMED DRIVING BEHAVIOR
Coast Opt	544±50 m 18.8±1.2 s	Constr. site is not visible	Driver sees a light right curve in front, no other vehicles are in the view	Driver keeps the foot on the accelerator
Sit Vis	450 m 14.8±1.7 s	Constr. site is visible, curve in front, no other traffic participants	Driver approaches the curve	Driver keeps the foot on the accelerator
Coast Real	384±93 m 13.0±2.7 s	Start of curve	Driver concentrates on driving the curve	Driver releases the accelerator pedal and starts coasting, sometimes interrupting it by slight acceleration
Sit Seen	273±78 m 10.2±3.0 s	End of curve, oncoming traffic appears near constr. site	Driver sees the construction site and oncoming traffic	Driver keeps coasting
BrakeReal	266±49 m 9.4±1.8 s		Driver realizes that the oncoming traffic will not allow overtaking	Driver starts braking

Time point SitSeen, at which the situation is seen, can be explained by following circumstances: the curve is left behind, the driver is on the straight part of the road, and approximately at this distance construction site first appears in the driver's focus of expansion. According to *Underwood et al. (2002)*, on the straight parts of the road two thirds of the time driver spends looking in the direction of the focus of expansion. In another investigation of *Schweigert (2003)*, it is shown that depending on the traffic density, type of road, etc., drivers spend 30 – 50% of the time looking towards the focus of expansion. Therefore, 270-320 m is an expected distance, at which the driver first time perceives the obstacle.

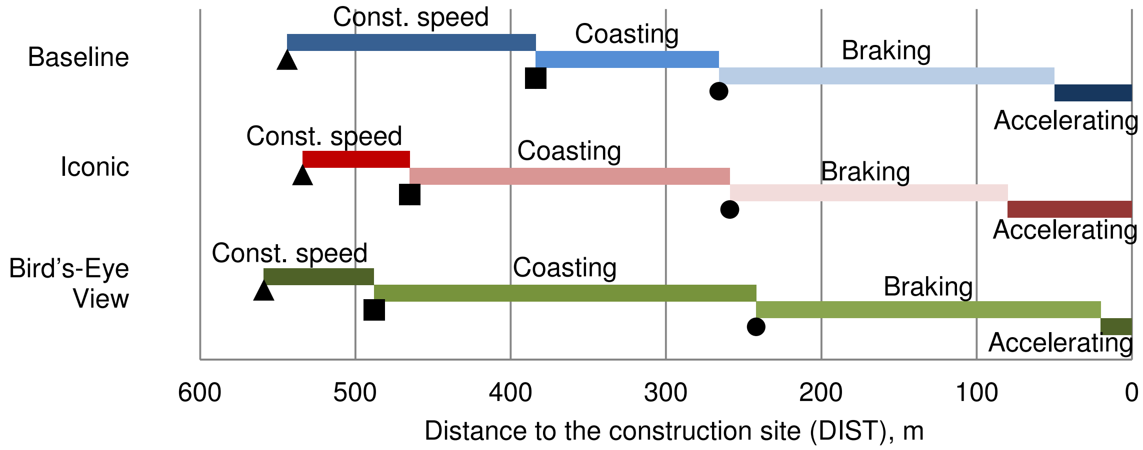
TTC at the point SitSeen in Baseline condition provides drivers with enough time to decide on the deceleration action and to perform it in a comfortable manner. This is confirmed by the beginning of the braking sequence, which is initiated between 300 m and 200 m before the construction site is reached. The distance at point BrakeReal is more than enough for comfortable deceleration way (distance needed to brake on the border of comfort is 160 m when decelerating from 100 to 0 km/h).

It should be noted, that approximately 40-50 m before the construction site, the beginning of overtaking maneuver becomes possible, i.e. oncoming traffic on the opposite lane is gone. This is the time point, when the test subjects start again accelerating while overtaking the obstacle.

To summarize these results with respect to potential of the anticipatory driver assistance system in this situation, it can be stated that unassisted deceleration actions of drivers can be improved with respect to the efficiency criterion. In this situation, it is possible to reduce estimated fuel consumption by providing early information about the deceleration situation and suggesting a coasting action. This assumption is verified by the results, presented in the following.

Driver anticipation horizon and resulting driver behavior in Bird's-Eye View and Iconic drives: in this section, the focus is put on the difference between start of coasting phases during assisted and Baseline drives. Also start of braking sequence is compared. Time and metric distances (TTC and DIST) to the situation for analysis points CoastOpt, Coastreal, and BrakeReal are provided in Diagram 4.13.

Drivers are not able to see the situation when the assistance proposes starting the coasting phase, approximately 550 m before the site. Nevertheless, test subjects accept the advice of the system and start coasting a vehicle. Test subjects start coasting approximately 100 m earlier as opposed to Baseline condition. Significantly earlier start of the coasting phase, $F(2;75)=64.39$, $p<0.001$ ($p=0.012$ for Iconic and $p=0.001$ for Bird's-Eye in post hoc comparisons to Baseline; done for TTC), results in reduction of estimated fuel consumption (Diagram 4.14): $F(2;75)=35.25$, $p<0.001$ ($p<0.046$ in post hoc comparison between Iconic and Baseline, $p<0.001$ between Bird's-Eye View and Baseline).



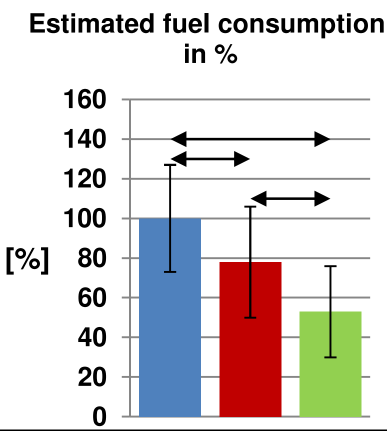
	▲CoastOpt DIST/TTC (Ø±SD)	■ CoastReal DIST/TTC (Ø±SD)	● BrakeReal DIST/TTC (Ø±SD)
Baseline	544±50 m 18.8±1.2 s	384±93 m 13.0±2.7 s	266±49 m 9.4±1.8 s
Iconic	534±79 m 18.5±1.9 s	465±91 m 16.0±3.0 s	259±102 m 8.9±3.3 s
Bird's-Eye View	559±42 m 18.4±1.6 s	488±75 m 16.0±2.3 s	242±101 m 7.9±3.4 s

Diagram 4.13: "Construction site behind a right curve" – enhanced driver anticipation horizon and resulting behavior, comparison to Baseline

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected <u>when driving through situation "Construction site behind a right curve"</u> in following conditions:

■ Baseline ■ Iconic ■ Bird's-Eye View

◄──► *signifies that p<0.05, ANOVA with post hoc comparisons using Bonferroni corrections*



	in %, Ø±sd
Baseline	100±27
Iconic	78±28
Bird's-Eye	53±23

Diagram 4.14: "Construction site behind a right curve" – estimated fuel consumption

The difference between mean values in Bird's-Eye View and Iconic assisted drives for estimated fuel consumption is not influenced by the assistance concept: during Bird's-Eye drives, additional factors contribute to lower fuel consumption. The initial speed with which the subjects enter the analyzed segment is higher during the Bird's-Eye View assisted drives, on average 106 km/h compared to 98 km/h in Iconic condition. Therefore, during Iconic condition, a test subject is generally farther away from the construction site at the time point when overtaking becomes possible, than in Bird's-Eye View condition. This fact leads to the longer acceleration phase (depicted in Diagram 4.14), and increased estimated fuel consumption for Iconic in comparison to Bird's-Eye View.

In Chapter 5.9 "Discussion", consideration of setup and interpretation of similar situations in the following experiments is discussed.

4.7.3 Construction site in a left curve

Evolution of driver anticipation horizon and resulting driver behavior in Baseline: This situation differs from the previously described situation by the sharper curve, and the construction site is located in the curve itself. Therefore, the situation becomes visible just at a distance of 280 m (TTC 10.1±1.2 s), see Table 4.2. Drivers see it close to their focus of expansion, at a distance of 210±37 m with TTC of 8.0±1.9 s. The braking action is performed at the distance 165 ± 89 m, TTC 5.7±2.8 s, which is already close to the distance needed to decelerate on the border of comfort. Longer times and traveled distances compared to the previous situation between SitSeen and BrakeReal are explained by the fact that in the curve drivers do not clearly see the oncoming traffic, and therefore delay the decision regarding performance of deceleration maneuver.

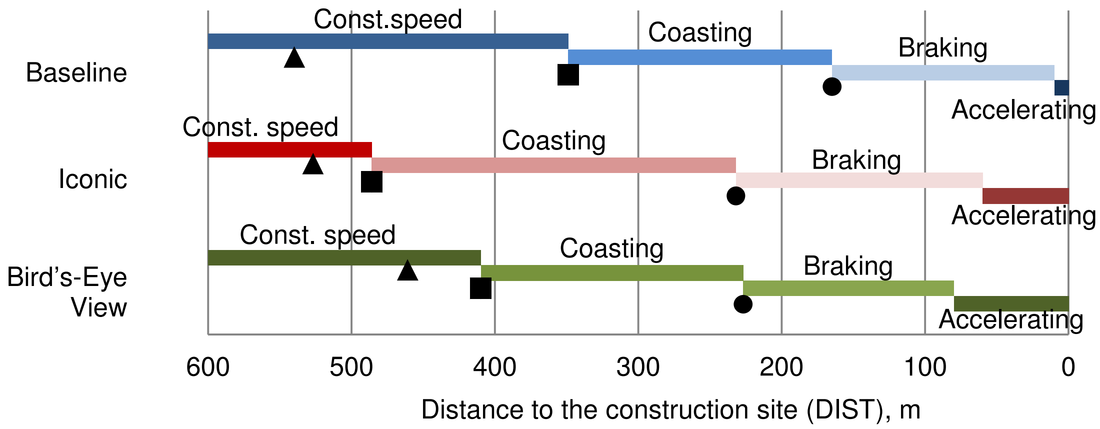
Table 4.2: Construction site in a left curve – evolution of driving and driver situations with resulting driver behavior during unassisted drives

ANALYSIS POINT	DIST/TTC (Ø±SD)	DRIVING SIT.	DRIVER SIT.	PERFORMED DRIVING BEHAVIOR
CoastOpt	540±93 m 17.9±2.5 s	Constr. site is not visible, straight part of the road	Driver sees a left curve in front, no other vehicles are in the view	Driver keeps the foot on the accelerator
CoastReal	349±163 m 11.6±4.6 s	Constr. site is not visible, start of the curve	Driver concentrates on driving the curve	Driver releases the accelerator pedal and starts coasting, sometimes interrupting it by slight acceleration
SitVis	280 m 10.1±1.2 s	Constr. site is visible	Driver is negotiating the curve	Driver keeps coasting
SitSeen	210±37 m 8.0±1.9 s		Driver sees the construction site, but not yet the oncoming traffic	Driver keeps coasting
BrakeReal	165±89 m 5.7±2.8 s	Constr. Site and oncoming traffic are both visible	Driver realizes that the oncoming traffic will not allow overtaking	Driver starts braking
Accelerate	On average 10 m	Oncoming traffic preventing overtaking is gone	Driver has to overtake the constr. site	Driver starts accelerating

In this situation, earlier information from ADAS could clearly increase efficiency and comfort. Drivers start coasting 200 m after the CoastOpt point.

Driver anticipation horizon and resulting driver behavior in Bird's-Eye View and Iconic drives: During assisted drives, test subjects accept the advice of the system and start coasting phase significantly earlier, up to 150 m, compared to Baseline condition: $F(2;75)=14.56$, $p<0.001$ (Diagram 4.16). However, earlier start of the coasting phase does not result in the reduction of estimated fuel consumption on the analyzed segment. Drivers are informed via the assistance about the construction site early enough to reduce their speed, let the oncoming traffic pass, and accelerate before coming too close to a construction site unlike in Baseline condition. During the unassisted drives, majority of the test subjects come to a full stop just before the construction site. Due to the longer acceleration phases in the assisted drives on the analyzed segment no fuel reduction is detected.

It should be mentioned, that the beginning of braking phases during assisted drives is earlier in comparison to those observed during Baseline condition. This fact contributes implicitly to the increase in comfort and safety via usage of the anticipatory ADAS.



	▲CoastOpt DIST/TTC (Ø±SD)	■ CoastReal DIST/TTC (Ø±SD)	● BrakeReal DIST/TTC (Ø±SD)
Baseline	540±93 m 17.9±2.5 s	349±163 m 11.6±4.6 s	165±89 m 5.7±2.8 s
Iconic	527±92 m 18.1±2.2 s	486±92 m 16.5±2.6 s	232±121m 8.2±3.5s
Bird's-Eye View	461±96 m 17.0±2.4 s	410±87 m 14.9±2.4 s	227±93m 8.3±3.4s

Diagram 4.15: "Construction site in a left curve" – enhanced driver anticipation horizon and resulting behavior, comparison to Baseline

4.7.4 Town entrance

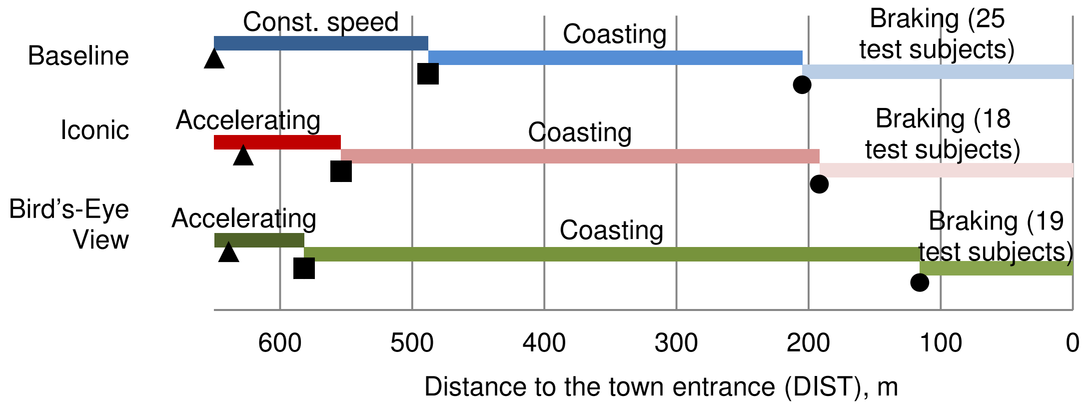
Evolution of driver anticipation horizon and resulting driver behavior in Baseline: This situation is well visible due to a surrounding field landscape and well recognizable even at the larger distances because of the multiple houses located near the town entrance. It also does not involve any other driving vehicles and there is little uncertainty in the development of the situation. Therefore, test subjects see the town entrance more than 300 m before they reach it, see Table 4.3 (comparatively large distance to the distances, observed in other investigated situations). Coasting phase, started earlier, approximately 500 m before the entrance, due to the light curves, is kept throughout the drive without unnecessary accelerations "in between". However, there is still a difference of at least 150 m between CoastOpt and CoastReal, leaving the room for ADAS efficiency potential.

Table 4.3: "Town entrance" – evolution of driving and driver situations with resulting driver behavior during unassisted drives

ANALYSIS POI	DIST/TTC (Ø±SD)	DRIVING SIT.	DRIVER SIT.	PERFORMED DRIVING BEHAVIOR
Coast Opt	650±50m 21,4±2,7s	Entr-ce is not visible	Driver sees the straight part of the road	Driver keeps the foot on the accelerator
Sit Vis	500m 16,7±5,1s		Driver sees the light curve in front	Driver keeps the foot on the accelerator
Coast Real	488±135m 15,8±4,1s		Driver concentrates on driving through the curve	Driver releases the accelerator pedal and starts coasting
Sit Seen	332±132m 11,8±4,1s	Entr-ce is visible	Driver sees the town entrance and decides not to change a driving action	Driver does not change the behavior, i.e. keeps coasting
BrakeReal	205±110m 6,5±3,4s		Most of drivers (25 out of 26) decide to decelerate stronger	Driver starts braking (minimum decelerations reached by the participants are usually > -3m/s2)

Driver anticipation horizon and resulting driver behavior in Bird's-Eye View and Iconic drives: Again the duration of coasting phases during assisted drives is longer, than those observed in Baseline. They start on average 50-100 m earlier ($F(2;75)=16.4$, $p<0.001$). Nevertheless, this fact does not result in a decrease of estimated fuel consumption.

Again difference in initial speeds and driving actions are important, with which the analyzed situation segment is entered. During Iconic and Bird's-Eye View assisted drives, in the beginning of analyzed segment the acceleration phases are observed. Drivers do not reach expected speed of 100 km/h at this time point, and still accelerate after the previous deceleration situation. These factors were not foreseen during the experimental design phase. To summarize, anticipatory assistance in this situation objectively possesses the potential to reduce the fuel consumption, and does prolong duration of coasting phases up to 100 m. Due to unforeseen acceleration phases, this fact is not confirmed by assisted drives, even though the duration of coasting phases is increased.



	▲CoastOpt DIST/TTC (Ø±SD)	■ CoastReal DIST/TTC (Ø±SD)	● BrakeReal DIST/TTC (Ø±SD)
Baseline	650 m 21.4±2.7 s	488±135 m 15.8±4.1 s	205±110 m 7.5±3.5 s
Iconic	628±44 m 23.9±1.9 s	554±90 m 20.5±4.3 s	192±137 m 8.1±5.7s
Bird's-Eye View	639±37 m 23.7±1.9 s	582±77 m 21.3±3.4 s	116±72m 5.0±2.8s

Diagram 4.16: "Town entrance" – enhanced driver anticipation horizon and resulting behavior, comparison to Baseline

The speed, with which the drivers enter the town, does not differ between unassisted and assisted drives, on average it is close to 60 km/h.

4.7.5 Speed limit on the rural road

Evolution of driver anticipation horizon and resulting driver behavior in Baseline: For this situation, no evolution of driver anticipation horizon considering perception of the situation is provided. This is due to a fact, that in the simulated conditions the visibility and especially readability of the traffic signs differ significantly from those under the real conditions. Therefore, the point of time, when drivers first see the sign in the simulated conditions, lies presumably later (mean TTC is 6.7 s, sd=1.5) as it would in reality. Adding to this fact, the readability of the sign is much worse in the simulated world. The speed limit of 70 km/h cannot be read from the distance, when the sign is first seen.

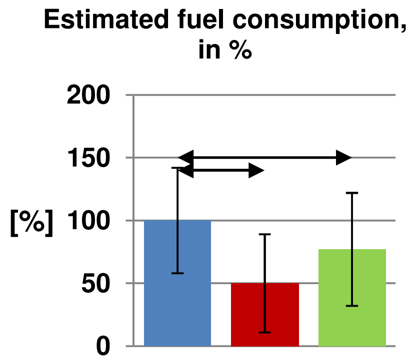
Driving actions in Baseline condition are analyzed with respect to efficiency, namely to see the influence on duration of coasting phases and resulting estimated fuel consumption of the assistance information (Diagram 4.17-18).

Driver anticipation horizon and resulting driver behavior in Bird's-Eye View and Iconic drives: During the situation "Speed limit on the rural road" the drivers are able to save on average between 30-50% of the fuel (Diagram 4.17): $F(2;75)=6.85$, $p<0.005$ ($p<0.004$ for Iconic and $p<0.05$ for Bird's-Eye in the post hoc comparison with Baseline).

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected when driving through situation "Speed limit on the rural road" in following conditions:

Baseline | Iconic | Bird's-Eye View

⟷ *signifies that p<0.05, ANOVA with post hoc comparisons using Bonferroni corrections*

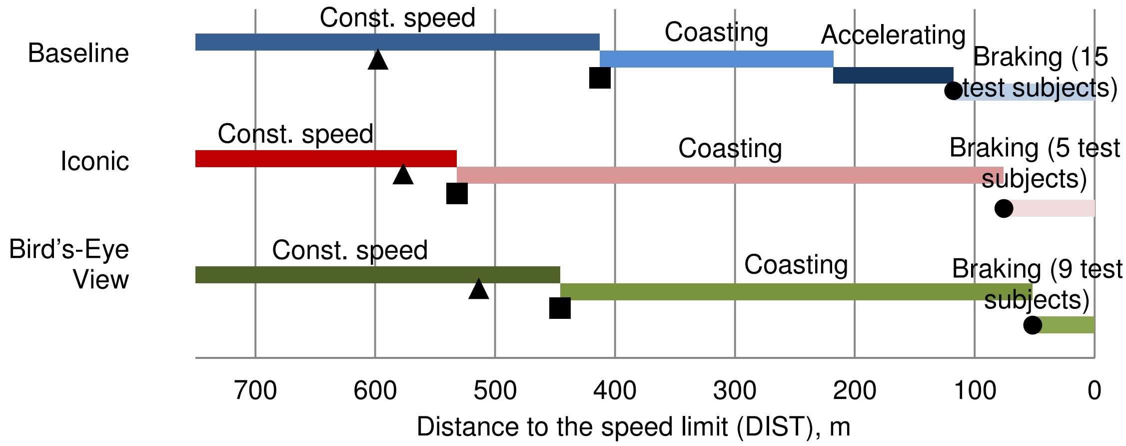


	in %, Ø±sd
Baseline	100±42
Iconic	50±39
Bird's-Eye	77±45

Diagram 4.17: "Speed limit on the rural road" – estimated fuel consumption

Test subjects, while driving without assistance, are accelerating on the straight parts of the course after first releasing the accelerator due to the incoming light curves before the speed limit sign becomes apparent. With assistance, they prefer to coast the vehicle until the speed limit sign is reached without accelerating "in between". Therefore, the longest coasting part in Baseline condition, approximately 200 m, is considerably shorter compared to those during assisted drives, which amount to 400 – 450 m (Diagram 4.18).

Another important result is the speed, with which the traffic sign is bypassed. It is on 10 km/h lower with the assistance concepts: during Baseline condition subjects drive by the traffic sign on average with 87 km/h, during Iconic – with 76 km/h, and Bird's-Eye View – with 78 km/h.



	▲CoastOpt DIST/TTC (Ø±SD)	■ CoastReal DIST/TTC (Ø±SD)	● BrakeReal DIST/TTC (Ø±SD)
Baseline	598±190 m 18.7±4.6 s	413±255 m 13.5±7.2 s	(15 test subjects) 118±46 m 5.4±2.2 s
Iconic	577±194 m 17.4±4.9 s	532±208 m 16.4±5.3 s	(5 test subjects) 76±53 m 4.0±2.6s
Bird's-Eye View	514±177 m 17.4±3.8 s	446±160 m 15.8±3.6 s	(9 test subjects) 52±44 m 2.8±2.3s

Diagram 4.18: "Speed limit on the rural road" – enhanced driver anticipation horizon and resulting behavior, comparison to Baseline

4.7.6 First and second slower preceding vehicles in the vicinity of prohibited overtaking

In this situation, no improvement in fuel consumption is established. Due to a comparatively low difference between driven and goal speed, as well as good visibility conditions, no significant difference between assisted and natural driving behavior is observed. Overall, it can be stated that if the driver can see the deceleration situation early enough and the optimal coasting phase lasts approximately 150 m, the drivers are able to time and perform the deceleration action in a comfortable and efficient manner.

