The role of the driver is changing now that vehicles with driving automation technologies appear on the road. The driver has to collaborate with the driving automation and remains responsible for transitions in control, in particular for changing back to manual control. In the context of automated congestion driving this research develops and analyses driver support in the form of a control transition strategy that issues soft and hard warnings based on lane changes by surrounding traffic. The strategy models the generation of a specific type of warning as well as the timing of issuing. The research comprises the analysis of a naturalistic driving study that built the initial input for the development of the control transition strategy. As part of an iterative development process, the control transition strategy was subjected to a series of participant based evaluations. The two driving simulator experiments as well as a small scale field test revealed that the control transition strategy provides valuable driver support for automated congestion driving technology.

WHO IS DRIVING MY CAR?

DEVELOPMENT AND ANALYSIS OF A CONTROL TRANSITION STRATEGY FOR COLLABORATIVE AUTOMATED CONGESTION DRIVING

About the author:
Joseph A. Urhahne works as a research and development engineer with Ford Motor Company in Cologne, Germany. He studied electrical engineering at the RWTH Aachen University and finalized his diploma thesis at the École Nationale Supérieure d’Arts et Métiers ENSAM in Paris. After working 25 years in the field of automotive engineering and research he resumed his academic career, which resulted in this PhD thesis in cooperation with the University of Twente, The Netherlands.

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Joseph A. Urhahne
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Joseph Andreas Urhahne
born on the 25th of July 1965
in Höxter, Germany
This dissertation has been approved by the supervisors:

Prof.dr.ir. M. C. van der Voort
Prof.dr.ir. F. J. A. M. van Houten
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Joseph A. Urhahne
Dissertation Committee:

Prof. dr. G. P. M. R. Dewulf
Prof. dr. ir. M. C. van der Voort
Prof. dr. ir. F. J. A. M. van Houten
Prof. dr. ir. M. F. A. M. van Maarseveen
Prof. dr. ir. A. O. Eger
Prof. Dr.-Ing. P. van der Jagt
Prof. Dr.-Ing. T. Viscido

University of Twente, Chairman/Secretary
University of Twente, Supervisor
University of Twente, Supervisor
University of Twente, ITC
University of Twente, CTW
Ford Research and Innovation Center, Aachen
University of Applied Sciences, Cologne, IFK

PhD Thesis, University of Twente, Enschede, The Netherlands

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Summary

While offering a wide range of driver assistance technologies in today’s road vehicles, the automotive industry promotes the subject of driving automation as a major trend for future transportation systems. In particular through media, it is ultimately envisioned to offer driverless operated vehicles for individual transportation tasks.

The first cars with driving automation technologies are currently appearing on the road. At present the driver on board remains fully responsible for the movements of the vehicle. The role of the driver is however changing. It evolves from being an active controller of the vehicle to being a supervisor of the automated driving. The driver will have to collaborate with the automation system and remains responsible for transitions in control, in particular for changing back to manual control. In the context of automated congestion driving this research develops and analyzes driver support in the form of a control transition strategy. This strategy issues warnings based on lane changes by surrounding traffic: While driving in automated mode on motorways with full longitudinal and lateral control the transitions in control are anticipated by soft and hard warnings to support the driver in this collaboration task. In the case of soft warnings, the driver is informed about surrounding traffic situations that are relevant but non-critical. The driver is reminded to regain awareness about his driving responsibility. However, hard warnings are intended to alert the driver of traffic scenarios that are perceived as a threat, therefore the driver should have the intention to instantaneously take over the driving task.

The research targets of this thesis are specified in the context of this technological proposal:

The control transition strategy focuses on driver’s ability to make use of the soft and hard warnings. This user-centred design approach requires the analysis of strategy usability, correct warning timing and the false error rate of the strategy. The strategy usability is studied with regards to efficiency, effectiveness and satisfaction. For correct warning timing, the hypothesis was made that warnings are desired as early as possible. For the false error rate, the assumption is that no false positive warnings are accepted by the drivers.

The chosen research approach consists of several phases: First a collection of real world drive data in traffic congestion is analysed. A preliminary model for the control transition strategy is developed. Hereupon a simulator experiment is conducted employing the developed strategy using naturalistic driving videos. Consequently the simulator study data is analysed to support the user centred design approach. An adapted strategy is created with the new findings. Finally, a field experiment is conducted to confirm the usability of the adapted control transition strategy in real-life traffic.