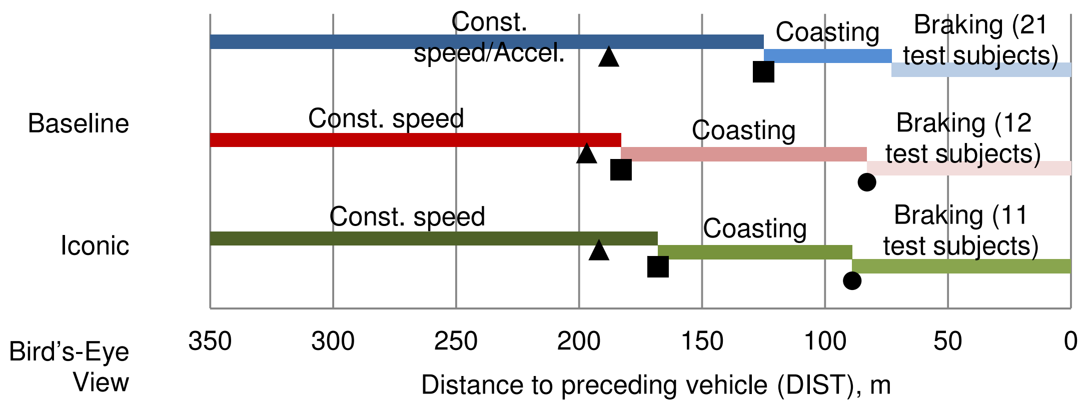
4.7.7 Slower preceding vehicle and oncoming traffic

Evolution of driver anticipation horizon and resulting driver behavior in Baseline: In this situation, test subjects see the slower preceding vehicle well before the coasting phase optimizing fuel consumption should begin. However, instead of decreasing the driven speed, drivers accelerate in the hope of overtaking this lead vehicle (Table 4.4). Only when noticing vehicles on the opposite lane prohibiting overtaking, test subjects first release the accelerator, and subsequently depress the brake pedal.

Table 4.4: Slower preceding vehicle and oncoming traffic – evolution of driving and driver situations with resulting driver behavior during unassisted drives

ANALYSIS POINT	DIST/TTC (Ø±SD)	DRIVING SIT.	DRIVER SIT.	PERFORMED DRIVING BEHAVIOR
SitVis/ SitSeen	350 m 32.4±17.9 s	Preceding vehicle is visible, but not the oncoming traffic	Driver keeps the constant speed or starts accelerating in the hope of uninterrupted overtaking	Driver does not release accelerator
Coast Opt	188±53 m 20.6±10.0 s			
Coast Real	125±47 m 14.1±11.9 s	Oncoming traffic prohibits overtaking	Driver starts moderately decreasing the speed	Driver releases the accelerator pedal and starts coasting
BrakeReal	73±22 m 7.6±3.0 s		Driver realizes that the oncoming traffic will not allow overtaking in foreseeable time	Driver starts braking

Driver anticipation horizon and resulting driver behavior in Bird's-Eye View and Iconic drives: The assistance advises the driver to coast the car down to 60 km/h because of a slower moving lead vehicle with the explanation that the oncoming traffic prohibits immediate overtaking. Thus, the test subject coasts until the oncoming traffic passes and the overtaking maneuver becomes possible without unnecessary acceleration phases; unlike during Baseline condition (Diagram 4.19).



	▲CoastOpt DIST/TTC (Ø±SD)	■ CoastReal DIST/TTC (Ø±SD)	● BrakeReal DIST/TTC (Ø±SD)
Baseline	188±53 m 20.6±10.0 s	125±47 m 14.1±2.9 s	73±22 m 7.6±3.0 s
Iconic	197±34 m 18.6±0.6 s	183±33 m 16.3±2.3 s	83±38 m 10.0±3.6s
Bird's-Eye View	192±44 m 18.5±0.9 s	168±57 m 16.1±2.7 s	89±37 m 10.3±4.6s

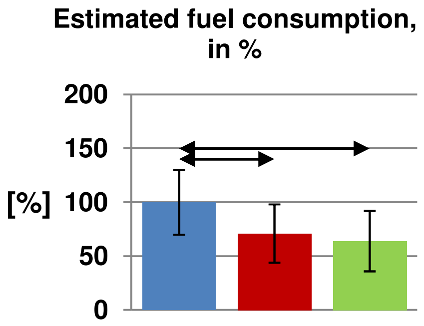
Diagram 4.19: "Slower preceding vehicle and oncoming traffic" – enhanced driver anticipation horizon and resulting behavior, comparison to Baseline

During assisted drives, unnecessary accelerations are minimized because of assistance information. Estimated consumption of fuel is reduced with the help of assistance (Diagram 4.20): $F(2;75)=14.45$, $p<0.001$ ($p=0.002$ for Iconic and $p<0.001$ for Bird's-Eye in post hoc comparisons to Baseline).

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected when driving through situation "Slower preceeding vehicle and oncoming traffic" in following conditions:

Baseline | Iconic | Bird's-Eye View

⟷ *signifies that p<0.05, ANOVA with post hoc comparisons using Bonferroni corrections*



	in %, Ø±sd
Baseline	100±30
Iconic	71±27
Bird's-Eye	64±28

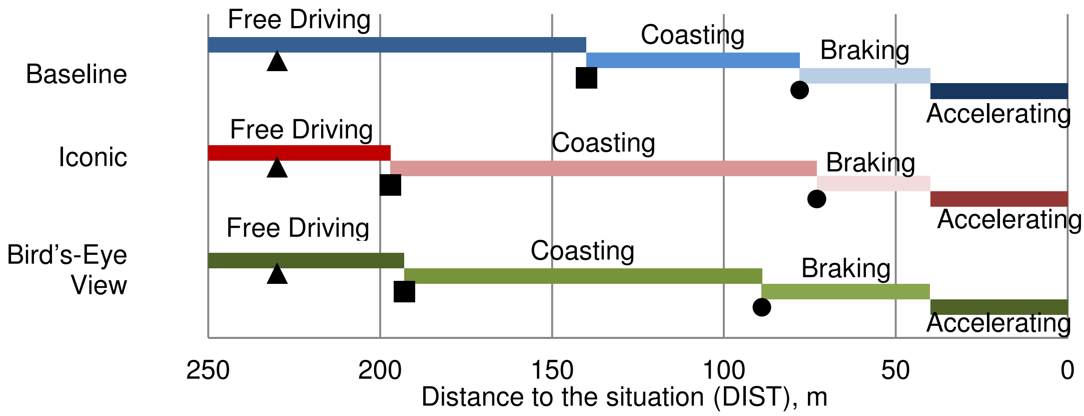
Diagram 4.20: "Slower preceding vehicle and oncoming traffic" – estimated fuel consumption

4.7.8 First and second traffic lights

Evolution of driver anticipation horizon and resulting driver behavior in Baseline: The visibility conditions in the simulated environment do not allow stating any results regarding anticipation horizon of the drivers in Baseline condition: traffic lights and especially their active phases are badly distinguished from the surrounding. Therefore, even when the traffic light box is being noticed, drivers are not able to see which state it is until they are 80-100 m in front of it.

Driver anticipation horizon and resulting driver behavior in Bird's-Eye View and Iconic drives: The analysis of the driver behavior and its comparison between assisted and unassisted drives reveal the difference in the beginning of coasting phases in the situation with the traffic light, in which the optimal coasting phase should start 230 m before it is reached (Diagram 4.21).

This earlier start of coasting phases, however, does not result in reduction of estimated fuel consumption on the analyzed segment: accelerations in the assisted drives are comparatively higher, than those in Baseline.



	▲CoastOpt DIST/TTC (Ø±SD)	■ CoastReal DIST/TTC (Ø±SD)	● BrakeReal DIST/TTC (Ø±SD)
Baseline	230 m 15.9±2.4 s	140±58 m 9.8±3.3 s	78±43 m 5.9±2.5 s
Iconic	230 m 16.7±2.3 s	197±33 m 13.9±3.3 s	73±21 m 6.2±2.1 s
Bird's-Eye View	230 m 13.5±3.0 s	193±32 m 12.5±2.4 s	89±34 m 6.3±1.7 s

Diagram 4.21: "Traffic light (shorter coasting phase)" – enhanced driver anticipation horizon and resulting behavior, comparison to Baseline

In the situation with traffic light, in which the optimal coasting phase should have lasted approximately 430 m, no changes either in driving behavior or in estimated fuel consumption are established. Basically, in this particular situation unlike in any other the advice of the system is ignored: drivers accelerate and do not reduce the driven speed until they come 200 – 250 m before the intersection.

4.7.9 Parking car

Evolution of driver anticipation horizon and resulting driver behavior in Baseline: In general, drivers see the situation early and react fast enough, which can be explained by relatively short distances on urban roads to make a maneuvers and particular alertness to the numerous obstacles requiring deceleration. However, on average the efficiency optimized action should have started 30 m before (Table 4.5). But it should be kept in mind, that in complex situations, which are common on the urban roads, the optimal coasting usually cannot be started even if the driver is informed in advance about particular incoming deceleration situation. More imminent situations can be of the outmost importance at this point of time, e.g. driving through the intersection, making a turn, etc.

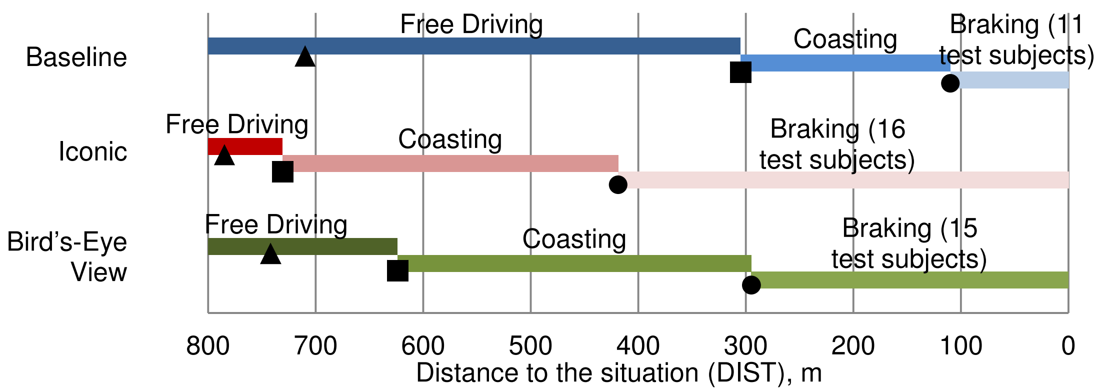
Driver anticipation horizon and resulting driver behavior in Bird's-Eye View and Iconic drives: In this situation, anticipatory assistance information does not lead to any change in driver behavior. No significant differences are detected neither in the beginning of coasting phases, nor in their duration. As a result, estimated fuel consumption is also approximately the same in every condition.

Table 4.5: "Parking car" – evolution of driving and driver situations with resulting driver behavior during unassisted drives

ANALYSIS POINT	DIST/TTC (Ø±SD)	DRIVING SIT.	DRIVER SIT.	PERFORMED DRIVING BEHAVIOR
CoastOpt/ SitVis	150m 10,6±1,2s	Park. car is visible	Driver looks at the upcoming intersection, where the driven road is the main road	Driver keeps the foot on the accelerator
CoastReal	126±33 9,1±2,4s		Driver sees the parking car and oncoming traffic, which makes immediate overtaking impossible	Driver releases the accelerator pedal and starts coasting
SitSeen	125±23 9,0±1,8s			
BrakeReal	69±19m 4,9±1,2s		Driver realizes that the oncoming traffic will not allow overtaking in foreseeable time	Driver starts braking*

4.7.10 Speed limit on highway

Evolution of driver anticipation horizon and resulting driver behavior in Baseline: For the same reasons as in the situation "Speed limit on rural road", natural anticipation horizon of drivers is not discussed in detail. However, it should be noticed, that even though during unassited drives test subjects are not able to see the incoming speed limit until approximately 150 m they reach it, they start coasting considerably earlier (Diagram 4.22).



	▲CoastOpt DIST/TTC (Ø±SD)	■ CoastReal DIST/TTC (Ø±SD)	● BrakeReal DIST/TTC (Ø±SD)
Baseline	728±205 m 15.0±3.0 s	323±188 m 6.7±3.6 s	110±60 m 2.5±1.5 s
Iconic	785±193 m 15.3±3.1 s	731±186 m 14.3±3.1 s	419±230 m 8.6±4.2 s
Bird's-Eye View	742±177 m 15.2±2.5 s	624±194 m 12.8±3.4 s	295±174 m 6.8±3.8 s

Diagram 4.22: "Speed limit on highway" – enhanced driver anticipation horizon and resulting behavior, comparison to Baseline

During the discussion after completing the drives, many of the test subjects admitted, that in this situation they decided to follow the exmaple of simulated lorries on the right lane, which start to moderately reduce speed 350 – 400 m before the speed limit.

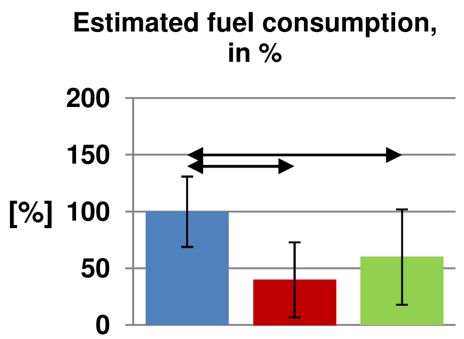
Driver anticipation horizon and resulting driving behavior in Bird's-Eye View and Iconic drives: During assisted drives, test subjects become aware of the 120 km/h speed limit 750 – 800 m before they reach it. They follow the advice of the system suggesting start of a coasting phase, and are able to reduce on average 50% of fuel on the analyzed segment (Diagram 4.23). Statistical analysis proves significant differences: $F(2;75)=22.55$, $p<0.001$ (post hoc: Baseline vs. Iconic – $p<0.001$, Baseline vs. Bird's-Eye View – $p<0.006$).

Also the speed, with which traffic sign is bypassed, is closer to the optimal speed during assisted drives than in unassisted. This speed in Baseline condition is on average 140 km/h, it is 124 km/h during drives assisted via Iconic HMI, and 130 km/h – during Bird's-Eye View HMI assistance.

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected <u>when driving through situation "Speed limit on highway"</u> in following conditions:

Baseline — Iconic — Bird's-Eye View

⟷ *signifies that p<0.05, ANOVA with post hoc comparisons using Bonferroni corrections*



	in %, Ø±sd
Baseline	100±31
Iconic	40±33
Bird's-Eye	60±42

Diagram 4.23: "Speed limit on highway" – estimated fuel consumption

4.7.11 Stagnant traffic on highway

Evolution of driver anticipation horizon and resulting driver behavior in Baseline: It is an easy situation to anticipate by drivers themselves. The imposed 100 km/h speed limit on this part of the road implicitly suggests that slower moving vehicles are to be expected. Table 4.6 provides a qualitative overview of evolution of anticipation horizon and resulting actions.

Table 4.6: "Stagnant traffic on highway" – evolution of driving and driver situations with resulting driver behavior during unassisted drives

ANALYSIS POINT	DIST/TTC (Ø±SD)	DRIVING SIT.	DRIVER SIT.	PERFORMED DRIVING BEHAVIOR
CoastOpt/ SitVis	159±56 m 24,5±12,6 s	Cars are visible	Driver sees the slower moving cars in front of him	Driver keeps the foot on the accelerator
SitSeen	152±50 m 18,5±3,2 s		Driver approaches the slower moving cars	Driver releases the accelerator pedal and starts coasting
CoastReal	122±33 m 14,7±4,6 s			
BrakeReal	80±34 m 9,6±4,0 s		19 drivers decide to decelerate stronger	Drivers start braking mildly

Driver anticipation horizon and resulting driver behavior in Bird's-Eye View and Iconic drives: Like in the situations "First and second slower preceding vehicles in the vicinity of prohibited overtaking" and "Parking car", driver behavior during assisted drives does not differ significantly when comparing to Baseline. No changes in fuel consumption or experienced decelerations are observed.

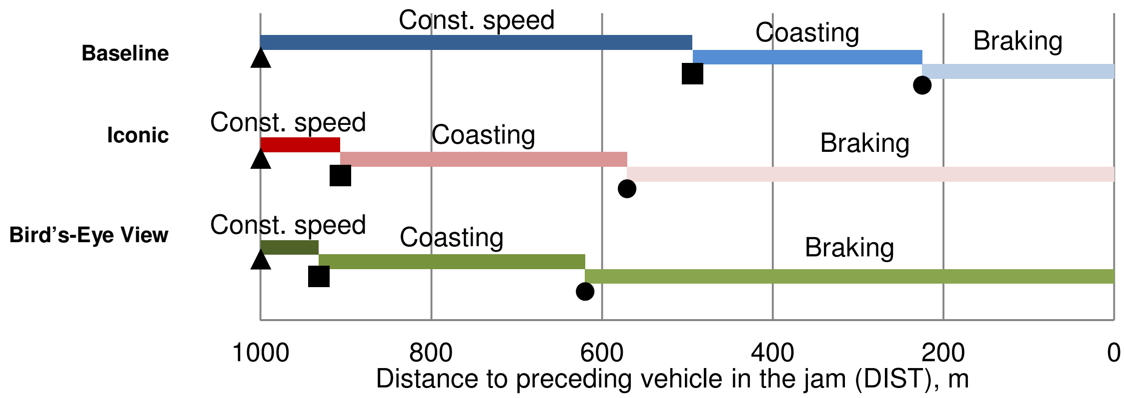
4.7.12 Highway jam

Evolution of driver anticipation horizon and resulting driver behavior in Baseline: In this situation, the safety criterion is crucial. The idle jam is located behind a curve with 700 m radius. Driven speed is deliberately chosen by the drivers. During experiment drives, the average speed driven at this segment is around 150 km/h. In reality, this kind of an idle jam located exactly behind a curve happens quite seldom, and can be caused by e.g. some accident. In such situations ADAS help can fundamentally increase safety. Coasting from the driven speed of 150 km/h would last for more than 1.5 km. Therefore, the focus is put on when and where the drivers should start moderately braking. The exact values are presented in Table 4.7.

Table 4.7: "Highway jam" – evolution of driving and driver situations with resulting driver behavior during unassisted drives

ANALYSIS POINT	DIST/TTC (Ø±SD)	DRIVING SIT.	DRIVER SIT.	PERFORMED DRIVING BEHAVIOR
BrakeOpt	1000 m -	Jam is not visible	Driver sees straight part of the highway road and a following curve	Driver keeps the foot on the accelerator
CoastReal	494±259 m 14.8±6.4 s		Driver concentrates on driving through the curve	Driver releases the accelerator pedal and starts coasting
SitVis	260 m 7.8±1.8 s	Jam is visible		
SitSeen	247±10 m 6.7±1.8 s		Driver sees the jam	Driver does not yet change the behavior, i.e. keeps coasting (reaction time)
BrakeReal	225±50 m 6.4±1.7 s		Driver rapidly decelerates	Driver starts braking hard (average decelerations reached -8,4m/s2)

Driver anticipation horizon and resulting driver behavior in Bird's-Eye View and Iconic drives: Drivers approach a jam behind a curve and have to come to a full stop. Here the efficiency criterion is less important than the safety. In baseline drives, four collisions occurred, while with assistance – none.



	▲BrakeOpt DIST/TTC (Ø±SD)	■ CoastReal DIST/TTC (Ø±SD)	● BrakeReal DIST/TTC (Ø±SD)
Baseline	1000 m 24.3±5.0 s	494±259 m 14.8±6.4 s	225±50 m 6.4±1.7 s
Iconic	1000 m 21.2±2.9 s	907±83 m 20.5±4.1 s	571±239 m 13.3±5.2s
Bird's-Eye View	1000 m 22.7±3.9 s	932±42 m 22.3±4.3 s	620±246 m 15.2±5.2s

Diagram 4.24: "Highway jam" – enhanced driver anticipation horizon and resulting behavior, comparison to Baseline

The coasting phase without the assistance starts in the curve with TTC of 13 s, followed by hard braking with TTC=6.4 s once the jam tail is seen by the drivers (Diagram 4.24-25). With assistance the driver starts coasting significantly earlier ($F(2;24)=28.289$, $p<0.001$), just after the situational information is displayed. The braking phase for assisted drives begins with TTC 13 s-15 s in the curve (Diagram 4.24-25), earlier than in baseline: $F(2;24)=28.817$, $p<0.001$. As a result, maximum decelerations are significantly reduced (Diagram 4.25), $F(2;24)=11.929$, $p<0.001$ (for Iconic $p<0.005$ and for Bird's-Eye View condition $p<0.001$, compared to the Baseline), and collisions are avoided.

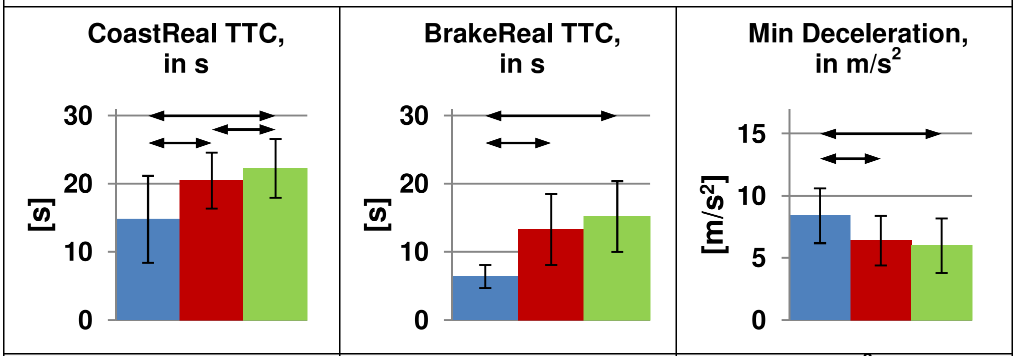
In-depth analysis of accidents: During this situation, four accidents happened (Table 4.8). The subjects that caused the accidents are all experienced drivers. In three of the cases (test subjects 10, 11, 19), drivers perceived the situation at the time point with critically small TTCs < 5 s *(van der Horst et al., 1990a)*. Their decelerations did not suffice to come to a full stop. In the beginning of emergence braking, non-trained drivers rarely are able to reach necessary maximum decelerations *(Breuer, 2009)*.

Subject 16 saw the situation when it first became visible. In this case, the evaluation of the situation was wrong – the driver did not realize that the vehicles are idle, and as a result did not try to perform the emergency braking.

Presented Ø and sd values are calculated using data of 26 test subjects, which are collected when driving through situation "Highway jam" in following conditions:

Baseline | Iconic | Bird's-Eye View

←→ *signifies that $p<0.05$, ANOVA with post hoc comparisons using Bonferroni corrections*



	in s, Ø±sd	in s, Ø±sd	in m/s², Ø±sd
Baseline	14.8±6.4	6.4±1.7	8.4±2.2
Iconic	20.5±4.1	13.3±5.2	6.4±2.0
Bird's-Eye	22.3±4.3	15.2±5.2	6.0±2.2

Diagram 4.25:" Highway jam" – start of coasting, braking phases, and resulting experienced minimal decelerations

Table 4.8: "Highway jam" – characteristic values observed during four accidents

Subject	Experience (km/year)	Driven speed at SitSeen	SitSeen DIST/TTC	BrakeReal DIST/TTC
10	15.000-20.000	180 km/h (50 m/s)	220 m 4.3 s	200 m 4 s
11	>20.000	184 km/h (51 m/s)	219 m 4.2 s	190 m 3.7 s
16	>20.000	168 km/h (47 m/s)	260 m 5.5 s	200 m 4.3 s
19	15.000-20.000	162 km/h (45 m/s)	209 m 4.6 s	170 m 3.8 s

4.8 DISCUSSION AND SUMMARY

General wish for a driver assistance system, enhancing anticipation horizon, is high – 24 test subjects would like to have the anticipatory ADAS installed in their vehicles. For that, Bird's-Eye View concept has significantly better evaluations regarding likability and understandability when comparing it with Iconic concept. Bird's-Eye View HMI is preferred over Iconic as the basis for the visual interface of the anticipatory ADAS. The assumption made in Chapter 1.2 and Chapter 2.4, that HMI complying with the guidelines for anticipatory ADAS (Chapter 2.3 "General HMI Guidelines for Anticipatory ADAS") possesses higher acceptance than the ones excluding consideration of planning and temporal aspects, is proved.

Results concerning visual distraction emphasize that no critical behavior is caused by tested visual assistance concepts. Neither animated Bird's-Eye View representation of upcoming situation, nor Iconic, do not provoke test subjects to spend more time looking away from the road than is recommended for in-vehicle displays. No critical values are reached either for glance frequency, mean duration of a glance, or its maximal durations.

Regarding efficiency benefit, significant reduction of the estimated fuel consumption is detected: 4% less in the assisted drives compared to Baseline condition. Also during assisted drives no collisions occurred in the situation "Highway Jam", while four collisions occurred in Baseline drives.

It should be noted that generally no significant differences are established between the influence of Bird's Eye View and Iconic assistance concepts on driver behavior. They both help to prolong coasting phases, which eventually lead to the reduction of estimated fuel consumption.

Determination of increased comfort regarding minimal decelerations during assisted drives is not provided in the results presented in this work. Minimal decelerations in non-critical situations, which are observed in Bird's-Eye View and Iconic conditions, rarely significantly differ from those in Baseline. This fact cannot be taken by default as final and correct, because minimal decelerations in static simulator can be deliberately lower compared to those under real conditions, namely with the presence of kinesthetic feedback. Nevertheless, one can find the results regarding minimal decelerations of this experiment in the work of *Rommerskirchen (2009),* and their close consideration shows, that no final conclusion even about their qualitative change can be reached without real life drives. Only in one situation, safety critical "Highway Jam", the qualitative change of minimal decelerations is apparent and obviously dependent on assistance information.

Analysis of anticipation horizon of the drivers in Baseline shows, that characteristic values of metric and time distances, for the points in time of when the situation is seen and when the driver reacts on the perceived information, depend on the situation. The observed tendency in the unassisted drives is that the vast majority of the drivers see non-critical situations involving static objects on time distances greater than 6 s (95% of the cases), and rarely – further than 12 s even if the situation is visible before. Not in all of the situations this suffices to perform the most efficient and safe action.

After the situation is seen, the time of the following reaction during unassisted drives depends on the driving style, driver's experience and age, certainty in future development of the situation, availability of time to plan and decide upon the action, etc. In the assisted drives, on the contrary, test subjects generally follow the advice of the system shortly after it is being displayed, and react by adopting the proposed action of coasting even if the situation is not immediately visible. Depending on the deceleration situation, this amounts to longer coasting phases, reduction of fuel consumption, milder decelerations, and absence of collisions.

4.8.1 Driver acceptance of the proposed visual HMI

Both HMI concepts, Iconic and Bird's-Eye View, increase subjective feeling of safety while driving, and also help adjusting to upcoming deceleration situations. Bird's-Eye View concept is found to be more attractive (likable) and understandable, than Iconic. When asked to choose their favorite of the two concepts, 22 test subjects chose Bird's-Eye View, and only three – Iconic. Commenting on their choice, test subjects most often were mentioning the benefits of timely development of the driving situation, presented via Bird's-Eye View HMI. This allows to judge the remaining distance to it, as well as provides the feeling of the time budget left to act. Enhancement of anticipation, and its planning activities, significantly increases the acceptance of the concept.

4.8.2 Visual distraction

Analysis of visual behavior proves that no critical distraction occurs due to the investigated visual HMI concepts. Even though during assisted drives mean duration of the glances, glance frequency, and percentage of the time spent looking on the instrument panel do increase, the values are by far do not reach limits recommended for in-vehicle displays. Iconic and Bird's-Eye View concepts do not provoke critical and endangering visual behavior neither throughout entire drive, nor during animated HMI phases displaying upcoming deceleration situations.

4.8.3 Earlier start of coasting phase

In majority of the analyzed deceleration situations, drivers start coasting phases significantly earlier when driving with the assistance. Table 4.9 gives the list of situations, for which null hypothesis stating that driving with assistance does not influence the beginning of coasting phase is either rejected in favor of the alternative hypothesis, or failed to be rejected.

Anticipatory driver assistance supports drivers in starting earlier coasting phases in eight investigated situations. These situations possess one or both of the following characteristics:

- situation is not in the field of driver's view, i.e. cannot be seen and therefore anticipated, at the time point, when the beginning of coasting phase from driven to the upcoming lower goal speed should take place;

- development of the situation is not clear at the time point, when the driver first sees it, i.e. slower lead vehicle is seen on the two-lane rural road, but not the oncoming traffic, which is about to prohibit immediate overtaking.

Table 4.9: Visual assistance of anticipatory driving – earlier start of coasting phases, hypothesis testing

H_0 rejected in favor of H_1	H_0 failed to be rejected
1. Construction site behind a right curve	1. First and second slower preceding vehicles in the vicinity of prohibited overtaking
2. Construction site in a left curve	2. Second traffic light
3. Town entrance	3. Parking car
4. Speed limit on the rural road	4. Stagnant traffic on the highway
5. Slower preceding vehicle and oncoming traffic	
6. First traffic light (with shorter coasting phase)	
7. Speed limit on the highway	
8. Highway jam	

In other investigated situations, no influence of the anticipatory assistance on the beginning of coasting phases is confirmed. Characteristic feature of these situations is:

- situation is in the field of driver's view and the necessity to decelerate is clearly evident at the time point, when the beginning of coasting phase from driven to the upcoming lower goal speed should take place.

No difference in the beginning of coasting phases is observed in two out of the three investigated situations in the urban area. It should be noticed, that the only situation in the urban area, in which the coasting with assistance is performed earlier in front of a traffic light, can be due to the specifics of simulated environment – traffic light and its phase are barely distinguishable. In another situation involving traffic light, in which it is proposed to coast a vehicle for a distance of 450 m, drivers generally ignore the advice of the system and do not follow it. It leads to a conclusion, that in urban area prolonged coasting phases are rejected by the drivers, and the longest coasting phases observed are around 200 m.

4.8.4 Efficiency benefit

Throughout entire drive, significant reduction of estimated fuel consumption on 4% due to anticipatory ADAS is observed. Therefore, null hypothesis stating that there are no differences in fuel consumption between Baseline and assisted drives can be rejected in favor of alternative hypothesis. However, situational analysis proved, that not on every analyzed segment drivers are more efficient with the assistance. Table 4.10 provides with the list of situations, in which the efficiency benefit is observed and for which null hypothesis failed to be rejected.

Table 4.10: Visual assistance of anticipatory driving – efficiency benefit, hypothesis testing

H_0 rejected in favor of H_1	**H_0 failed to be rejected**
1. Construction site behind a right curve	1. Construction site behind a left curve
2. Speed limit on the rural road	2. Town entrance
3. Slower preceding vehicle and oncoming traffic	3. First and second slower preceding vehicles in the vicinity of prohibited overtaking
4. Speed limit on the highway	4. First and second traffic light
5. Highway jam	5. Parking car
	6. Stagnant traffic on the highway

Not in every situation, in which coasting phases are longer during assisted drives, efficiency benefit can be observed. These situations are: “Construction site behind a left curve”, “Town entrance”, and “First traffic light”. The main reason is that observed acceleration phases on these segments during assisted drives are longer, than in unassisted. In situation “Construction site behind a left curve”, this is due to the fact that timely development of the situation does not differ between conditions: oncoming traffic prohibiting overtaking allows overtaking at the exactly same time point. Longer coasting phase in assisted drives contributes to the start of earlier acceleration phase compared to Baseline.

In “Town entrance”, test subjects enter analyzed segment in assisted drives still accelerating to reach allowed speed of 100 km/h, while in Baseline they drive steadily this speed. This is due to unconsidered feature of experimental design.

In the urban situation “First traffic light”, test subjects accelerate slightly stronger during assisted drives, and moderately increased coasting phase (on average 50 m) does not amount to a significant reduction of estimated fuel consumption.

Even though on analyzed segments of these three situations no efficiency benefit is observed, longer coasting phases do contribute to overall reduction of fuel consumption. Acceleration phases observed during assisted drives in “Construction site behind a left curve” also are present in Baseline. However, in Baseline condition these accelerations occur later, just after the end of the analyzed segment. On contrary, in situation “Town entrance”, in Baseline condition acceleration to 100 km/h is performed earlier, before the beginning of analyzed segment is reached.

4.8.5 Safety benefit

Both of null hypotheses, stating that neither extreme decelerations nor collisions are reduced when driving with assistance, are rejected. Safety benefit of early information about upcoming potentially critical situation, requiring considerable reduction of speed within limited time, is apparent. Four collisions occurred in Baseline, and none in assisted drives. Also, significant reduction of extreme decelerations is observed.

4.8.6 Discussion

During situational analysis, it became apparent, that the difficulties emerge when the considered segment is entered with the different average speed depending on the condition. This is reflected subsequently on the prolongation of coasting phases and estimated fuel consumption on this particular segment. This fact is considered in the second and third experiments, in which the similarity of average speeds at the beginning of the situational segments is proved before the start of experimental runs.

Also, acceleration phases became during the analysis of importance when explaining estimated fuel consumption. Not only the prolongation of coasting and braking phases, but preceding and following acceleration phases should be considered in any of the similar experiments.

5 SECOND EXPERIMENT: INACCURACIES IN ASSISTANCE INFORMATION PRESENTATION

Second experiment addresses possible inaccuracies in situational data, based on which the assistance provides information to the driver. In five out of nine deceleration situations investigated in this experiment, the system supplies drivers with imprecise and partially missing information about upcoming driving situation.

Two HMI concepts of the anticipatory ADAS are tested: visual Bird's-Eye View HMI concept, which is proved to be preferred by the test subjects in the first study, and multimodal concept, in which Bird's-Eye View presentation of the upcoming driving situation is coupled with haptic AGP intermittent impulse (for its description see Chapter 2.4 "Implemented HMI Concepts for Anticipatory ADAS").

User acceptance of and fidelity in the system is evaluated via questionnaires. Impact on driver behavior is analyzed using estimated fuel consumption measurements.

In addition, this study explores the general acceptance of introduced multimodal HMI concept. Obtained results regarding this issue provide the basis for the third experiment, dedicated solely to the analysis of the user acceptance and influence on driver behavior of the multimodal HMI for the anticipatory ADAS.

5.1 PURPOSE OF SECOND EXPERIMENT

Due to shared responsibilities in the project, within which this dissertation is originated, in this investigation the author concentrates particularly on impreciseness and partially missed detection in the anticipatory ADAS.

Two concepts of the system are tested: visual, based on the Bird's-Eye View presentation of the situation, and multimodal, in which visual modality (Bird's-Eye View presentation) is coupled with haptic (intermittent impulse of AGP).

In the following, main investigation questions are introduced and explained.

5.1.1 User acceptance of inaccurate assistance information

The main investigation question about acceptance of inaccurate assistance information is: to what extent do the drivers notice and accept possible inaccuracies in different driving situations?

Following issues and peculiarities of traffic information sources are taken into account:

Impreciseness - data regarding distances to the situations can be imprecise: what is the acceptance of a system, when it provides information about upcoming situation with imprecise consideration of remaining distance? And what is the acceptance of a system, when the lateral position of the driven vehicle is identified erroneously?

Partially missed detection - not all of the vehicles will posses C2C communication possibilities in the nearest future, this may lead to inconsistencies in data used by assistance systems: what is the acceptance of a system, when it misses C2C data regarding some of the relevant traffic participants?

5.1.2 Potential for multimodal HMI of anticipatory ADAS

As mentioned earlier, two concepts of HMI for the anticipatory driver assistance system are tested in this experiment: visual and multimodal. For multimodal concept, in addition to visual modality based on Bird's-Eye View presentation of the upcoming driving situation, the haptic modality is introduced. It is done not only to see possible influence of inaccurate assistance information on the acceptance of multimodal HMI, but also to explore general acceptance of such system. The generalized question relevant to the presented investigation of multimodal anticipatory driver assistance system is: what is the user impression regarding AGP possibly dominant character in the assistance?

The investigational issue concerning multimodal HMI, however, does not deal with details, i.e. what characteristics the driving situation should possess for a greater acceptance of AGP, and is done as the base study for the third experiment.

5.2 SETUP OF SECOND EXPERIMENT

The hardware and software tools used for the set-up and analysis of the experiment are described in Chapter 3 “Evaluating Anticipatory ADAS”.

Nine situations are included into simulated test course, among which none of the urban situations are considered. The investigated situations are:

- construction site behind a right curve, construction site in a left curve, first slower preceding vehicle in the vicinity of prohibited overtaking, slower preceding vehicle and oncoming traffic, speed limit on the rural road, town entrance, speed limit on the highway, stagnant traffic on the highway, and highway jam.

For the exact description of listed deceleration situations see Chapter 3.4 “Test Scenarios and Evaluation Environment”. The resulting length of the test drive is 22.5 km, main part of which is rural and highway roads. Short urban road after the situation “Town entrance” is incorporated into the course; however, no urban deceleration situations occur and therefore are not investigated in the experiment.

Imprecise or partially missing data about driving situation is displayed in:

Partially missed detection

• construction site behind a right curve • construction site in a left curve	oncoming traffic is not fully recognized – assistance displays empty opposite lane, when in reality the last vehicle from oncoming traffic prohibits overtaking
• stagnant traffic on the highway	information about traffic on the left lane is not available – assistance displays empty left lane, when in reality there are vehicles occupying the lane

Impreciseness

• highway jam	information about the distance to the situation is not correct – assistance detects and displays it 500 m further away than it is in reality; nevertheless, at the time point when the jam is not yet visible. In this case presented imprecise information is still considered to be anticipation-relevant on maneuvering level of driving task
• driven lane	while driving on the highway, driven lane is not recognized for approximately 1 km – assistance displays, that the driven lane is the right one instead of left

16 test subjects with average age of 23 years took part in the experiment (see below the detailed description of the test subject group in Chapter 5.3 “Test Subjects”). None of the subjects took part in the experiment described in Chapter 4 “First Experiment: Visual HMI for Anticipatory ADAS”.

Overview of the experimental design is presented in Figure 5.1.

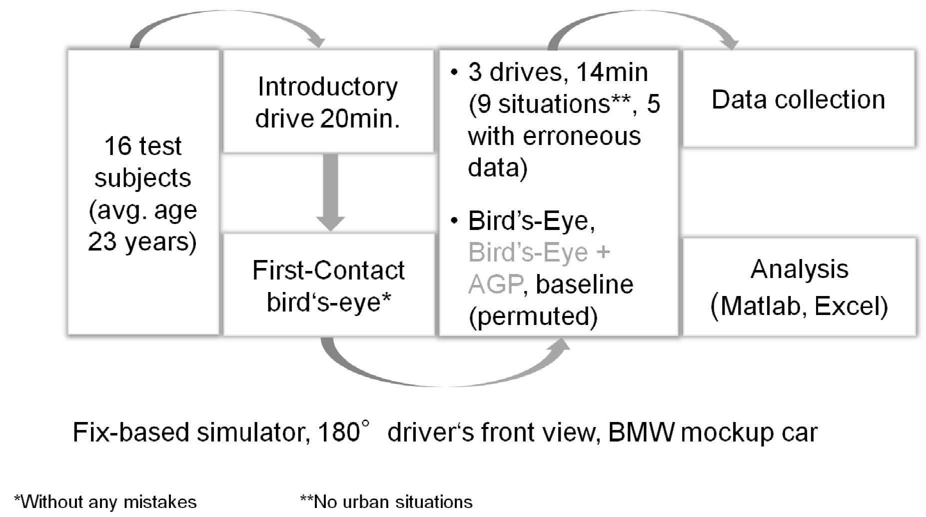


Figure 5.1: Inaccuracies in assistance information presentation – overview of the experimental design

At first, the general information about age and driving experience of a test subject is collected using demographic questionnaire (Appendix C.1). Afterwards each test subject has to complete introductory drive (20 min) in order to get used to the driving environment of the static simulator. During this drive, no assistance is displayed: test subjects have a digital instrument cluster in front with only speedometer and tachometer. Afterwards the explanation of visual Bird’s-Eye View HMI concept and intermittent functionality of AGP is provided, followed by a short first-contact drive with visual HMI concept. During this drive test subjects are confronted with three deceleration situations in order to get the feeling of system’s functionality. None of these example situations occur later during the analyzed drives to omit the recognition effects. So far no driving, visual, or related to the system’s subjective acceptance data are collected. The test subjects are not told about the purpose of the experiment or about possible inaccuracies in assistance information.

After this phase, the main experiment drives are performed. Three drives, the order of which is permuted for each test subject, occur. Permutation diminishes the effect of familiarization in the within-subject design of the experiment. One of them is a reference drive without any assistance, referred to as **baseline**, or **baseline condition.** One of two other drives is assisted with Bird’s-Eye View HMI, referred to as **visual condition**, and another – with intermittent haptic feedback of AGP in combination with Bird's-Eye View presentation of the upcoming driving situation, **multimodal condition**.

During drives with assistance, after each deceleration situation two questions are asked and the answers are noted down by the conductor of the experiment. First of the questions regards the helpfulness of assistance system in the last situation, grade from 1 (not at all helpful) to 5 (absolutely helpful), and second question suggests to express any special observations, if such are made, in the assistance of the last deceleration situation. After the completion of three experiment drives, final questions are asked regarding HMI preferences (Appendix C.4).

Throughout three experiment drives, driver behavior measurements are recorded for further analysis. Visual data are not collected, the changes in visual behavior of the drivers due to visual Bird's-Eye View HMI of the system is investigated in described in detail in Chapter 4 "First Experiment: Visual HMI for Anticipatory ADAS".

In following, the detailed description of test subject group, analysis approach, and results are provided.

5.3 TEST SUBJECTS

16 test subjects (thirteen male and three female) took part in the experiment. All of them hold valid category B European driver's licenses. The average age of the test subjects is 23 years (sd=1.8), the age ranges from 21 to 28 years. The driving experience varies: six participants drive less than 10,000 km per year, nine – between 10,000 and 20,000, and one – more than 20,000 km per year.

5.4 ANALYSIS APPROACH

At first, the analysis of driver behavior is done with respect to the beginning of coasting phases, estimated fuel consumption, and collisions in safety critical situation. This is performed in order to determine, if the advice of a system to coast or moderately brake is accepted after possible inaccuracies are noticed.

Conclusions regarding acceptance of investigated inaccuracies is done based on subjective evaluation of assistance in particular situations. During assisted drives after occurrence of each deceleration situation test subject is asked to grade helpfulness of assistance. Grades range from 1 to 5: 1 is "absolutely not helpful", 2 – "not helpful", 3 – "neither nor", 4 – "helpful", 5 – "absolutely helpful". After this question, test subject is asked to comment on the displayed assistance information and on any peculiarities, if such are noticed. Acceptance of assistance in particular situations, therefore, is derived based on the discrepancy between the grades given by the test subjects who notice imprecise or missing information, and rest of the votes. Also, after the experiment drives are completed, test subjects are asked to what extent they have felt uncertain in following the advices assistance information due to noticed inaccuracies. Grades range from 1 – “Not at all I feel uncertain if to follow the advice of the system”, to 5 – “Absolutely I feel uncertain if to follow the advice of the system”.

Pilot investigation of AGP applicability and its user acceptance is also based on collected subjective data. These consider likability and increased feeling of safety. Likability and increased feeling of safety of the system is graded from 1 – “Not at all I like the proposed system”, respectively “Not at all I feel safe using the proposed system”, to 5 – “Absolutely I like the proposed system” respectively “Absolutely I feel safe using the proposed system”.

At the end, direct comparison between purely visual Bird’s-Eye View HMI and its combination with AGP is done: test subjects are asked to choose the preferred concept.

5.5 RESULTS OF DRIVER BEHAVIOR AND QUESTIONNAIRES

As for the driver behavior regarding start of coasting and its implications on estimated fuel consumption, no differences are found in comparison to these situations in the first experiment, when the assistance provides accurate information. It is explained by the fact, that the point in time when the assistance is activated in almost all of the situations is the same, as in the first experiment. The only situation, in which it lays 500 m later, is “Highway jam”. In this situation the efficiency criterion is not investigated, the focus of analysis is the safety.

Throughout the entire drive, however, the estimated fuel consumption due to the assistance sinks 11-12% on average. As the post hoc analysis reveals, this increase in efficiency benefit versus results obtained in the first experiment is due to the absence of urban situations and slightly increased density of highway/rural situations.

Regarding evaluation of uncertainty in the reliance on the assistance information after inaccuracies are noticed, following results are obtained: five (for visual condition) and two test subjects (for multimodal condition) admit that they feel uncertain if to follow the advice of a system when it appears (Diagram 5.1).

Based on this fact, the conclusion is reached, that the majority of participants are not bothered by observed inaccuracies. The common remarks received from the test subjects are, that received imprecise and partially missing information about upcoming situation is still useful and helps to adjust to the situation.