The first phase of the research starts with an in depth analysis of 30 hours of traffic jam data that is collected in a naturalistic driving study (NDS). The research analysis reveals that lane change manoeuvres are a solid basis for the control transition strategy. This data are further augmented with label signals (post-processing or “coding”) of lane changes. The additional label signals require manual work, but support a more substantial research of indicators for the strategy.

The second phase focuses on the development of a first concept for the control transition strategy employing the lane change labels in conjunction with vehicle sensor signals. The research analysis of traffic data points to a correlation between the need for transition from automated driving to manual driving and the important indicator “Q” which represents the inverse of the headway time. The model generates soft warnings for cut-in and cut-out manoeuvres that exceed certain thresholds
of Q. The model also intends to limit soft warnings to only those instances that are relevant to the driver. Regarding the correct warning timing, a basic timing model is presented that sets the warning time to the exact point in time when a lane-changing vehicle touches the lane marking. Alternatively an enhanced timing model is developed in order to enable earlier warnings. Both timing models cannot achieve the objective to completely avoid false positive warnings.

During the course of the iterative development process, the control transition strategy is subjected to a series of participant based evaluations. The core experiment is conducted in a laboratory driving simulator. The study results reveal that satisfactory usability cannot be built on Q as a single indicator. The study also shows that false positive warnings are acceptable for the drivers in conjunction with the basic timing model.

Prior to the follow-up experiment a new refined warning model is compiled that includes further sensor signals and enhanced trigger logic for warnings. The follow-up experiment reveals that the refined model results in an improved and satisfactory level for efficiency and effectiveness which paves the way for a small scale field test. The field test involves participants as real drivers in an automated congestion driving system. The results of the field experiment confirm the efficiency and effectiveness for the control transition strategy. This confirmation is also based on the fact that drivers in real traffic conditions request a higher amount of soft warnings compared to the laboratory test environment. Participants in the field study rate their satisfaction with the strategy above 80%. Participants also indicate a high level of contentment with the timing of issued warnings. The objective to warn earlier than the basic timing model is therefore discarded. It is also confirmed that the control transition strategy based on surrounding lane changes can be embedded in automated congestion driving systems in combination with additional warning elements. The involvement of different driver types shows that the strategy is well perceived, independent from earlier driving experiences.

The proposed control transition strategy reveals technical requirements for the sensing of lane change maneuvers. It finally provides valuable driver support for contemporary and future automated congestion driving technologies.
Samenvatting

Nu huidige personenvoertuigen reeds een brede range aan bestuurderondersteunende systemen bieden, promoot de automobielindustrie het geautomatiseerd rijden volop als de trend voor toekomstige vervoersystemen. Zeker in de media wordt een ultiem toekomstbeeld geschetst waarin bestuurderloze voertuigen ingezet worden voor individuele verplaatsingen.

Momenteel verschijnen de eerste zelfrijdende auto’s op de weg. Hierin blijft de bestuurder voorlopig eindverantwoordelijk voor de bewegingen van het voertuig. De rol van de bestuurder verandert echter wel. Deze rol ontwikkelt zich van de bestuurder als actieve chauffeur van het voertuig tot passieve controleur van het geautomatiseerd rijden. De bestuurder zal moeten samenwerken met de automatisering en blijft verantwoordelijk voor controle overname, in het bijzonder voor het terugnemen van manuele controle.

In de context van geautomatiseerd file rijden is in dit onderzoek ondersteuning voor de bestuurder in de vorm van een control transition strategy ontwikkeld en geanalyseerd. Deze strategie geeft waarschuwingen wanneer omringend verkeer wisselt van rijstrook: tijdens het rijden in automatische modus op snelwegen, d.w.z. met volledig geautomatiseerde controle van longitudinale en laterale bewegingen, wordt op (mogelijk) benodigde overnames van controle geanticepeer door de bestuurder van softe en harde waarschuwingen te voorzien. Softe waarschuwingen informeren de bestuurder over situaties rond omringend verkeer die relevant zijn, maar niet kritiek. Bij harde waarschuwingen daartegen wordt de bestuurder gewaarschuwd voor verkeerssituaties die gezien worden als acuut gevaarlijk, met het doel de bestuurder aan te sporen de besturing van het voertuig per direct over te nemen.