Do you feel uncertain if to follow the advice of a system because of experienced inaccuracies in the provided information?

16 test subjects answered the question by choosing one of the proposed grades in both Visual *(Bird's- Eye View)* and Multimodal *(Bird's-Eye View & AGP)* conditions

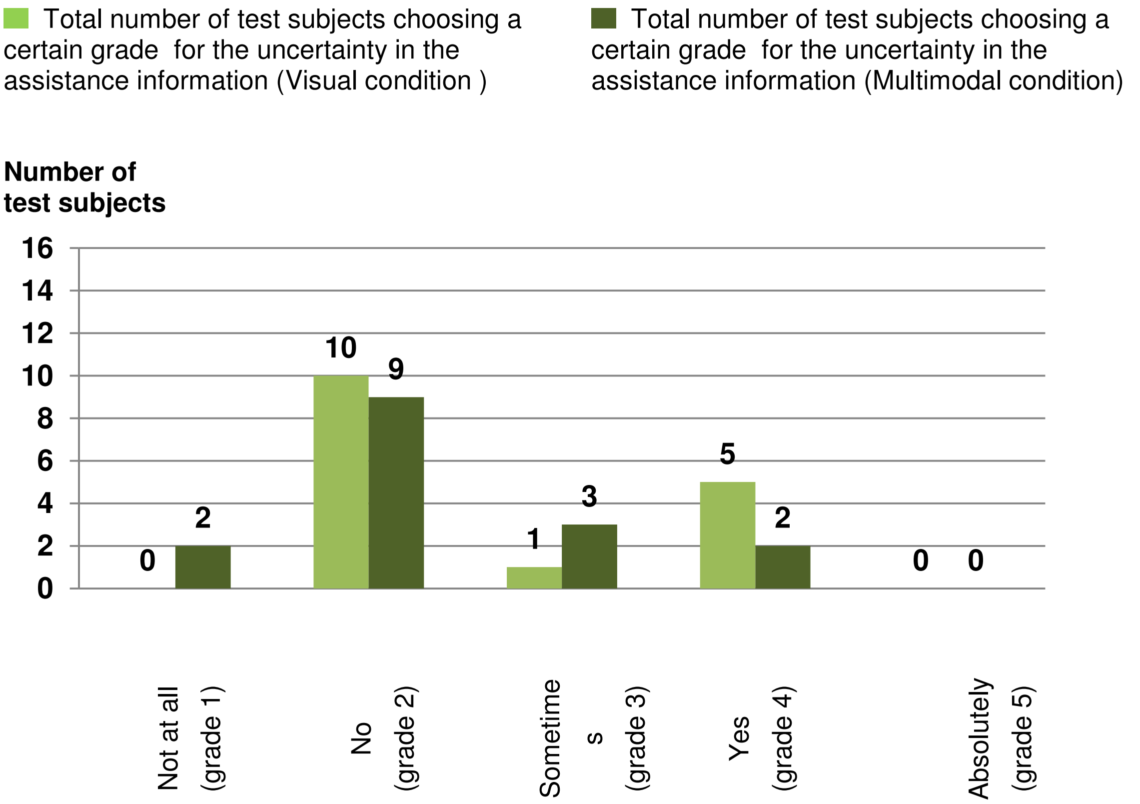


Diagram 5.1: Questionnaire – uncertainty in the reliance on the assistance information

Below the results of subjective evaluation of each situation assisted based on not complete/erroneous data are provided.

5.5.1 Oncoming traffic is partially missing

In two situations, "Construction site behind a right curve" and "Construction site in a left curve", oncoming traffic prohibiting immediate overtaking is not correctly shown by the assistance. Namely, the last vehicle occupying the opposite lane is not recognized and therefore not displayed. The assumption is that this fact might endanger driving, if test subjects rely solely on the assistance information without proving the actual driving situation, and as the consequence collide with upcoming vehicle.

The results show, however, that no collisions occur: none of the test subjects blindly rely on the displayed information. In the situation "Construction site behind a right curve", only two test subjects notice the inconsistency between displayed information and actual driving situation during a drive under multimodal condition (Diagram 5.2). They grade this inaccurate information provided via assistance as “Helpful” (grade 4) and “Absolutely helpful” (grade 5).

To what extent is the system helpful in the situation “Construction site behind a right curve”?

16 test subjects answered the question by choosing one of the proposed grades in both Visual *(Bird’s- Eye View)* and Multimodal *(Bird’s-Eye View & AGP)* conditions

- Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Visual condition)
- Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Multimodal condition)

Number of test subjects, who noticed that oncoming traffic is not recognized by the system, is provided in parenthesis

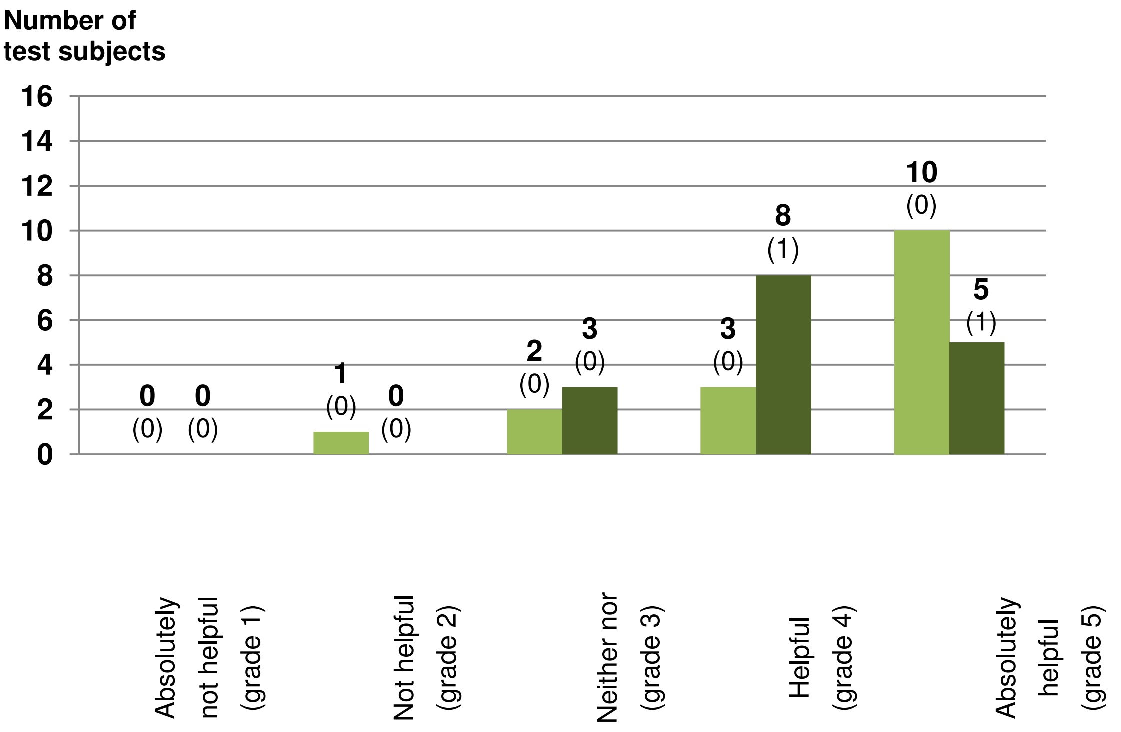


Diagram 5.2: Questionnaire – helpfulness of the system in the situation “Construction site behind a right curve”, oncoming traffic is partially missing

In the situation “Construction site in a left curve”, six (during the drives with visual HMI) and seven (drives with multimodal HMI) test subjects have reported that the oncoming traffic is not properly identified by the assistance system. Majority of these drivers grades the system with 4 (“Helpful”), or 5 (“Absolutely helpful”). This distribution of the grades is similar to the one, which is based on the grades received from the test subjects, who do not notice the inaccuracies (Diagram 5.3).

To what extent is the system helpful in the situation "Construction site in a left curve"?

16 test subjects answered the question by choosing one of the proposed grades in both Visual *(Bird's- Eye View)* and Multimodal *(Bird's-Eye View & AGP)* conditions

Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Visual condition)

Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Multimodal condition)

Number of test subjects, who noticed that oncoming traffic is not recognized by the system, is provided in parenthesis

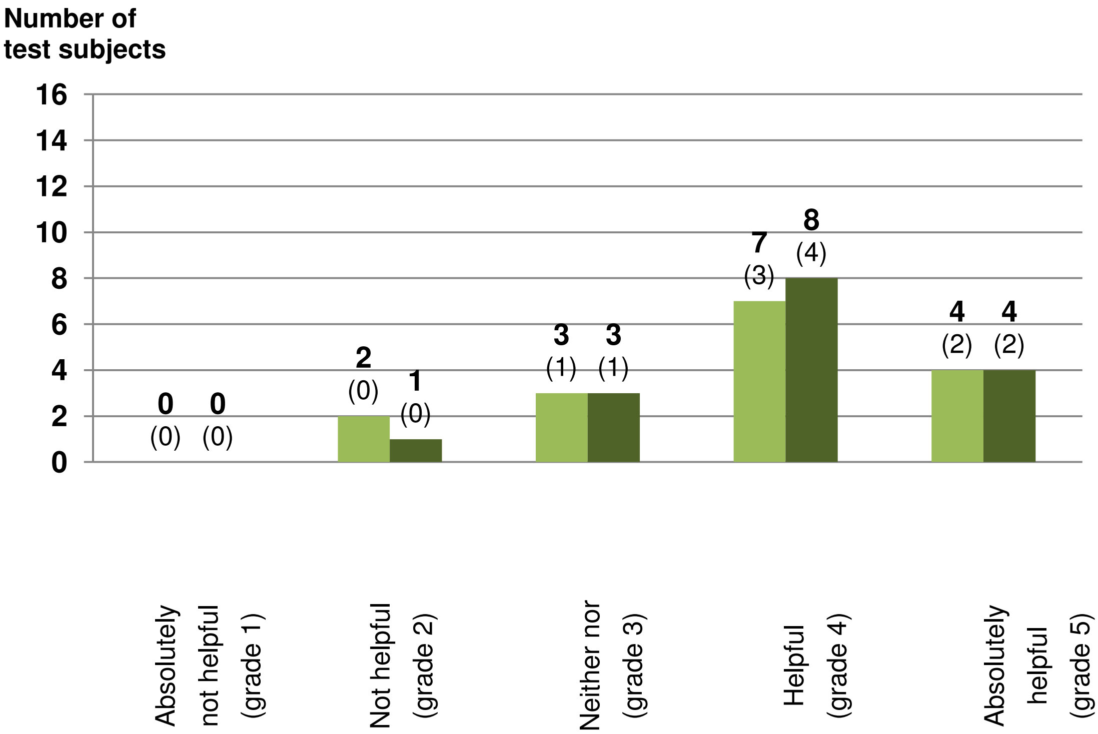


Diagram 5.3: Questionnaire – helpfulness of the system in the situation "Construction site in a left curve", oncoming traffic is partially missing

These results, depicted in Diagrams 5.2 and 5.3, lead to a conclusion, that test subjects perceive assistance information rather as the general hint about what is awaiting ahead. They do not drive based only on visual representation of the driving situation by the anticipatory ADAS, and sufficiently control the development of it on their own from the road and traffic observations. Some of the test subjects note, that in these two situations they do not count the displayed vehicles on the opposite lane and understand, that assistance information should be taken as the warning about their possibility, and is not necessarily the exact representation of driving situation. In this case, it can be concluded that HMI presentation awakes appropriate mental models, which are filled by certain pieces of information based on not only HMI presentation of the situation, but also from the real conditions.

5.5.2 Information about vehicles occupying left lane is missing

During “Stagnant traffic on the highway” situation, missing information about the left lane is noticed by majority of the test subjects: by nine – in multimodal condition, and by ten – during the drives with visual assistance (Diagram 5.4).

To what extent is the system helpful in the situation “Stagnant traffic on the highway”?

16 test subjects answered the question by choosing one of the proposed grades in both Visual *(Bird’s- Eye View)* and Multimodal *(Bird’s-Eye View & AGP)* conditions

- Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Visual condition)
- Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Multimodal condition)

Number of test subjects, who noticed that information about left lane is not available and therefore not displayed by the system, is provided in parenthesis

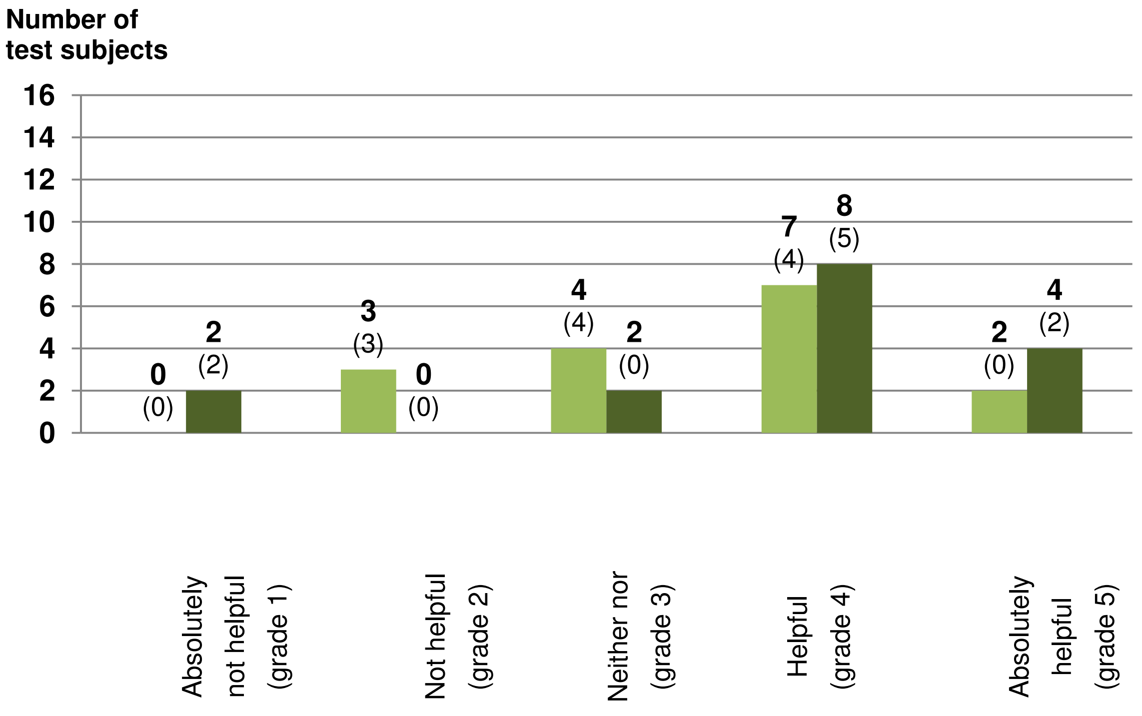


Diagram 5.4: Questionnaire – helpfulness of the system in the situation “Stagnant traffic on the highway”, information about vehicles occupying left lane is missing

Overall, the general evaluation of assistance information does not differ much between the test subjects that notice the inconsistency and the ones that do not. The standard grade is between “Neither nor” and “Helpful” for the helpfulness of the system in this situation in both conditions (visual and multimodal), only three test subjects do not see any help of the presented information in neither of the conditions. However, it is hard to deduct if this evaluation is due to observed inaccuracies, or generally they do not see help of the system in this particular situation.

5.5.3 Imprecise distance is displayed

To what extent is the system helpful in the situation "Highway jam"?

16 test subjects answered the question by choosing one of the proposed grades in both Visual *(Bird's- Eye View)* and Multimodal *(Bird's-Eye View & AGP)* conditions

Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Visual condition)

Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Multimodal condition)

Number of test subjects, who noticed that the system displays incorrect distance to the jam, is provided in parenthesis

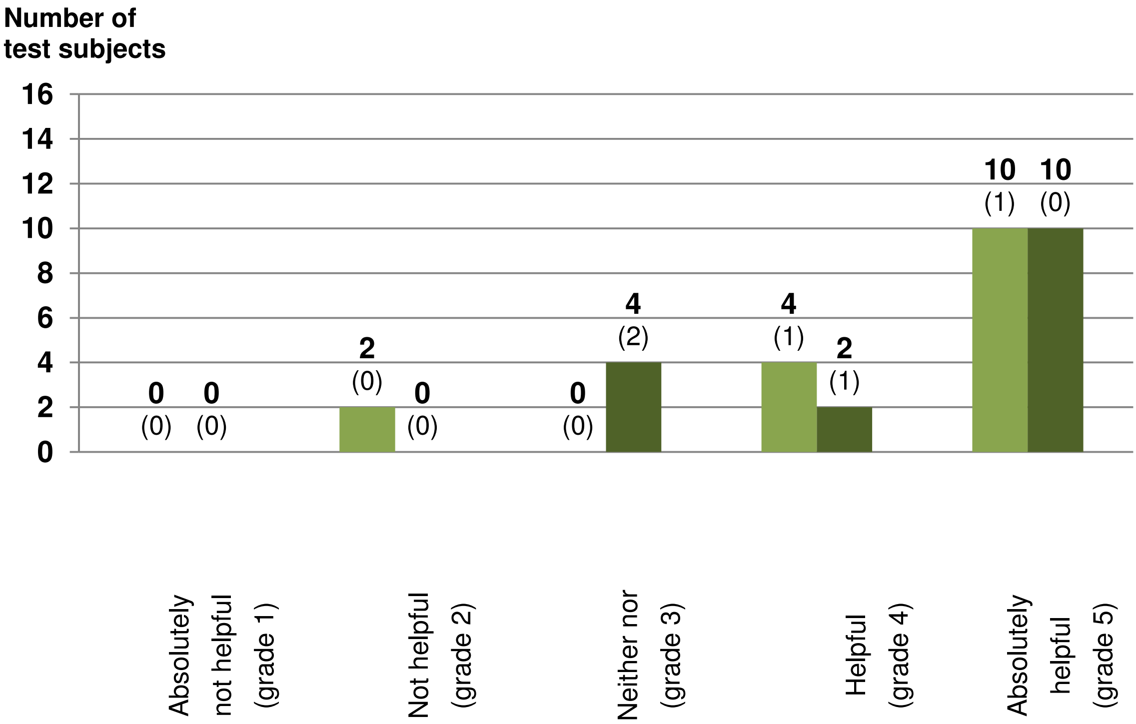


Diagram 5.5: Questionnaire – helpfulness of the system in the situation "Highway jam", imprecise distance to the situation is displayed

Five times throughout all assisted drives the mistake of incorrect distance representation is noticed in the situation "Highway jam": two test subjects comment on it in the drives with visual HMI, and three – while driving with multimodal HMI. Nevertheless, the help of the assistance in this situation is appreciated (Diagram 5.5): majority of the test subjects (ten in both conditions) rate it as “Absolutely helpful”, and only two in the condition with visual HMI – as “Not helpful”. One of these test subjects during a drive with multimodal HMI grades this system, however, as “Absolutely helpful”, another – as “partially helpful”. It can be implied that in this particular situation not the impreciseness, but the HMI modality can in some of the cases influence the subjective perception about the helpfulness of the system. Especially in potentially critical situations, in which the timely reduction of the driven speed is crucial, AGP feedback seems to possess high acceptance potential among test subjects. It should be further noticed, that in baseline drives three collisions occurred, and in assisted drives – none.

5.5.4 Driven lane is imprecisely identified

To what extent the information about driven lane is helpful in the introduced system?

16 test subjects answered the question by choosing one of the proposed grades in both Visual *(Bird’s- Eye View)* and Multimodal *(Bird’s-Eye View & AGP)* conditions

Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Visual condition)

Total number of test subjects choosing a certain grade for the helpfulness of the system in investigated situation (Multimodal condition)

Number of test subjects, who noticed that information about driven lane is incorrect, is provided in parenthesis

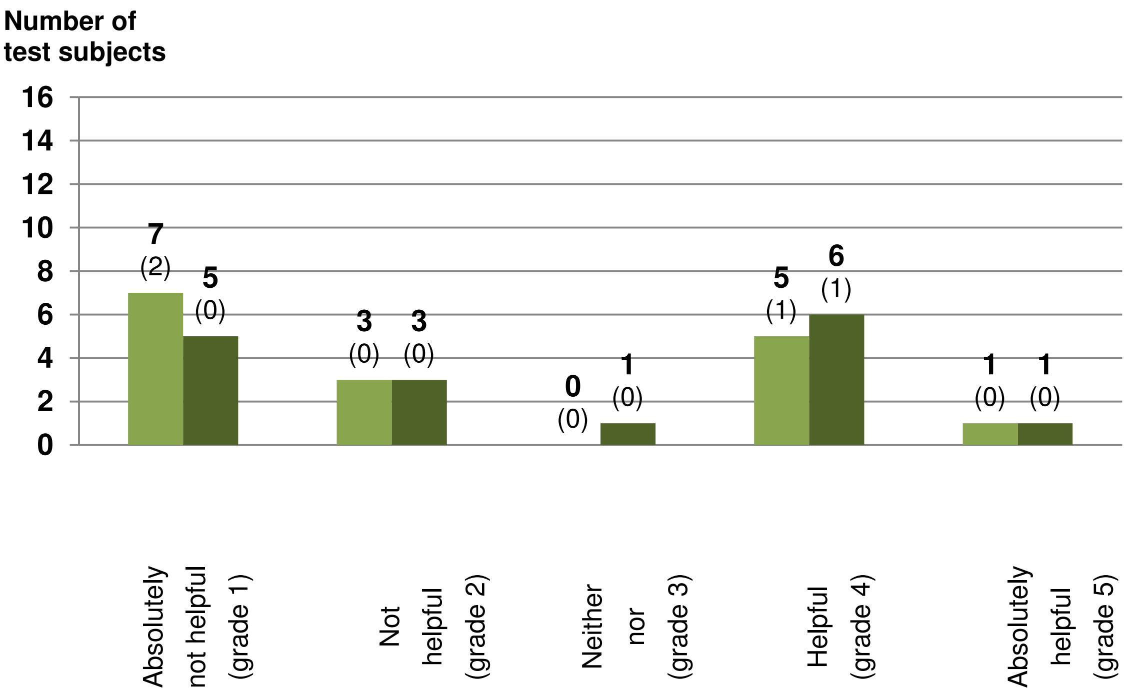


Diagram 5.6: Questionnaire – helpfulness of the system on the highway, when the driven lane is imprecisely identified

The general grade from the test subjects regarding the information about driven lane, who do not notice the impreciseness, is low: less than half of them see any help in this information (Diagram 5.6). The common remark is that a test subject knows himself/herself very well in which lane he/she is driving, the its exact representation is irrelevant and does not help in enhancement of deceleration strategy. Once again, the distributions of the grades from the test subjects, who notice impreciseness, and the ones that do not, are similar.

5.5.5 Results regarding potential of multimodal HMI for anticipatory ADAS

When asked to choose the preferred modality of HMI, twelve test subjects state that multimodal HMI is better, than purely visual.

Likability of the visual and multimodal concepts is approximately the same: mean values are 4 in both of the cases, interpreted as “I like the proposed concept for anticipatory assistance”. The majority (15) of test subjects rate both concepts in the range from 3 - “On average, I like the concept for anticipatory assistance”, and 5 – “I absolutely like the concept of anticipatory assistance”.

Regarding increased safety feeling when driving with assistance, the multimodal HMI and purely visual both receive on average very good evaluations: vast majority of test subjects (14 in visual condition, and 15 in multimodal condition) find, that proposed assistance increases feeling of safety.

5.6 DISCUSSION AND SUMMARY

In this experiment, some of the possible inaccuracies in the presentation of assistance information are investigated. These inaccuracies reflect impreciseness in the situational data and partially missed detection of relevant traffic participants. The focus of analysis lays in identification, if the provided key information is sufficient to invoke appropriate mental models, so that even with imprecise/partially missing data the driver feels the helpfulness of the system and benefits from the assistance information.

Subjective feeling of the helpfulness provided by the anticipatory ADAS, with account on possibly missing data regarding some of the relevant traffic participants, is high (on average rated with grade 4, as “Helpful”, on the range from 1 to 5). The system provides the general picture over the driving situation for the driver to expect other participants common for this type of a situation.

Certain degree of impreciseness is also tolerated: if the remaining distance used by the assistance is not exact and does not lead to a complete optimization of deceleration maneuver, but certainly increases expectancy and therefore safety in the deceleration situations, the helpfulness of the system is not questioned. It can be stated, that anticipatory information about the situation, which cannot be yet seen by the drivers themselves and is anticipation-relevant on the maneuvering level of driving task, even if the exact distance to it is not identified properly, helps drivers to adjust to the situation and be prepared to its occurrence.

Impreciseness in the identification of driven lane is not tolerated by two test subjects out of 4, who notice it during experiment drives. Majority of the test subjects who do not notice this impreciseness (10 test subjects in visual condition, and 9 – in multimodal), however, do not perceive any additional help via system. This information can be considered as excessive for the aims of investigated assistance and therefore is not found particularly helpful by the test subjects, who do and do not notice this impreciseness.

These facts, namely high degree of perceived general helpfulness of the system, similar distributions of the grades in separate situations given by the test subjects noticing introduced inaccuracies and the ones that don't, lead to a conclusion, that the key information in presented HMI is chosen in accordance to appropriate mental models of the drivers. Certain impreciseness and partially missed detection is compensated by the drivers themselves without exercising potentially dangerous driver behavior, and it does not create strong negative feeling.

When asked to choose the preferred HMI modality for the anticipatory driver assistance system, 12 out of 16 test subjects choose multimodal HMI. It therefore can be concluded, that the dominance of AGP feedback is generally tolerated in investigated situations. Together with brief analysis of driver behavior, showing the tendency for the increased reaction times and decreased fuel consumption compared to the drives with visual HMI, it gives the basis for deeper and precise investigation described in Chapter 6 “Third Experiment: Multimodal HMI for Anticipatory ADAS”.

It should be mentioned, that missed detections and ghost targets, which are not investigated in presented experiment, should not be ignored in the development process of ADAS. From previous works of *Swets and Green (1974), Parasuraman et al. (1997), Maltz et al. (2004), Cummings et al. (2007)* is known, that if the rate of missed detections and ghost targets exceeds certain limit, this can significantly influence the acceptance and user's fidelity in a system. This limit, according to *Parasuraman et al. (1997)*, should not exceed 40%, i.e. 60% of issued advices of a system must be correct. The results of this experiment do provide the indication, that certain amount of missed detections and ghost targets might be accepted by the drivers and this fact will not drastically reduce the fidelity in the system. Test subjects do not expect the system to provide the perfect data about every deceleration situation, and are able to adequately judge driving situation in reality even when the system's information is not fully consistent with it. However, based on the results of this experiment, it is not possible to define the exact limit rate of missed detections and ghost targets for the considered system, after which the fidelity in the system vanishes. This is recommended to be done in following experiments, dedicated to the introduced anticipatory ADAS.

6 THIRD EXPERIMENT: MULTIMODAL HMI FOR ANTICIPATORY ADAS

This experiment is dedicated to the investigation of multimodal HMI for anticipatory ADAS, which consists of visual (Bird's-Eye View visualization of the upcoming driving situation) and haptic (intermittent AGP impulse) modalities.

Presented analysis takes into account subjective opinion of the drivers in regard to multimodal HMI, change in estimated fuel consumption while driving with the assistance, and decrease of collisions in safety critical situation.

Subjective user acceptance of the multimodal HMI is evaluated using questionnaires. These consider feeling of helpfulness of the proposed system in different deceleration situations, as well as perceived benefit or, on contrary, unpleasant dominance of AGP feedback. Also driver's opinion on possible usage of AGP feedback depending on the type of driven road and expectancy of the driving situation is investigated.

Changes in driver behavior, while driving with the assistance, are presented using measurements relevant to the start of coasting phases and estimated fuel consumption, and number of collisions in safety critical situation "Highway jam".

6.1 PURPOSE OF THIRD EXPERIMENT

The overview of previous studies of *Reichart et al. (1998)*, *Dorrer (2000)*, *Samper et al. (2001)*, *Lange (2008)*, and *Lange et al. (2010)* on multimodal HMI used for different driver assistance systems provides strong evidence for the assumption, that multimodal in comparison to purely visual HMI results in quicker reaction of the drivers on the assistance information. The implication for the introduced anticipatory ADAS is that via intermittent AGP impulse in addition to Bird's-Eye View presentation of the upcoming driving situation, estimated fuel consumption might be further reduced. However, together with objective benefit in regard to reduced estimated fuel consumption, it is necessary to observe subjective user acceptance of the AGP feedback: it can easily become unpleasantly dominant and, as a result, be rejected by users.

Purpose of presented investigation is to establish the influence of multimodal HMI on driver behavior with respect to efficiency and safety criteria (correspondingly lower estimated fuel consumption and absence of collisions), and subjective user acceptance.

6.2 SETUP OF THIRD EXPERIMENT

The hardware and software tools used for the set-up and analysis of the experiment are described in Chapter 3 “Evaluating Anticipatory ADAS”.

Twelve deceleration situations are included into simulated test course. The resulting length of the test drive is 24.5 km. Seven of the investigated situations occur on the rural road, three – on the highway, and two – in urban area:

construction site behind a right curve, construction site in a left curve, first slower preceding vehicle in the vicinity of prohibited overtaking, slower preceding vehicle and oncoming traffic, speed limit on the rural road, town entrance, speed limit on the highway, stagnant traffic on the highway, highway jam, parking car, traffic light (optimal coasting phase of 450 m), and speed limit on the rural road with slower preceding vehicle.

For the exact description of mentioned eleven deceleration situations see Chapter 3.4 “Test Scenarios and Evaluation Environment”. The twelfth situation, “Speed limit on the rural road with slower preceding vehicle”, is modified situation “Speed limit on the rural road”, in which preceding vehicle driving 70 km/h is present. This situation is included to investigate, what is the acceptance of AGP intermittent feedback in the case, when the assisted deceleration phase is caused by more than one factor.

In the experiment 30 test subjects took part. Flow of the experiment is schematically shown in Figure 6.1.

At first, every test subject fills demographic questionnaire (Appendix D.1) and performs introductory drive of 20 min to get used to the static simulator and simulated world. After the completion of this drive, explanation of the anticipatory driver assistance system, its visual Bird’s-Eye View HMI and haptic feedback of AGP, is given.

Two experiment drives follow. One of these drives is the **baseline** drive through the simulated test course without any assistance. Another is the drive, assisted with multimodal HMI – Bird’s-Eye View presentation of upcoming driving situation and AGP intermittent feedback. This drive is later referred to as **assisted drive**, or drive under **multimodal condition.** The order of baseline and assisted drives is permuted for each test subject. Permutation diminishes the effect of familiarization in the within-subject design of the experiment.

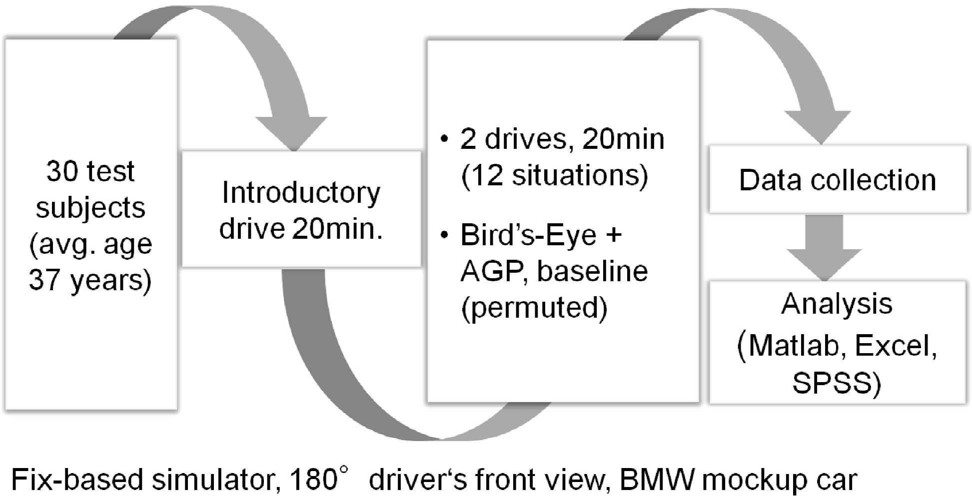


Figure 6.1: Multimodal assistance for anticipatory ADAS – overview of the experimental design

During assisted drive, after each situation three questions are asked (Appendix D.2): if the proposed anticipatory assistance is helpful in this particular situation in regard to perceived efficiency and safety benefits, if AGP feedback is helpful, and if AGP feedback posses negative dominating character. The answers are written down by the conductor of the experiment for the following analysis.

After the drives, test subjects receive final questionnaire (Appendix D.3). They are asked to express their additional remarks about proposed assistance and AGP feedback depending of the driving conditions (e.g. rural, highway, or urban roads) and driving situation (e.g. unexpected, rare).

During both baseline and assisted drives, driving measurements are recorded for further analysis of driving behavior. Visual data are not collected, the changes in visual behavior of the drivers due to visual Bird’s-Eye View HMI of the system is investigated in described in Chapter 5 “First Experiment: Visual HMI for Anticipatory Driver Assistance System”.

6.3 TEST SUBJECTS

30 test subjects took part in the experiment (25 male and five female). Average age of them is 37.4 years, standard deviation, sd=15.2. Driving experience varies: nine of them drive up to 10,000 km per year, 14 – between 10,000 and 20,000, and seven – more than 20,000 km per year. Vast majority of them (28 test subjects) strive to choose the driving strategy aimed at the reduction of fuel consumption.

6.4 ANALYSIS APPROACH

Subjective data regarding helpfulness of the assistance, AGP feedback, and perceived dominance of AGP, consist of the agreement or disagreement with the statements “I find the assistance in the last situation helpful”, “I find the assistance via AGP in the last situation helpful”, and “I find AGP feedback unpleasantly dominant in the last situation”. Disagreement/agreement with the statements can be expressed by one of the following answers:

- absolutely yes,
- yes,
- neither nor,
- no,
- absolutely no.

In the diagrams provided in the result section, “absolutely yes” and “yes” are grouped as agreement statements (marked as agree in the diagrams in the result section), and “absolutely no” and “no” – as disagreement statements (disagree). In the same way, the questions in final questionnaire (Appendix D.3) are asked regarding the wish for the investigated multimodal assistance depending on traffic conditions (highway, rural, and urban roads), and depending on the occurrence rate and expectancy of the situations.

Driver behavior measurements, collected during experiment drives, are the same as in the first experiment (see Chapter 4.2 “Analysis of Anticipatory Driver Assistance System”). Results of driving behavior presented in this experiment include mainly the ones concerning estimated fuel consumption. If during a deceleration situation significantly different behavior in drives assisted via multimodal HMI from those assisted via visual Bird’s-Eye View (see Chapter 5 “First Experiment: Visual HMI for Anticipatory Driver Assistance System”) is observed, this fact is stated and described. In this case, the so-called **reaction times** proved to be helpful. These are the elapsed times, in s, between assistance activation and reaction of a test subject on the information, i.e. full release of an accelerator.

Descriptive statistics of the measurements is presented using **mean values, denoted as Ø**, and **standard deviation, sd**. Inferential analysis for the differences in the driving behavior between baseline and assisted drives is performed using paired T-Test. When comparing results of the first experiment with the current one, unpaired T-Test is used. The significance level is 0.05 in both cases.

6.5 RESULTS OF QUESTIONNAIRES

Results regarding AGP appeal to the test subjects in deceleration situations are following: eight test subjects do not show any interest in currently proposed multimodal HMI concept for anticipatory driver assistance system (two of whom clearly state their dissatisfaction), 21 participants find the concept as “good” or “very good”, and one test subject hesitates to give a definite answer. Nevertheless, the comments of four test subjects which do not like the current AGP assistance strategy show, that they could imagine great benefit of the intermittent AGP assistance in very rare and potentially critical situations, but not in frequently occurring deceleration situations. This complies with the summary of the rest of the comments, which shows that test subjects appreciate AGP intermittent feedback especially in seldom, unexpected, and critical driving situations. Overall, it can be stated that test subjects perceive haptic assistance in the form of gas pedal impulses in deceleration situations rather as warning, than the information indications dedicated to the fuel saving strategy.

In Diagram 6.1 and 6.2, numbers of participants are provided, who find general assistance and AGP influence in particular investigated situation as

- helpful (agree with the statement “I find the assistance in the last situation helpful”, Diagram 6.1, or with the statement “I find the assistance **via AGP** in the last situation helpful”, Diagram 6.2),
- neither helpful nor unhelpful,
- and not helpful (disagree with the mentioned statements).

These data are gathered for every investigated situation from 30 test subjects. Some of the test subjects hesitate to give an answer. Their number is not directly presented in Diagrams 6.1 and 6.2.

As it can be seen from Diagram 6.1, >60% of the test subjects value the helpfulness of the system in investigated highway and rural road situations. These particular situations, in which the helpfulness of the system is evaluated the highest, involve traffic jams (“Highway jam”, “Stagnant traffic on the highway”), construction sites (“Construction site behind a right curve”, “Construction site in a left curve”), and speed limits (“Speed limit on the rural road with slower preceding vehicle”, “Speed limit on the highway”, “Speed limit on the rural road”).

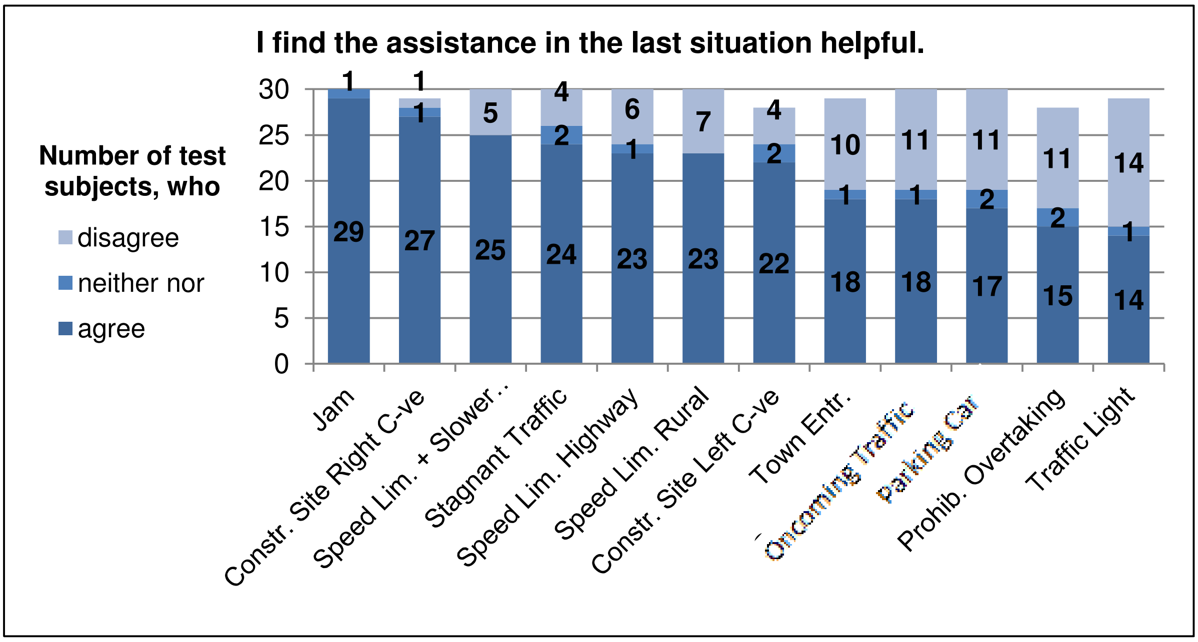


Diagram 6.1: Results of questionnaires – helpfulness of the anticipatory ADAS with multimodal HMI in each investigated situation

The helpfulness of AGP feedback is appreciated by at least 60% of test subjects in the situations “Highway jam”, “Construction site behind a right curve”, “Stagnant traffic on the highway”, “Construction site in a left curve”, and “Speed limit on the rural road” (see Diagram 6.2). Overall, in comparison to general feeling of system’s helpfulness (Diagram 6.1), there is especially increased number of test subjects, who do not find AGP feedback to be particularly helpful in the situations involving speed limits on the highway and slower preceding vehicles on the rural roads (“Speed limit on the rural road with slower preceding vehicle”, “Speed limit on the highway”).

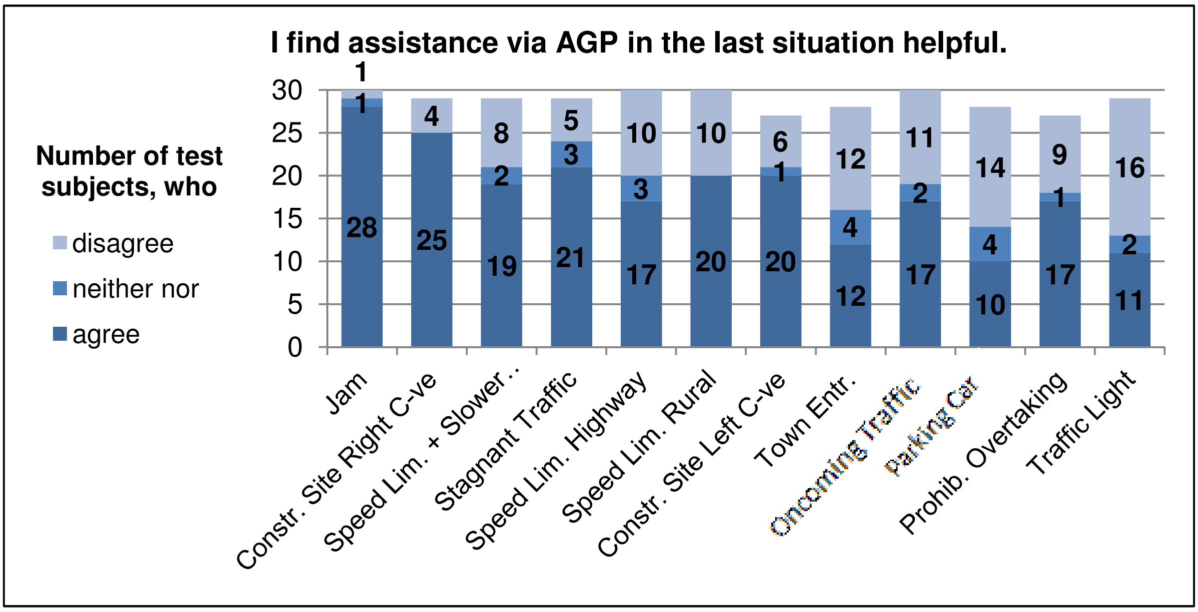


Diagram 6.2: Results of questionnaires – helpfulness of AGP feedback in each investigated situation

Both assistance and its AGP feedback in situations relevant to urban area (“Parking car”, “Traffic light”, and “Town entrance”) and some of the rural situations with slower preceding vehicles (“Slower preceding vehicle and oncoming traffic”, “First slower preceding vehicle in the vicinity of prohibited overtaking”) is found to be helpful by the lowest number of the test subjects (Diagrams 6.1 and 6.2).

Another important factor influencing the acceptance of AGP is the negative feeling the user gets when dominated by the system (Diagram 6.3). In this case, after each situation the statement “I find AGP feedback unpleasantly dominant in the last situation” is either supported by a test subject (“Absolutely yes / yes, I agree that AGP feedback is unpleasantly dominant in the last situation”), dismissed (“Absolutely no / no, I disagree that AGP feedback is unpleasantly dominant in the last situation”), or is of no particular importance (“I find AGP feedback neither unpleasantly dominant nor pleasant in the last situation”).

Similar to the helpfulness of the system in general and AGP feedback in particular, most of test subjects find accelerator impulse not dominant in highway and rural situations involving jams and construction sites (see Diagram 6.3). Approximately half of the test subjects are not ready to accept introduced haptic modality of assistance when approaching speed limits: 14 test subjects felt unpleasantly dominated by AGP in both situations “Speed limit on the rural road and slower preceding vehicle” and “Speed limit on the highway”, 13 – in the situation “Speed limit on the rural road”.

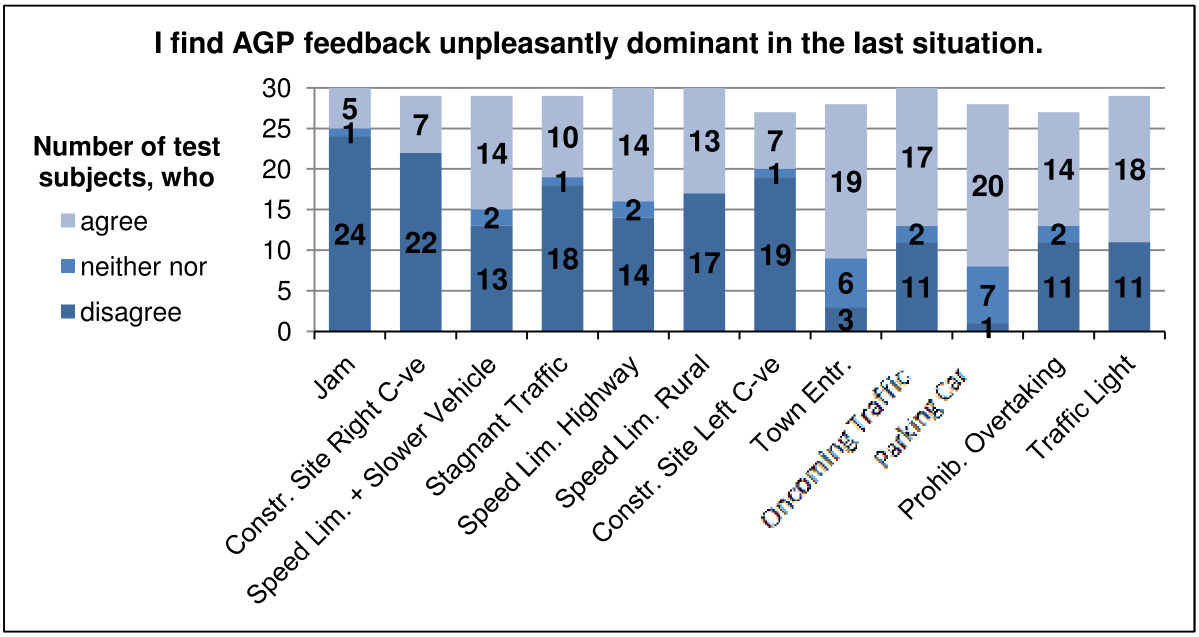


Diagram 6.3: Results of questionnaires – dominance of AGP feedback in each investigated situation

When asked, in which situations depending on the road type the drivers would activate the assistance, 23 test subjects see the potential benefits of the proposed multimodal concept on the highway roads, 21 of them – also on the rural road. 21 test subjects appreciate assistance in rare situations, and 27 – in not foreseeable situations. Most commonly named as rare and unforeseeable situations are “Highway jam”, “Stagnant traffic on the highway”, “Construction site behind a right curve”, and “Construction site in a left curve”.

6.6 RESULTS OF DRIVER BEHAVIOR

Throughout the entire drive, the test subjects are able to reduce fuel consumption on average 7.5% in multimodal condition (estimated fuel consumption during baseline drives: Ø=100.0%, sd=16.2%; assisted drives: Ø=92.4%, sd=12.0%). The result of the inferential analysis proves the significance of the obtained reduction: $t(29)=9.86$, $p<0.001$. Also the duration of a drive increases: during baseline drives it is Ø=100.0% or 18.2 min, sd= 11.1%; assisted drives – Ø=106.7% or 19.4 min, sd=35.8%, $t(29)= 5.17$, $p<0.001$.

The benefit in saving the fuel in multimodal condition is higher compared to the results of the first experiment, in which on average 4% of estimated fuel is saved when driving with only visual Bird’s-Eye View presentation of the upcoming deceleration situation. This fact is explained by generally quicker reaction of the test subjects on the received information, and discussed in detail in Chapter 6.6.2 “Comparison to results of first experiment”.

In the following Chapter 6.6.1 “Analysis of separate situations”, the analysis of driver behavior in separate situations and its implication on estimated fuel consumption is provided.

6.6.1 Analysis of separate situations

The release of the gas pedal after the advice is being issued by the system follows within next 1.2 s in 50% of all the cases. 75% of the reaction times on the system’s assistance are under 2 s, except in situations “Slower lead vehicle in vicinity of prohibited overtaking”, “Parking car”, “Traffic light”, and “Stagnant traffic on the highway”. In the mentioned situations, remaining 50% of test subjects, who do not react within 1.2 s, take their time before following the advice.

There is no significant difference in prolongation of coasting phases and estimated fuel consumption between baseline and multimodal condition in the situations “Slower lead vehicle in the vicinity of prohibited overtaking”, $t(29)=1.06$, $p<0.3$, and “Stagnant traffic on the highway”, $t(29)=0.38$, $p<0.70$.

Approximately 25% of the fuel is reduced due to the system’s advice in “Traffic light” situation, $t(29)=3.68$, $p<0.001$, 20% - in “Parking car”, $t(29)= 2.39$, $p<0.02$. Even with delayed reaction from some test subjects in assisted drives, coasting phases are on average 60 m longer in “Traffic light” and 10 m – in “Parking car” (analyzed segment for this particular situation is 140 m, and even barely increased coasting phase in multimodal condition results in significant gain in efficiency).

In situations on the rural road involving construction sites, test subjects coast on average 180-250 m longer than in the baseline condition and save on average estimated 30% of fuel in “Construction site behind a right curve”, $t(29)=7.17$, $p<0.001$, and 20% – in “Construction site in a left curve”.

Costing phases last up to 300 m longer and lead to lower estimated fuel consumption on 35% in the situations “Speed limit on the rural road”, $t(29)=2.19$, $p<0.04$, and “Speed limit on the rural road and slower lead vehicle”, $t(29)=6.92$, $p<0.001$. In “Slower lead vehicle with oncoming traffic”, coasting phase in assisted drives starts 50 m earlier than in baseline, and results in on average 15% lower estimated fuel consumption, $t(29)=2.19$, $p<0.04$.

In highway situations, the coasting phases are longer on more than 450 m while approaching critical “Highway jam” and this helps to reduce extreme decelerations and avoid collisions, four of which happen during baseline drives.

Coasting phases are longer on 200 m in the situation “Speed limit on the highway” in assisted drives. The results regarding estimated fuel consumption in this situation are following: baseline drives Ø=100%, sd=50%, assisted drives Ø=47%, sd=118%, $t(29)=-4.40$, $p<0.001$. Five test subjects during assisted drives decide to accelerate again after initially performing coasting phase, which increases estimated fuel consumption in these cases and is reflected in standard deviation. Corresponding graphs can be found in the work of *Hajek (2010)*.

The greatest reduction in estimated fuel consumption is achieved in “Town entrance” situation by following the system’s advice, $t(29)=7.03$, $p<0.001$. In this case standard deviation is of particular interest. During baseline drives, estimated fuel consumption Ø=100%, sd=25%, during assisted drives – Ø=42%, sd=78%. Again, the proposed coasting phase is perceived as too long for some of the test subjects, and eight of them accelerate after approximately 200-300 m of coasting. The experienced coasting phase with the activated system of more than 650 m is subjectively perceived by test subjects as extremely prolonged, and in this case AGP feedback is clearly evaluated as dominating.

6.6.2 Comparison to results of first experiment

In this section, observed differences between driver behavior enhanced by assistance with multimodal and only visual HMI are presented.

The increase in saved fuel to 7.5% during multimodal assisted drives compared to 4% when assisted via visual Bird’s-Eye View HMI is explained by more homogeneous reaction of the test subjects in most of investigated situations. As an example in Table 6.1, following situations are chosen: “Town entrance”, “Traffic light (longer coasting phase)”, “Parking car”, and “Construction site behind a left curve”. In these situations, unlike in the first experiment, the estimated fuel consumption is reduced in multimodal condition compared to baseline.

In Table 6.1, for each of mentioned situations, reaction times on assistance information and estimated fuel consumption on corresponding road segments while driving with multimodal and visual HMI are provided. Reaction times are given for 50%, 75%, and 90% of subject cases. Estimated fuel consumption is given in %, where 100% correspond to baseline results. Differences in estimated fuel consumption between drives with visual and multimodal HMI are proved using unpaired T-Test.

Table 6.1: Comaprison to the first experiment - elapsed time from assistance activation till coasting begins

		Reaction times, in s, according to cumulative percentage of subject cases			Estimated fuel consumption, in % Ø±sd	Results of unpaired T-Test
		50%	75%	90%		
Town entrance	Multimodal	0.88 s	1.75 s	7.09 s	41±78%	t(54)=3.2
	Visual (Bird's-Eye View)	1.26 s	1.98 s	6.10 s	109±80%	p<0.002
Traffic light (longer coasting phase)	Multimodal	1.08 s	2.26 s	8.11 s	75±35%	t(54)=1.97
	Visual (Bird's-Eye View)	2.35 s	3.73 s	5.92 s	90±18%	p<0.05
Parking car	Multimodal	1.19 s	2.37 s	4.04 s	78±46%	t(54)=3.64
	Visual (Bird's-Eye View)	1.75 s	2.55 s	3.94 s	126±52%	p<0.001
Construction site in a left curve	Multimodal	1.11 s	1.36 s	5.52 s	79±25%	t(54)=3.91
	Visual (Bird's-Eye View)	1.45 s	2.08 s	4.12 s	117±46%	p<0.001

In two of the mentioned situations, "Town entrance" and "Traffic light (longer coasting phase)", test subjects complained, that suggested coasting phases are too long, and under real traffic conditions they would most probably ignore the advice of the system.

6.7 DISCUSSION AND SUMMARY

The proposed driver assistance concept proves to be useful for the reduction of fuel consumption. Due to adequate coasting phases suggested by the system and quick drivers' responses (in 50% of the cases within 1.2 s, and generally in 80% - within 2 s), the estimated fuel consumption drops on average by 7.5%.

Especially beneficial is the system in the situations, which cannot be perceived by the driver at the point of time when the optimal beginning of coasting should take place. However, efficiency improving >650 m coasting phase even on the empty road is considered to be too long (situation "Town entrance"), and AGP impulse as dominant and unnecessary.

Coasting phases lasting less than 200 m, which can be anticipated by the drivers without any additional help, are equally good performed with and without assistance.

AGP feedback is considered to be dominant in non-critical and common situations. As example, in situations “Traffic light” and “Slower lead vehicle with oncoming traffic”, following AGP advice results correspondingly in 25% and 15% less estimated fuel, but subjectively is not preferred by the majority of the test subjects. In the situations involving speed limits, system helps to save 30-35% of estimated fuel. In these situations AGP impulse is found to be not dominant by 50% of the test subjects.

The most applicable situations for AGP, as the opinion of test subjects, are the ones, which possess critical or unexpected character. Such assistance would be appreciated by the majority of the test subjects on the rural and highway roads. Investigated situations involving construction sites show both high potential in improved efficiency through the system, as well as user acceptance of AGP. Also in the highly critical situation requiring extreme decelerations if not for the system’s information, AGP is highly appreciated.

7 DISCUSSION AND CONCLUSION

Results of the investigation show, that anticipation of a driver, as a rule, suffices for a timely decision and an execution of a safe deceleration action, except in rare situations, which become visible too late to reduce the speed without exercising emergency braking. However, usually anticipation of drivers cannot result in an efficiency optimized action. The efficiency optimized action (in this work – coasting of a vehicle) is an action, which often should start before the time point, at which the driver perceives the situation. It is proved, that via additional information of anticipatory ADAS it is possible to improve efficiency criterion of driving strategy, and increase safety in critical situations, which require execution of an emergency braking to reach lower speeds in a due time after the situation first becomes visible.

Proposed in this dissertation anticipatory ADAS possesses a potential in reducing fuel consumption and increasing safety. By displaying the upcoming deceleration situation and proposition to coast the vehicle at the appropriate point in time via visual HMI based on Bird’s-Eye View or Iconic concepts, it is possible to save on average 4% of estimated fuel on the route, which is 27.5 km long and includes thirteen relevant situations. Bird’s-Eye View concept is preferred by vast majority of the test subjects over Iconic.

HMI of the system, consisting of Bird’s-Eye View visual concept and additional haptic feedback in the form of AGP impulse at the time point when the coasting should be initiated, helps to save on average 7.5% of estimated fuel. The course, on which the reduction in estimated fuel consumption is observed when driving with this multimodal HMI of anticipatory assistance, is 24.5 km long and incorporates twelve assisted deceleration situations. Intermittent AGP feedback is especially appreciated on the highway and rural roads in the deceleration situations, which are of rare and unexpected occurrence.

Anticipatory ADAS, both with solely visual HMI and coupled with AGP feedback, help drivers to increase safety: in the potentially critical situation (“Highway Jam”) eight collisions occur during unassisted drives. In the assisted drives they are prevented, and resulting minimal decelerations are significantly milder – the driven speed is reduced in advance due to the preceding coasting phases before the braking sequence is initiated.

Visual behavior due to investigated concepts does not show any characteristics, which potentially can endanger the driver and distract his/her attention from the primary task of driving.

In the following, the general findings and corresponding recommendations regarding dissertational questions from Chapter 1.2 “Objectives of the work” are provided.

What is the subjective user acceptance of anticipatory ADAS with different HMIs?

The innovative approach of HMI for anticipatory ADAS (see Chapter 1.1 “Motivation”, Figure 1.5), in which it is stated that supporting anticipation on planning (knowledge-based) level will lead to higher acceptance of the anticipatory ADAS, proved to be the most appreciated by the drivers. The subjective preferences regarding investigated HMI concepts are following: likability and understandability of Bird’s-Eye View concept are significantly higher than of the Iconic, and it is rated by 22 votes against 3 as the better basis for a visual HMI of anticipatory ADAS. HMI complying with the principles of SA and SRK and considering temporal development of driving situation have higher degree of acceptance than the ones that only partially involve these principles (see Chapter 2.4.2 “Overview of HMI concepts in related research”, Figure 2.6).

HMI, consisting of visual Bird’s-Eye View presentation and intermittent AGP feedback, is accredited on the rural and highway roads, especially in the rare, unexpected situations. In the urban area, haptic feedback via AGP impulse is found to be unpleasantly dominant by vast majority of the test subjects. In the situations, involving slower moving vehicles, it is disliked by approximately 2/3 of experiment participants.

Results of the experiments prove that SA and anticipation of the driver are important processes influencing driving maneuvers. Enhancement of them via anticipatory ADAS can lead to significant improvement in fuel efficiency and safety on the guidance level of primary driving task. In (partially) unforeseeable situations, the resulting benefit of improved SA and anticipation is especially obvious and appreciated by the test subjects, when comparing to unassisted driving.

This work also validates the introduced coupling between SA and SRK theories. Especially for satisfactory user acceptance, support of anticipation resulting in maneuvering actions is necessary on all three levels of underlying information processing mechanisms: skill-, rule-, AND KNOWLEDGE-BASED. In previous related research, investigators ignored the support of planning activity occurring on the knowledge-based level, and concentrated solely on skill- and rule-based behavior. As a result, the user acceptance of the system, presenting information about future, not yet visible situations and demanding application of certain actions now, was poor. The author assumes, that the roots of this decision are dictated by historical reasons: until recently, ADAS possessed limited prediction capabilities regarding upcoming driving situations – up to 10 s ahead (see more on the sources of traffic information in Chapter 1.1 “Motivation”). Basically, ADAS was correcting and/or improving actions of the driver based on the actual situation, leaving the driver to search for the explanation of the interference from the visible surrounding. Planning of the driver did not have to be influenced – it already took place at the time point when ADAS interfered on the rule- and skill-based levels. However, the situation changes with new sources of traffic information and their extended operational horizon. Recently ADAS became the possibility to predict situation residing >10 s ahead and most of them might not be visible to the driver.

The assumption made in the beginning of the presented work is that before expecting the driver to perform a certain action because of the upcoming situation, it is necessary to enhance planning activity on the first place. Only this can provide the sufficient understanding why exactly the system evokes certain rule- and skill-based demands on driver behavior. Significantly higher acceptance of the anticipatory ADAS influencing planning activity, than of that not considering it, proves this assumption.

Amount of assisting information presented to the driver in modern vehicles is high. Additional indicators, needed for the support of planning, i.e. schematic representation of the working domain and temporal relations between relevant participants, do not result in the increased distraction from the primary task of driving. Driver reaction with Bird's-Eye View and Iconic concepts (see results in Chapter 4 "First Experiment: Visual HMI for Anticipatory ADAS") is similar: even though the amount of visual indicators objectively rises, the understanding, or comprehension, increases. This is why negative implication in form of longer reaction times, implicating higher workload, is not observed. Well-integrated information in anticipatory ADAS supporting planning justifies certain increase in objective amount of used indicators.

Recommendation: to increase the appeal and acceptability of HMI dedicated to the purposes of anticipatory ADAS, it is necessary to incorporate SA and SRK principles to its design. Temporal development of the situation and support of the planning are vital for the better understanding of the provided information. Intermittent AGP feedback is suitable when approaching rare and potentially dangerous situations, but should be avoided in common and often occurring ones, which involve for example slower preceding vehicles, and speed limit signs. Especially in the urban situations AGP feedback is of low acceptance. An assumed explanation for a restricted AGP acceptance is that AGP feedback is a strong indicator on the skill-based level, which might tame attention of the driver from system's support on the planning level, or from current complex driving situations. As a result, user acceptance of AGP feedback is high only in the situations, which are critical and not foreseeable. In these cases, drivers understand, why the system's support of planning becomes secondary, and rather skill-based actions are triggered.

To what extent does the proposed assistance influence efficiency, comfort, and safety? In which deceleration situations is the most significant benefit?

The coasting advice is adapted within 2-3 s in correspondingly 50-75% of the cases when driving with visual Bird's-Eye View HMI, and within 1.2-1.7 s when driving with additional AGP feedback. During the drives with visual Bird's-Eye View HMI, length of some coasting phases increases up to 200 m (rural road), and 400 m (highway) compared to Baseline condition. Longest resulting coasting phases last 13 s on rural roads, and 8 s on highway. For HMI with visual and haptic modalities, the observed increase is up to 250-300 m (rural road), 400 m (highway), and 100 m (urban road.) Resulting longest coasting phase durations are 16 s on rural and 8 s on highway roads.

As a result, in the case of visual assistance it is possible to reach on average reduction of 4% in estimated fuel throughout a complete drive, and with additional haptic feedback – 7.5%. The benefit lays mostly in the situations, which are unexpected and cannot be seen by the driver at the point in time, when the efficiency optimized action should begin. These involve oncoming traffic prohibiting immediate overtaking of obstacles (i.e. construction sites and slower lead vehicles) on the rural roads, and speed limit signs both on highway and rural roads. In the situations involving construction sites, drivers usually act in Baseline at the last moment once their development become obvious, namely they are generally hard to predict without any additional information. With traffic signs, the drivers are unable to read the exact written limit even if it becomes visible from the larger distances. Therefore, without anticipatory ADAS, drivers wait with their actions before they are aware to what extent exactly they have to reduce their speed. As a result, in both cases efficiency criterion is not preserved if not for anticipatory ADAS.

In the drives with multimodal HMI, during longer (>250 m) coasting phases in the urban situations the reduction of fuel consumption is observed. However, the subjective acceptance of prolonged coasting phases on the urban road is extremely low.

Recommendation: when designing the anticipatory ADAS, it is necessary to consider the activation time point of the system. Even though extended coasting phases and correspondingly earlier notification of the system might result in higher reduction of estimated fuel consumption, it is not recommended to provide advices in the urban area, which require >200 m coasting phases, or last over 5-6 s. On the rural road, maximal accepted coasting phases are of 16 s, and on the highway – 8 s. Earlier advices of the anticipatory ADAS, requiring longer coasting phases, might not be followed and perceived as unnecessary, which subsequently may lead to a lower user acceptance of a system.

Do possible inaccuracies if the presented information about the upcoming situation lead to critical driving behavior, i.e. accidents? Does it influence the overall acceptance of the system advices?

No accidents are observed due to introduced inaccuracies in the visual Bird's-Eye View HMI. As long as assisting information provides the driver with the general overview of the upcoming situation and enhances his/her anticipation (one of the comments is "I can at least expect the situation of the shown type, otherwise I would not know anything about its emergence"), the detailed presentation of the number of oncoming traffic prohibiting overtaking, or somewhat inaccurate distance to the situation is tolerated. Once the situation can be seen by the driver, assistance information plays secondary role in further decisions about driving actions.

It can be speculated, that the acceptance of inaccurate information could be lower, if it resulted in the complete absence or wrong preconditioning of the actions according to the upcoming situation. However, missed detections, ghost targets, and their tolerated rate are not investigated within the scope of this dissertation.

Recommendation: HMI should provide generic information, supporting appropriate mental models for the specific situation. Exact presentation of all relevant traffic participants is not necessary – the driver fills the mental model with certain pieces also by observing the real environment. The key elements of HMI should reflect the domain structure and its temporal characteristics (support for knowledge-based behavior), the rules needed to be followed (rule-based behavior), and signals associated with optimal action (skill-based behavior). In this work, the domain is schematically depicted by the curvature of the road and positioning of relevant driving situation, which moves on this "road" according to the temporal development of events; applicable rules are represented in the form of small icons representing corresponding traffic regulation signs; actions – via change of colors and AGP feedback.

Does the visual concept of assistance cause potentially critical visual behavior?

Neither Iconic, nor Bird's-Eye View visual concept of HMI results in potentially critical visual distraction from the primary task of driving. Mean glance durations observed when driving with Iconic or Bird's-Eye View HMI are between 0.54-0.55 s, which is comparable to the mean duration of glances directed towards the rear mirror. The average blind road time, caused by looking at the instrument cluster, does not exceed 14% for both visual concepts. The average frequency, at which the test subjects look at the instrument cluster when driving with Iconic concept, is 0.24 times per second, with Bird's-Eye View – 0.28. These values are complying with advices, found in related research.

Recommendation: visual assistance should not cause the distraction from the primary task of driving. It is recommended to compare the results of visual behavior analysis with following standards, which are found by the author in related research:

- "2 s - Rule": according to *Noy (2009),* 85% of the glances directed towards the in-vehicle devices should be less than 2 s;
- *Hada (1994)* has established, that comfort and safety tolerant limit of the road blind time caused looking at instrument cluster is 32%;
- in the same work, *Hada (1994)* advises the maximal limit of 0.35 times per second for the glance frequency directed towards instrument cluster;
- mean glance duration on instrument cluster containing additional information should be comparable with the duration of glances, which are typical for in-vehicle devices being frequently looked at: e.g. 0.5 s for the standard instrument cluster, 0.6-0.7 s for rear and side mirrors.
- also the distribution of the glances with and without assistance information should be taken into account. In this work, glance duration values corresponding to 25%, 50%, 75%, and 95% of all the glances are compared between the conditions.

Additional implication of introduced anticipatory ADAS can be derived for the recuperation strategy (see Chapter 1.1 “Motivation”), important for hybrid and electric vehicles. The presented system implies experiencing mostly mild decelerations not exceeding 0.3g (comfort criterion). Therefore, the recuperation should occur within this deceleration range.

In the **outlook** for further investigation of presented system in the real traffic conditions, following factors should be considered:

- driven lane – e.g. on German roads it is prohibited to overtake the vehicles travelling in the same direction on the lanes, located left to the driven lane. That means that by decreasing the speed by prolonged coasting on the left lane might lead to irritation of the drivers occupying the right lane, as well as to increase the density of vehicles trying to keep behind the coasting vehicle on the right lanes;
- distance to the vehicles, travelling behind on the same lane – if the vehicle is present and follows or rapidly approaches the driven vehicle, it is also questionable, if the prolonged coasting is acceptable, not irritating, and does not result in unnecessary overtaking maneuver by the ones driving behind;
- driver’s state – when in a hurry, the abundance of coasting phases can be perceived as a “slow down” process to the journey, and driver’s readiness to perform such phases might be reduced. Deceleration situations, which are investigated within the scope of this dissertation, occur with high density in the real-life conditions – almost every 500 m according to *Reichart et al. (1998)*;
- sustainability - acceptance of the system during long-term usage;
- error rate – certain amount of missed detections and ghost targets results in decreased acceptance of the system. It is necessary to investigate, what is the ratio between erroneous and correct information presentation, after which the anticipatory ADAS becomes contra productive and is ignored by the drivers.

Below the assumptions regarding mentioned issues, which are made on the basis of presented investigations, are provided.

Higher density of the deceleration situations will most probably lead to shorter coasting phases, than observed in the described experiments. However, even with slightly longer coasting phases, but increased number of deceleration situations, the reduction in fuel consumption is expected (e.g. coasting phases increase on 100 m instead of 200 m, but number of them is twice as high). As it is shown in this work, the expected minimal benefit reaches on average 4-7.5%.

On the other hand, one should consider using multimodal HMI only for the rare situations. Receiving a feedback of AGP every 500 m can be found as excessive alertness towards the situations, which are of frequent occurrence.

Regarding the long-term influence of the system, it can be said that the visual distraction factor will decrease. As it is shown by the field operational test of *Wohlfarter (2005)*, visual demand of newly introduced visual indicators decreases with the exploitation time of a system.

No assumptions can be made regarding influence of the vehicles, which are driving behind or on the right lane, when the decision to perform a coasting phase takes place. It is expected, that the coasting phases will decrease, but to which extent – is to be answered by following investigations.

Missed detections and ghost targets are inevitable while usage of the anticipatory ADAS in real traffic. The question remains open: what is the tolerable quota of this type of erroneous data, before driver decides to ignore system advices? The assumption based on the results of performed investigation show that certain amount of this erroneous information is likely to be tolerated: drivers do not expect the data provided to be impeccable, and base their decisions also from observed driving situation in the real conditions.

For further development of HMI, it is advised to address emotional, motivational, and persuasive design theories *(Norman, 2005, Fogg, 2010,* and *Bengler, 2010)*. Feedback about immediate gain in efficiency, and the one at the end of the route, can increase the appeal of following the advice of a system. The driver assistance system can encourage anticipatory strategy by providing the ability and increasing the motivation to perform it; but it is solely left to the driver to change his/her habitual driving according to the system's information.

LIST OF FIGURES

LIST OF DIAGRAMS

LIST OF TABLES

APPENDIX A – DURATION AND LENGTH OF COASTING PHASES DEPENDING ON DRIVEN AND TARGET SPEEDS

Duration, in s

Driven Speed [km/h]	Target Speed [km/h] 140	130	120	110	100	90	80	70	60	50	40
150	2,99	6,25	9,83	13,76	18,12	22,98	28,43	34,6	41,66	49,84	59,45
140	-	3,26	6,84	10,77	15,13	19,99	25,44	31,61	38,67	46,85	56,46
130		-	3,57	7,51	11,87	16,72	22,18	28,35	35,41	43,59	53,2
120			-	3,94	8,29	13,15	18,6	24,78	31,84	40,01	49,63
110				-	4,36	9,21	14,67	20,84	27,9	36,08	45,69
100					-	4,86	10,31	16,48	23,54	31,72	41,33
90						-	5,45	11,63	18,69	26,86	36,48
80							-	6,17	13,24	21,41	31,02
70								-	7,06	15,24	24,85
60									-	8,18	17,79
50										-	9,61
40											-

Length, in m

Driven Speed [km/h]	Target Speed [km/h] 140	120	100	80	60	40	20
150	120	367	619	876	1.132	1.376	1.585
140		246	499	756	1.011	1.256	1.465
130		124	377	633	889	1.133	1.342
120			253	509	765	1.009	1.218
110			127	384	639	884	1.093
100				257	512	757	966
90				129	384	629	838
80					256	500	709
70					127	372	581
60						244	453
50						120	329
40							209
30							97

APPENDIX B.1 – FIRST EXPERIMENT, DEMOGRAPHICAL QUESTIONS

Page 1

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	○	○	○	○	○

Page 2

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

Page 3

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? __________

APPENDIX B.2 – FIRST EXPERIMENT, QUESTIONS REGARDING ICONIC HMI AFTER THE EXPERIMENT DRIVE

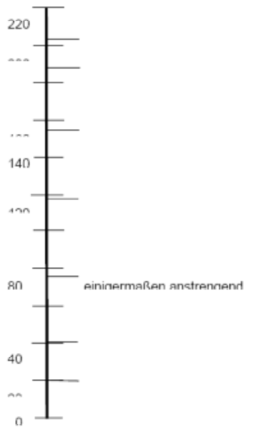
Page 1

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B2 Fragen nach der Fahrt mit Anzeige A zur Unterstützung bein vorausschauenden Fahren (2D-Anzeige)

1) Bitte kreuzen Sie auf der folgenden Skala an, wie **anstrengend** die gerade absol te **Fahrt** für Sie war. Hierbei können Sie das Kreuz an jeder beliebigen Stelle der Skala chen – auch zwischen den Markierungsstrichen.



Page 2

2) Wie **gefällt** Ihnen die eben gesehene **Anzeige** zur Unterstützung beim voraus-schauenden Fahren?

Sehr schlecht	○	○	○	○	○	Sehr g

3) Haben Sie sich bei der eben gesehenen Darstellung **sicher gefühlt** bzgl. der von Ih erwarteten Handlung?

Überhaupt nicht	○	○	○	○	○	Voll ur ganz

4) Empfanden Sie bei der eben gesehenen Darstellung den **Zeitpunkt der Informati** als angemessen?

Viel zu früh	○	○	○	○	○	Viel zu spät

5) Die Darstellung der Situation war **verständlich**

Gar nicht	○	○	○	○	○	Sehr g

6) Mir ist es durch die Visualisierung leicht gefallen mich auf die Situation einzuste bevor ich sie gesehen habe.

Sehr leicht	○	○	○	○	○	Sehr schwe

Page 3

7) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegeben Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einst fen, 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

Page 4

8) Was hat Ihnen an dieser Anzeige insgesamt **besonders gut gefallen**? (Farbe, Gr ße, Form, Bewegung, Schnelligkeit der Informationsdarbietung etc.)

____

9) Was sollte **unbedingt verbessert** werden? Nehmen Sie hier bitte insbesondere Be auf Fragen und Aussagen, die Sie auf den vorangegangenen Seiten des Fragebogens ne tiv bewertet haben.

____

APPENDIX B.3 – FIRST EXPERIMENT, QUESTIONS REGARDING BIRD'S-EYE VIEW HMI AFTER THE EXPERIMENT DRIVE

Page 1

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B3 Fragen nach der Fahrt mit Anzeige B zur Unterstützung bein vorausschauenden Fahren (3D-Anzeige)

1) Bitte kreuzen Sie auf der folgenden Skala an, wie **anstrengend** die gerade absol te **Fahrt** für Sie war. Hierbei können Sie das Kreuz an jeder beliebigen Stelle der Skala chen – auch zwischen den Markierungsstrichen.

220

140

80 einigermaßen anstrengend

40

0

Page 2

2) Wie **gefällt** Ihnen die eben gesehene **Anzeige** zur Unterstützung beim voraus- schauenden Fahren?

Sehr schlecht	○	○	○	○	○	Sehr g

3) Haben Sie sich bei der eben gesehenen Darstellung **sicher gefühlt** bzgl. der von Il erwarteten Handlung?

Überhaupt nicht	○	○	○	○	○	Voll u ganz

4) Empfanden Sie bei der eben gesehenen Darstellung den **Zeitpunkt der Informat** als angemessen?

Viel zu früh	○	○	○	○	○	Viel zu spät

5) Die Darstellung der Situation war **verständlich**

Gar nicht	○	○	○	○	○	Sehr g

6) Mir ist es durch die Visualisierung leicht gefallen mich auf die Situation einzust bevor ich sie gesehen habe.

Sehr leicht	○	○	○	○	○	Sehr schwe

Page 3

7) Bitte **bewerten** Sie die **Anzeige** möglichst spontan mit Hilfe der unten angegebene Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können oder die Anzeige neutral einstu fen, 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

Page 4

8) Was hat Ihnen an dieser Anzeige insgesamt **besonders gut gefallen**? (Farbe, G ße, Form, Bewegung, Schnelligkeit der Informationsdarbietung etc.)

____

____

____

____

____

____

____

____

____

____

9) Was sollte **unbedingt verbessert** werden? Nehmen Sie hier bitte insbesondere Be auf Fragen und Aussagen, die Sie auf den vorangegangenen Seiten des Fragebogens n tiv bewertet haben.

____

____

____

____

____

APPENDIX B.4 – FIRST EXPERIMENT, FINAL QUESTIONS

Page 1

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 S tuationen?

	Sehr stö-rend	Eher stö-rend	Weder hilfreich noch stö-rend	Eher hilf-reich	Sehr hil reich
Baustelle	○	○	○	○	○
Einparkendes Vor-derfahrzeug	○	○	○	○	○
Ampel	○	○	○	○	○
Langsames Vorder-fahrzeug	○	○	○	○	○
Geschwindigkeits-begrenzung	○	○	○	○	○
Zähfließender Ver-kehr	○	○	○	○	○
Stau	○	○	○	○	○

2) Gab es bei **Anzeige A** (2D-Anzeige) **Symbole**, die Sie **nicht verstanden** haben?

○ ja ○ nein

Wenn ja, welche waren das?

____

____

____

____

Page 2

3) Haben Sie bei **Anzeige A** (2D-Anzeige) bestimmte **Informationen vermisst**?

○ ja ○ nein

Wenn ja, welche waren das?

____

____

____

____

____

4) Haben Sie bei **Anzeige A** (2D-Anzeige) **überflüssige Informationen** bemerkt?

○ ja ○ nein

Wenn ja, welche waren das?

____

____

____

____

____

Page 3

C2) Fragen zu Anzeige B (3D-Anzeige)

1) Wie **störend bzw. hilfreich** fanden Sie **Anzeige B** (3D-Anzeige) in den folgenden Si tuationen?

	Sehr stö-rend	Eher stö-rend	Weder hilfreich noch stö-rend	Eher hilf-reich	Sehr hilf reich
Baustelle	○	○	○	○	○
Einparkendes Vor-derfahrzeug	○	○	○	○	○
Ampel	○	○	○	○	○
Langsames Vorder-fahrzeug	○	○	○	○	○
Geschwindigkeits-begrenzung	○	○	○	○	○
Zähfließender Ver-kehr	○	○	○	○	○
Stau	○	○	○	○	○

2) Gab es bei **Anzeige B** (3D-Anzeige) **Symbole**, die Sie **nicht verstanden** haben?

○ ja ○ nein

Wenn ja, welche waren das?

____

____

____

Page 4

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?

____

____

____

____

____

Page 5

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	unbedin
Anzeige A (2DAnzeige)	○	○	○	○	○
Anzeige B (3DAnzeige)	○	○	○	○	○

2) Wenn Sie sich ein Auto nach Ihren **Wünschen** zusammenstellen könnten, hätten S 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 wurder Sie wählen?

○ Anzeige A ○ Anzeige B

4) Was gab den Ausschlag für Ihre oben getroffene Wahl? Was ist Ihnen am wichtigsten?

____
____
____
____
____
____
____
____

Page 6

5) Gab es Situationen, in denen Sie sich vorstellen könnten im realen Straßenverkehr z dem angezeigten Zeitpunkt bereits vom Gas zu gehen? Falls, ja, nennen Sie bitte die Situ tionen:

____
____
____
____
____
____
____
____

6) Haben Sie weitere Vorschläge oder Anmerkungen? Bitte notieren Sie diese hier:

____
____
____
____
____
____
____
____

Vielen Dank für Ihre Unterstützung!

APPENDIX C.1 – SECOND EXPERIMENT, DEMOGRAPHICAL QUESTIONS

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) 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
○	○	○	○	○

6) Ist dies Ihre erste Fahrt in einem Fahrsimulator? ○ ja ○ nein

APPENDIX C.2 – SECOND EXPERIMENT, QUESTIONS DURING THE EXPERIMENT DRIVE WITH VISUAL ASSISTANCE

Page 1

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B Fragen während der Fahrt mit visueller Anzeige

Bitte antworten Sie die folgenden Fragen in einer Skala von 1 bis 5, wobei 1 der Antwort „gar nicht“ entspricht und 5 der Antwort „sehr gut“ bzw. „sehr viel“.

B.1 Überholverbot

1) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

2) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

____

B.2 Baustelle Gerade

3) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

4) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

Page 2

____

____

____

B.3 Gegenverkehr

5) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

6) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

____

B.4 Autobahn Spur

7) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

8) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

Page 3

B.5 Autobahn Stau

9) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

10) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

____

B.6 Begrenzung auf 120-100

11) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

12) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

____

B.7 Stop & Go

13) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

Page 4

14) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

____

B.8 Begrenzung auf 120

15) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

16) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

____

B.9 Begrenzung auf Landstraße 70-50

17) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

18) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

Page 5

B.10 Stadteinfahrt

19) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

20) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

____

B.11 Baustelle Kurve

21) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

22) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

APPENDIX C.3 – SECOND EXPERIMENT, QUESTIONS DURING THE EXPERIMENT DRIVE WITH VISUAL AND HAPTIC (ACTIVE GAS PEDAL) ASSISTANCE

Page 1

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

C Fragen während der Fahrt mit visueller Anzeige und Aktivem Gaspedal (AGP)

Bitte antworten Sie die folgenden Fragen in einer Skala von 1 bis 5, wobei 1 der Antwort „gar nicht“ entspricht und 5 der Antwort „sehr gut“ bzw. „sehr viel“.

C.1 Überholverbot

1) In wie fern waren die Anzeigen in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

2) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

C.2 Baustelle Gerade

3) In wie fern waren die Anzeigen in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

4) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

Page 2

B.3 Gegenverkehr

5) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

6) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

B.4 Autobahn Spur

7) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

8) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

Page 3

B.5 Autobahn Stau

9) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

10) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

B.6 Begrenzung auf 120-100

11) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

12) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

B.7 Stop & Go

13) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

Page 4

14) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

B.8 Begrenzung auf 120

15) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

16) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

B.9 Begrenzung auf Landstraße 70-50

17) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

18) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

Page 5

B.10 Stadteinfahrt

19) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

20) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

____

B.11 Baustelle Kurve

21) In wie fern war die Anzeige in der letzten Situation für Sie hilfreich?

Gar nicht	○	○	○	○	○	Sehr gut

22) Ist Ihnen was Besonderes an der letzten Situation aufgefallen?

____

____

____

APPENDIX C.4 – SECOND EXPERIMENT, FINAL QUESTIONS

Page 1

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

D Abschlussfragebogen

1) Wie **gefällt** Ihnen die eben gesehene **Anzeige** zur Unterstützung beim voraus schauenden Fahren?

Visuelle Anzeige	Sehr schlecht	○	○	○	○	○	Sehr gut
Visuelle Anzeige +	Sehr schlecht	○	○	○	○	○	Sehr gut

2) Haben Sie sich mit der Anzeige **sicher gefühlt** bzgl. der von Ihnen erwarteter Handlung?

Visuelle Anzeige	Überhaupt nicht	○	○	○	○	○	Voll unc ganz
Visuelle Anzeige + Aktives Gaspedal	Überhaupt nicht	○	○	○	○	○	Voll unc ganz

Page 2

3) Sind Ihnen Unklarheiten oder Fehler an der Anzeige aufgefallen?

Visuelle Anzeige: ○ ja ○ nein

Visuelle Anzeige und Aktives Gaspedal: ○ ja ○ nein

4) Wenn Ja, welche waren es und an welchen Situationen ist es Ihnen aufgefallen?

____

____

____

____

5) Haben Sie sich in den folgenden Anzeigen, aufgrund der auftretenden Fehler, unsicher gefühlt?

Visuelle Anzeige	Überhaupt nicht	○	○	○	○	○	Sehr
Visuelle Anzeige + Aktives Gaspedal	Überhaupt nicht	○	○	○	○	○	Sehr

6) Wenn Sie sich **für eine Anzeige entscheiden** müssten – Welche von beiden würder Sie wählen?

○ Visuelle Anzeige ○ Visuelle Anzeige und aktives Gaspedal

Page 3

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.

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

APPENDIX D.1 – THIRD EXPERIMENT, DEMOGRAPHICAL QUESTIONS

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) 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
○	○	○	○	○

6) Ist dies Ihre erste Fahrt in einem Fahrsimulator? ○ ja ○ nein

7) Ich bin meistens dazu motiviert meine Fahrweise entsprechend anzupassen, dass ich den Kraftstoffverbrauch reduziere.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

APPENDIX D.2 – THIRD EXPERIMENT, QUESTIONS DURING THE EXPERIMENT DRIVE WITH VISUAL AND HAPTIC (ACTIVE GAS PEDAL) ASSISTANCE

Page 1

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

B Fragen während der Fahrt mit visueller Anzeige und Aktivem Gaspedal (AGP)

B.1 Überholverbot

1) In der letzten Situation fand ich die Unterstützung allgemein hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.2 Baustelle Kurve

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

Page 2

VP-Nr.:	Datum:

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.3 Stadteinfahrt

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.4 Einparkendes Fahrzeug

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

Page 3

VP-Nr.:	Datum:

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.5 Ampel

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.6 Begrenzung auf 70 mit langsamem Fahrzeug voraus

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

Page 4

VP-Nr.:	Datum:

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.7 Stau

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.8 Geschwindigkeitsbegrenzung auf der Autobahn

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

Page 5

VP-Nr.:	Datum:

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.9 Stop & Go

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.10 Baustelle Gerade

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

Page 6

VP-Nr.:	Datum:

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.11 Gegenverkehr

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

B.12 Begrenzung auf Landstraße 70-50

1) In der letzten Situation fand ich die Unterstützung hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

2) In der letzten Situation fand ich die Unterstützung durch AGP hilfreich.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

Page 7

VP-Nr.:	Datum:

3) In der letzten Situation empfand ich die Unterstützung durch AGP bevormundend.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu

APPENDIX D.3 – THIRD EXPERIMENT, FINAL QUESTIONS

Page 1

VP-Nr.:	Datum:

Fragebogen zum Fahrsimulatorexperiment

C Abschlussfragebogen

1) Im Allgemeinen empfand ich den Einsatz des aktiven Gaspedals (AGP) als sehr gut.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu		○ nicht zu beantworten

2) Bitte bewerten sie das aktive Gaspedal mit Hilfe der unten angegebenen Adjektiv-Paare. Wenn Sie keine Zuordnung treffen können, beziehungsweise Ihnen die Adjektive irrelevant erscheinen, kreuzen Sie bitte „nicht zu beantworten" an. Der Mittelpunkt der Skale bedeutet „weder noch".

Der Einsatz des aktiven Gaspedals ist...

angenehm	○	○	○	○	○	unangenehm		○ nicht zu beantworten
nicht ablenkend	○	○	○	○	○	ablenkend		○ nicht zu beantworten
nicht störend	○	○	○	○	○	störend		○ nicht zu beantworten
unzweckmäßig	○	○	○	○	○	zweckmäßig		○ nicht zu beantworten
hilfreich	○	○	○	○	○	nicht hilfreich		○ nicht zu beantworten
verwirrend	○	○	○	○	○	eindeutig		○ nicht zu beantworten
macht Freude	○	○	○	○	○	frustrierend		○ nicht zu beantworten
bevormundend	○	○	○	○	○	befreiend		○ nicht zu beantworten
entlastend	○	○	○	○	○	belastend		○ nicht zu beantworten

Page 2

VP-Nr.:	Datum:

3) Würden Sie es bevorzugen, wenn das aktive Gaspedal während der Fahrt deaktiviert werden könnte?

○ ja ○ nein

4) Wie haben Sie den Impuls des aktiven Gaspedals empfunden?

○ zu schwach	○ eher zu schwach	○ optimal	○ eher zu stark	○ zu stark

5) Wie empfanden Sie den Zeitpunkt zu welchem das aktive Gaspedal zum Einsatz kam?

○ zu früh	○ eher zu früh	○ optimal	○ eher zu spät	○ zu spät

Auf dem Informationsblatt neben sich sehen Sie noch einmal alle Situationen, die Sie durchfahren haben. Bitte tragen sie nachfolgend jeweils die zugehörigen Buchstaben ein:

6) Folgende Situationen habe ich im Straßenverkehr selten erlebt:

____

Den Einsatz des aktiven Gaspedals (AGP) wünsche ich mir besonders in Situationen, die selten vorkommen.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu		○ nicht zu beantworten

7) Folgende Situationen konnte ich zum Zeitpunkt, an dem die Assistenz aktiv wurde, nicht vollständig überblicken (z.B. war der weitere Straßenverlauf oder Gegenverkehr nicht sofort ersichtlich):

____

Page 3

VP-Nr.:	Datum:

Den Einsatz von AGP wünsche ich mir besonders in Situationen, die ich nicht vollständig überblicke.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu		○ nicht zu beantworten

8) Den Einsatz von AGP wünsche ich mir besonders in der Stadt.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu		○ nicht zu beantworten

9) Den Einsatz von AGP wünsche ich mir besonders bei der Überlandfahrt.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu		○ nicht zu beantworten

10) Den Einsatz von AGP wünsche ich mir besonders auf der Autobahn.

○ stimme nicht zu	○ stimme eher nicht zu	○ weder noch	○ stimme eher zu	○ stimme voll zu		○ nicht zu beantworten

11) Hier finden Sie Raum für Anmerkungen und Wünsche. Was sollte unbedingt verbessert werden? Was hat Ihnen besonders gut gefallen?

____

____

____

____

Vielen Dank für Ihre Teilnahme!
Ihr Lehrstuhl für Ergonomie.

BIBLIOGRAPHY

Ahrholdt, M. (2006): A Swidish Reseach Initiative on Sensor Data Fusion. Proceedings of ITS Conference, London, UK.

AIDE Deliverable 2.1.1 (2004): Review of existing tools and methods. http://www.aide-eu.org/pdf/sp2_deliv_new/aide_d2_1_1.pdf, accessed June 2001

AIDE Deliverable 2.4.1 (2008): Specification of AIDE methodology. http://www.aide-eu.org/pdf/sp2_deliv_new/aide_d2_1_4_summary.pdf, accessed June 2011

Alt, M;, Schaffner, P.; Rothenberger, P. (2006): Effizienzsteigerung des Ottomotors durch Technologiekombinationen GM Powertrain. Presentation at 15. Aachener Kolloquium Fahrzeug- und Motorentechnik Aachen, October.

Barlett, F.C. (1932): Remembering. Cambridge University Press.

Bengler, K. (2010): Nachhaltige Effizienzsteigung durch höhere Integration des Nutzers. Proc. 56. Frühjahrskongress der Gesellschaft für Arbeitswissenschaft e.V.(GfA), Darmstadt Germany, March.

Benson, J. (1997):The developmet of planning: It's about time. The developmental psychology of planning: Why, how, and when do we plan?, (pp. 43-75). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Bernotat, R. (1970): Antropotechnik in der Fahrzeugführung. Ergonomics, 13, 353-377.

Bertram, M. (1996): Antrieb mit intermittierendem Motorbetrieb. ATZ 98(6), 312-320.

Bogenberger, R., Kosch, R. (2002): Ad-hoc Peer-to-Peer Communication-Webs on the Street. ITS-Paper No. 2149, Proc. 9th World Congress on Intelligent Transport Systems, Chicago, 14-18 October.

Bortz, J. (2005): Statistik für Human- und Sozialwissenschaftler. Springer Medizin Verlag.

Bortz, J., Döring, N. (2007): Forschungsmethoden und Evaluation. Springer.

Breuer, J. (2009): Bewertungsverfahren von Fahrerassistenzsystemen. Handbuch Fahrerassistenzsysteme, Vieweg & Teubner.

Bruckmaier, M. (2010): Einfluss von MMI-Anzeigen zum antizipativen Fahren auf das Blickverhalten. Semester thesis, Technische Universität München.

Brünger-Koch, M., Briest, S., Vollrath, M. (2006): Virtual driving with different motion *characteristics – braking manoeuvre analysis and validation.* Proceedings of Driving Simulation Conference, pp.69-78.

Bubb, H. (1993a): Systemergonomische Gestaltung. Schmidtke, H. (Hrsg.), Ergonomie 3. Auflage, München, Hanser Verlag.

Bubb, H. (1993b): Informationswandel durch das System. Schmidtke, H. (Hrsg.), Ergonomie 3. Auflage, München, Hanser Verlag.

Bubb, H. (2001): Haptik im Kraftfahrzeug. Klaus-Peter Timpe: Kraftfahrzeugführung, Springer-Verlag.

Burckhardt, M., Burg, H., Gnadler, R., Näumann, E., Schiemann, G. (1981) : Die Brems-Reaktionsdauer von Pkw-Fahrern. Verkehrsunfall und Fahrzeugtechnik, 12.

Cassirer, E. (1944): Essay on Man. New Haven, CT: Yale University Press.

Casson, R.W. (1983): Set Phasers on Stun. Santa Barbara, CA: Aegean.

Chatziastros, A.; Wallis, G.; and Bulthoff, H. (1999): The Use of Splay Angle and Optical Flow in Steering a Central Path. Technical Report 72, Max Planck Institute for Biological Cybernetics.

Cherri, C.; Nodari, E.; Toffetti, A. (2005): Review of existing Tools and Methods. Deliverable 2.1.1 of the Integrated Project AIDE, Brussels, AIDE Consortium.

Cook, M.J., Noyes, J.M., Masakowski, Y. (2007): Decision making in complex environments. Ashgate Publishing Limited, ISBN 978-0-7546-4950-2.

Cummings, M.L.; Kilgore, R.H.; Wang, E.; Tijerina, L. (2007): Effects of Single Versus Multiple Warnigns on Driver Performance. Human Factors, 49(6), 1097-1106.

Dahmen-Zimmer, K.; Gründl, M. (2007): Antizipation. Unpubished presenation within TUMMIC VI project. Regensburg, Lehrstuhl für Experimentelle und Angewandte Psychologie.

Dettinger, J (2008a): Reaktionsdauer bei Notbremsungen Entwicklung und Status quo des Erkenntnisstandes – Teil 1. Verkehrsunfall und Fahrzeugtechnik, Juni, 180-187.

Dettinger, J (2008b): Reaktionsdauer bei Notbremsungen Entwicklung und Status quo des Erkenntnisstandes – Teil 2. Verkehrsunfall und Fahrzeugtechnik, Juli, 230-235.

Deutschle, S. (2005): Fahrerassistenzsysteme (FAS) – Wer fährt, das System oder der Fahrer?. http://www.pelops.de/pdf/2005/5de0011-koeln_19-01-2005.pdf

Dominguez, C. (1994). Can SA be defined? M. Vidulich, C. Dominguez, E. Vogel, G. McMillan (Eds.), Situation Awareness: Papers and Annotated Biography (pp. 5-15). United States Air Force Armstrong Laboratory, Brooks Air Force Base.

Donges, E. (1975): Experimentelle Untersuchung des menschlichen Lenkverhaltens bei *simulierter Straßenfahrt.* Automobiltechnische Zeitung, 77(5), 141–146.

Donges, E. (1978). Ein regelungstechnisches Zwei-Ebenen-Modell des menschlichen Lenkverhaltens im Kraftfahrzeug. Zeitschrift für Verkehrssicherheit, 24, 98-112.

Donges, E. (2009). Fahrerverhaltensmodelle. Handbuch Fahrerassistenzsysteme, CWV Fachvelage GmbH, Wiebaden, Germany, pp.15-23.

Dorrer, C. (2003): Effizienzbestimmung von Fahrweisen und Fahrerassistenz zur Reduzierung des Kraftstoffverbrauchs unter Nutzung telematischer Informationen. Doctoral dissertation, Technische Universität München.

Duschl, M., Popiv, D., Rakic, M., Klinker, G. (2010): Birdeye View Visualization for assisting prospective driving. Proc. FISITA 2010 World Automotive Congress, Budabest, Hungary, 30 May - 4 June.

Ecomove (2010): Clean-up operation. Traffic Technology International, June/July

Endsley, M.R. (1995b): Toward a theory of situation awareness in dynamic systems. Human Factors, 37, 32-64

Endsley, M.R.; Bolte, B.; Jones, D.G. (2003): Designing for situation awarness: An approach to human-centered design. New York, Taylor & Francis

Endsley, M.R., Kiris, E.O., (1995a): The out-of-the-loop performance problem and level of control in automation. Human Factors, 37(2), 381-394

Färber, B. (1986): Abstandswahrnehmung und Bremsverhalten von Kraftfahren im fließenden Verkehr. Zeitschrift für Verkehrssicherheit 32(1), 9-13

Farid, M. (2008): unpublished work of BMW Group Forschung und Technik

Farid, M.; Kopf, M.; Bubb, H.; Essaili, A. (2006): Methods to develop a driver observation system used in an active safety system. Proc. 22nd Internationale VDI/VW-Gemeinschaftstagung, Wolfsburg, Germany

Fastenmeier, W. (1995): Autofahrer und Verkehrssituation – Neue Wege zur Bewertung von Sicherheit und Zuverlässigkeit moderner Straßenverkehrssysteme. Köln: Verlag TÜV Rheinland, Mensch-Fahrzeug-Umwelt.

Fogg, BJ (2010): A Behavior Model for Persuasive Design. http://bjfogg.com/fbm.html, accessed June 2010.

Freymann, R. (2004): Möglichkeiten und Grenzen von Fahrerassistenz- und Aktiven Sicherheit. Proc. Tagung Aktive Sicherheit durch Fahrerassistenz, Garching bei München, 11-12 March.

Gibson, J.; Schumann, V. (1973): Die Wahrnehmung der visuellen Welt. Weinheim, Beltz.

Goldstein, B. (2008): Cognitive Psychology. Connecting Mind, Research, and Everyday

Experience. Thomson Higher Education, Belmond, CA, USA.

Gray, D. (2011): Electric mobility, renewables and smart grids: the state of the art. http://eharbours.eu/wp-content/uploads/David-Gray-eharbours-launch-presentation.pdf.

Green, P. (1995): Measures and Methods Used to Assess the Safety and Usability of Driver Information Systems. Technical report, Transportation Research Institute, University of Michigan.

Hada, H. (1994): Driver's Visual Attention to In-Vehicle Displays: Effects of Display Location and Road Type. Technical report, Transportation Research Institute, University of Michigan.

Hanselka, H., Jöckel, M. (2010): Elektromobilität – Elemente, Herausforderungen, Potenziale. In: Elektromobilität. Potenziale und wissenschaftlich-technische Herausforderungen. Hüttl R.F., Pischetsrieder, B., Spath, D. (Hrsg.), Springer Verlag.

Hajek, H. (2010): Untersuchung des Einflusses von einem aktiven Gaspedal auf die Fahrerreaktion und die Akzeptanz zur Unterstützung des vorrausschauenden Fahrens. Diplom thesis, Technische Universität München.

Heißing, B. (2008): Fahrwekhandbuch. Vieweg und Teubner.

Hoffmann, J., Gayko, J. (2009): Fahrerwarnelemente. Handbuch Fahrerassistenzsysteme, Vieweg & Teubner, 343-354.

Horst, van der, R. (1990): A time-based analysis of road user behaviour in normal and critical encounters. PhD Thesis, Delft University of Technology, Delft.

Horst, van der, R. (2007): Time-Related Measures for Modeling Risk in Driver Behavior. Modeling Driver Behaviour in Automotive Environments, Springer.

Horst, van der, R., Hogema, J. (1990): Time-to-Collision and Collision Avoidance Systems. Salzburg: Proc. of the 6th ICTCT Workshop: Safety Evaluation of Traffic Systems. 109-121.

Hulst, van der, M., Meijman, T. & Rothengatter, T. (1999): Anticipation and the adaptive control of safety margins in driving. Ergonomics, 42, Nr. 2, 336-345.

Internet entry ADAC: www1. adac.de/images/ADAC Sprit-Spar-Training_10 Tipps SST_Toyota_tcm8-219614.pdf, accessed June 2010.

Internet entry Beyond Petroleum: *Statistical Review of World Energy 2010.* www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/statistical_review_of_world_energy_full_report_2010.pdf, accessed June 2010.

Internet entry BMW Efficient Dynamics. http://www.bmw.de/de/de/insights/technology/efficientdynamics/phase_1/introduction.html, accessed June 2011.

Internet entry Bosch GmbH, Fernbereichsradarsensor. http://www.bosch-kraftfahrzeugtechnik.de/de/fahrsicherheitssysteme/asr/fernbereichsradarsensor_1/fernbereichsradarsensor.asp, accessed June 2011.

Internet entry Conti-Online. http://www.conti-online.com/generator/www/de/en/continental/automotive/themes/passenger_cars/chassis_safety/chassis_components/fahrwerkselektronik/fahrwerkselektronik_en.html, accessed June 2011.

Internet entry EcoDrive: www.ecodrive.org/the-golden-rules-of-ecodriving.249.0.html, accessed June 2010.

Internet entry Electromobility+: http://www.transport-era.net/electromobility.html, accessed June 2011.

Internet entry Energy Information Administration, Official Energy Statistics from U.S. Government, International Energy Outlook 2008: www.eia.doe.gov, accessed June 2010.

Internet entry EuroActiv: www.euractiv.com/en/transport/europe-auto-industry-roadmap-fire/article-150832, accessed June 2010.

Internet entry Ergoneers: http://www.ergoneers.com, accessed June 2010.

Internet entry Fiat: http://www.fiat.com/ecodrive/, accessed June 2010.

Internet entry Honda: http://automobiles.honda.com/insight-hybrid/fuel-efficiency.aspx, accessed June 2010.

Internet entry Lateral Support: http://www.prevent-ip.org/en/prevent_subprojects/lateral_support_driver_monitoring/, accessed June 2011.

Internet entry Safe Speed and Safe Following: http://www.prevent-ip.org/en/prevent_subprojects/safe_speed_and_safe_following/, accessed June 2011.

Internet entry SILAB: http://www.wivw.de/ProdukteDienstleistungen/SILAB/index.php.de/, accessed June 2010.

Internet entry Wireless Charging: http://www.e90post.com/forums/showthread.php?t=515821, accessed June 2011.

ISO-15007-1:2002. Road vehicles - Measurement of driver visual behavior with respect to transport information and control systems - Part 1: Definitions and parameters.

ISO-15007-2:2002. Road vehicles – Measurement of driver visual behavior with respect to transport information and control systems – Part 2: Equipment and procedures.

ISO-9241-210:2010. Human-centered design for interactive systems.

Johansson, G., Epstein, W., Jansson, G. (1994): Perceiving events and objects. Lawrence Erlbaum Associates.

Johnson-Laired P.N. (1993): Mental Models. Cambridge University Press.

Kirlik, A.C. (1989): The organization of perception and action in complex control skills. Dissertation, The Ohio State University.

Klein, G.A. (1989): Recognition-primed decisions. W.B. Rouse, Ed. Advances in Man-Machine Systems Research, 5, Greenwich, JAI Press, 47-92.

Kosch, T. (2004): Den Horizont der Fahrerassistenz erweitern: Vorausschauende Systeme durch Ad-hoc Vernetzung. Proc. Tagung Aktive Sicherheit durch Fahrerassistenz, Garching bei München, 11-12 March.

Küssel, M. (2010): The future of electromobility. Bosch technologies for electric vehicles. http://www.bosch-presse.de/presseforum/download/de/Presseworkshop_Kuesell-e.pdf

Kutz, M. (2008): Environmentally conscious transportation. John Wily & Sons, Inc., Hoboken, New Jersey.

Lange, C. (2008): Wirkung von Fahrerassistenz auf der Führungsebene in Abhängigkeit der Modalität und des Automatisierungsgrades. Doctoral Dissertation, Technische Universität München.

Lange, C.; Schmitt, G.; Arcati, A.; Bengler, K.; Bubb, H. (2010): Parametrierung eines Schaltpunkthinweises am aktiven Gaspedal und Bestimmung des Potenzials zur Verbrauchsreduzierung. Proc. 56. Frühjahrskongress der Gesellschaft für Arbeitswissenschaft e.V.(GfA), Darmstadt Germany, March

Laquai, F.; Rigoll, G. (2010): Geschwindigkeitsbeeinflussung durch großflächige abstrakte optische Anzeigen. Proc. 4. Tagung Sicherheit durch Fahrerassistenz, Munich, 15-16 April.

Maltz, M.; Shinar, D. (2004): Imperfect In-Vehicle Collision Avoidance Warning Systems can aid Dirvers. Human Factors, 46.

Metz, B.; Rauch, N.; Krueger, H.-P.; Bengler, K. (2008): Situation awareness in driving with in-vehicle information systems. Proc. Driver Metrics Workshop der SAEInternational und AAM, San Antonio, 2 June.

Michon, J.A. (1985): A critical view of driver behavior models: what do we know, what should we do? L. Evans & R.C. Schwing (Hrsg.), Human behavior and traffic safety, New York: Plenum Press.

Miller, G. A. (1956): The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. Psychological Review, 110(2), 343– 352.

Moray, N. (1999): Mental models in theory and practice. D. Gopher and A. Koriat (Eds.), Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application (223-258). Attention and performance: MIT Press.

Müller, T. (2010): Integration eines Bewertungsverfahrens von Kraftstoffverbrauchsangaben im PKW Fahrsimulator anhand unterschiedlicher Fahrdynamikmodelle. Diplom thesis, Technische Universität München.

Naab, K. (2004): Sensorik und Signalverarbeitungsarchitekturen für Fahrerassistenz und Aktive Sicherheitssysteme. Proc. Tagung Aktive Sicherheit durch Fahrerassistenz, Garching bei München, 11-12 March.

Nestler, S., Duschl, M., Popiv, D., Rakic, M., Klinker, G. (2009): Concept for visualizing concealed objects to improve the driver's anticipation. Proc. 17th World Congress on Ergonomics IEA, Beijing, China, August

Nöcker, G.; Mezger, K.; Kerner, B. (2005): Vorausschauende Fahrerassistenzsysteme. Walting: Workshop Fahrerassistenzsysteme. http://www.prevent-ip.org/download/Events/20050406%20DC%20Workshop/PR-22000-SLI-050406-v10-DC-Workshop%20Vorausschauende_FAS.pdf.

Norman, D.A. (2002): The design of everyday things. Basic Books.

Norman, D.A. (2005): Emotional design: why we love (or hate) things. Basic Books.

Noy, I. (1999): Workshop on ITS safety test & evaluation in Washington, D.C., 14-15 April 1999. International harmonized research activities: Intelligent transport systems.

Parasuraman, R.; Riley, V.A. (1997): Humans and Automation: Use, misuse, disuse, abuse. Human Factors, 39, 230-253

Plavsic, M. (2010): Analysis and Modeling of Driver Behavior for Assistance System at Road Intersections. Doctoral Dissertation, Technische Universität München.

Popiv, D., Rakic, M., Nestler, S., Bengler, K., and Bubb, H. : Timing concept for assistance of anticipatory driving. Proc. 17th World Congress on Ergonomics IEA, Beijing, August.

PReVENT: Deliverable D16.1 (2007): Review of validation procedures for preventive and active safety functions. http://www.prevent-ip.org/download/deliverables/PReVAL/PR-16000-SPD-070611-v20-D16_1_RewiewOfProcedures.pdf, accessed June 2011

PReVENT: Deliverable D16.4 PReVAL (2008): Final Report. http://www.prevent-ip.org/download/deliverables/PReVAL/PR-16000-SPD-070208-v11-D16_4_Final_Report.pdf, accessed January 2011.

ProFusion, subproject of PReVENT (2008), http://www.prevent-ip.org/download/Events/20061008-12_ITS_WC_London/TS103/Paper%201711.pdf, accessed June 2011

Rasmussen, J. (1983): Skills, rules and knowledge; signals, signs and symbols and other *distructions in human performance models.* IEEE Transaction on Systems, Man and Cybernetics. Vd. SMC – 13, 257-266.

Rassl, R. (2004): Abkenkungswirkung tertiärer Aufgaben im Pkw. Systemergonomische Analyse und Prognose. Doctoral Dissertation, Technische Universität München.

Repa, B., Leucht, P., Wierwille, W. (1982): The effect of simulator motion on driver performance. Society of automotive Engineers.

Reichart, G. et al. (1998): Potentials of BMW Driver Assistance to Improve Fuel Economy. Proceedings of Internetional Federation of Automotive Engineering Societies World Congress, Paris.

Reichart, G. (2001): Menschliche Zuverlässigkeit beim Führen von Kraftfahrzeugen. Forschritt-Berichte VDI, Reiche 22, Nr.7, Düsseldorf: VDI Verlag.

RESPONSE 3 (2007): Annex to the code of practice for the design and evaluation of ADAS. http://www.prevent-ip.org/download/deliverables/RESPONSE3/D11.2/Response3_Annexes_to_the_CoP_v3.0.pdf accessed June 2011

Rommerskirchen, C. (2009): Zeitliche Anforderungen zur Unterstützung von vorausschauendem Fahren unter Optimierung von Effizienz und Akzeptanz. Diploma Thesis, Technische Universität München.

Reymond, G., Kemeny, A., Droulez, J., Berthoz, A. (2001): Role of Lateral Acceleration in Curve driving: Driver Model and Experiments on a Real Vehicle and a Driving Simulator. Human Factors, 43(3), pp.483-495

Samper, K.; Kuhn, K.-P. (2001): Reduktion des Kraftstoffverbrauchs durch ein vorausschauendes Assistenzsystem. Düsseldorf, in: VDI-Berichte 1613, VDI Verlag 2001, ISBN 3-18-091613-3.

Sarter, N.; Woods, D. D. (1991). Situation awareness: a critical but ill defined phenomenon. The International Journal of Aviation Psychology, 1(1), 45-57.

Schmidt, T. (2000): Visual perception without awareness: Priming responses by color. T. Metzinger (Ed.), Neural Correlates of Consciousness: Empirical and Conceptual Questions (157-169). Cambridge, MA: MIT Press.

Schmidtke, H. (Hrsg.) (1993): Ergonomie. Hanser, 3. Auflage.

Schultz, A.; Frömig, R. (2008): Analyse des Fahrerverhaltens zur Darstellung adaptiver Eingriffsstrategien von Assistenzsystemen. ATZ 12/2008, 1124-1132.

Schwarz, J. (2007): Response3: Beyond the Code of Practice. IP PReVENT Cosortium

Workshop, in Brussels, Belgium, 2 February 2007

Schweigert, M. (2003): Fahrerblickverhalten und Nebenaufgaben. Doctoral Dissertation, Technische Universität München.

Serafin, C. (1994): Driver Eye Fixations on Rural Roads: Insight into Safe Driving Behavior. Technical report, Transportation Research Institute, University of Michigan.

Siegler, I., Reymond, G., Kemeny, A., Berthoz, A. (2001): Sensorimotor integration in a driving simulator: contribution of motion cueing in elementary driving tasks. Proceedings of Driving Simulation Conference, pp.21-32

Sträter, O. (2009): Cognitive Parameter for the Relationship of Situation Awareness and Behaviour. Zeitschrift für Arbeitswissenschaft, February, 45-54.

Swets, J., A.; Green, D.M. (1974): Signal Detection Theory and Psychophysics. R. E. Krieger Pub. Co.

Teylor, R.M., Finnni, S.E., MacLeod, I. (1996): Enhancing Situational Awareness Through System Cognitive Quality. Farnborough, Hampshire, Defense Research Agency.

Thoma, S., Lindberg, T., Klinker, G. (2008): Speed Recommendation During Traffic Light Approach: A Comparison of Different Display Concepts. D. de Waard, F.O. Flemisch, B. Lorenz, H. Oberheid, and K.A. Brookhuis (Eds.) (2008), Human Factors for assistance and automation (63 - 73). Maastricht, the Netherlands: Shaker Publishing.

Underwood, G.; Brocklehurst, N.; Crundall, D.; Underwood, J.; Chapman, P. (2002): Sequences of eye fixations while driving: effects of driving experience and sensivity to types of roads. Gale, A.G. (Hrsg.): Vision in Vehicles IX. Elsevier North Holland Press, Amsterdam

Vicente, J. (2002): Ecological Interface Design: Progress and Challenges. Human Factors, 44(1), 66-78.

Vicente, J.; Rasmussen, J. (1992): Ecological Interface Design: Theoretical Foundations. IEEE Transaction on Systems, Man, and Cybernetics, 22(4), 589-606.

Wisselmann, D., Gresser, K., Spannheimer, H., Bengler, K., Huesmann, A. (2006): ConnectedDrive – ein methodischer Ansatz für die Entwicklung zukünftiger Fahrerassistenzsysteme. Proc. Tagung Aktive Sicherheit durch Fahrerassistenz, Garching bei München, 11-12 March.

Wohlfarter, M. (2005): Akzeptanz und Effektivität von Fahrerassistenzanzeigen im Head-Up-Display am Beispiel ACC und NAVI - Teil 1: Ergebnisse der Untersuchung. Technical report, Lehrstuhl für Ergonomie, Technische Universität München.

Wyman, O. (2007): Auto und Umwelt 2007. Study, Munich.