De onderzoeksoogdoelen van deze thesis sluiten specifiek aan bij dit technologische voorstel: De control transition strategy focust zich op het vermogen voor bestuurders om gebruik te maken van de softe en harde waarschuwingen. Deze gebruikersgerichte ontwerpenadering vereist een analyse van de gebruiksvervriendelijkheid van de strategie, correcte timing van waarschuwingen, en het percentage false errors voor de strategie. De gebruiksvervriendelijkheid van de strategie is geanalyseerd ten aanzien van de efficiëntie, effectiviteit en tevredenheid. Ten aanzien van correcte timing van waarschuwingen is de hypothese gesteld dat bestuurders waarschuwingen zo vroeg mogelijk willen ontvangen. Voor het false error percentage is de aanname gedaan dat ‘false positive’ waarschuwingen niet door bestuurders worden geaccepteerd.

De gekozen onderzoeksaanpak omvat meerdere fasen: Eerst is een collectie van reële verkeersdata van filerijden geanalyseerd. Daarna is een eerste model van de control transition strategy ontwikkeld. De ontwikkelde strategie is getest door middel van een rijsimulatorexperiment dat gebruik maakte van de eerder verkregen video’s van filerijden. Aansluitend is de data van het rijsimulatorexperiment geanalyseerd om de gebruiksgerichte ontwerp aanpak te ondersteunen. Gebaseerd op de bevindingen is een aangepaste strategie ontwikkeld. Vervolgens is een veldexperiment uitgevoerd om de gebruiksvervriendelijkheid van de aangepaste control transition strategy onder reële verkeersomstandigheden te testen.

In de eerste fase van het onderzoek is een diepgaande analyse uitgevoerd van 30 uur aan congestie data dat was verzameld in een naturalistic driving study (NDS). De analyse van dit materiaal toont aan dat wisselingen van rijstrook een solide basis vormen voor de control transition strategy. De data is daarna uitgebreid door rijstrookwisselingen te labelen (een nabewerking proces op basis van “coding”). Deze extra labels moesten met de hand toegevoegd worden, maar maakte een substantiëler onderzoek naar indicatoren voor de strategie mogelijk.

De tweede fase richtte zich op het ontwikkelen van een eerste model, gebaseerd op de rijstrookwissel-labels in combinatie met sensor-signalen van het voertuig. De analyse van de
verkeersdata toont een correlatie aan tussen de noodzaak voor een transitie van geautomatiseerd rijden naar handmatig rijden en de belangrijke “Q”-indicator, welke staat voor de inverse van volgtijd. Het model genereert softe waarschuwingen voor invoegende en uitvoegende manoeuvres die boven bepaalde drempelwaarden van Q uittreden. Het model heeft tevens tot doel om de softe waarschuwingen te beperken tot enkel de situaties die relevant zijn voor de bestuurder. Ten aanzien van de correcte timing van waarschuwingen is een basismodel gepresenteerd dat de waarschuwing afgeeft op het exacte moment waarop het van rijstrook wisselende voertuig de wegmarkering raakt. Als alternatief is een uitgebreider timing model ontwikkeld om vroegere waarschuwing mogelijk te maken. Beide timing modellen blijken niet in staat om de doelstelling te behalen om false positive waarschuwingen compleet te voorkomen.

Tijdens het iteratieve ontwikkelproces is de control transition strategy onderworpen aan een serie van evaluaties met testdeelnemers. Het basiseperiment is uitgevoerd met behulp van een rijsimulator. De resultaten tonen aan dat de gewenste gebruiksvriendelijkheid niet kan worden bereikt met alleen Q als indicator. Het experiment toont tevens aan dat false positive waarschuwingen voor de bestuurders aanvaardbaar zijn in combinatie met het basis timing model.

Voorafgaand aan het vervolgexperiment is een verfijnd waarschuwingsmodel opgesteld dat aanvullende sensorsignalen en verbeterde logica achter generatie van waarschuwingen bevat. Het vervolgexperiment laat zien dat het verfijnde model resulteert in een verhoogd en toereikend efficiëntie- en effectiviteitsniveau, wat het pad effende voor een kleinschalige veldexperiment. In dit veldexperiment reden de deelnemers als bestuurders in een voertuig met een geautomatiseerd filerijsysteem. De resultaten van het veldexperiment bevestigen de efficiëntie en effectiviteit van de control transition strategy. Deze bevestiging is mede gebaseerd op het feit dat de bestuurders onder reële verkeersomstandigheden een hoger aantal softe waarschuwingen wensen dan tijdens het rijsimulatietoetsen. Deelnemers aan het veldexperiment waarderen hun tevredenheid met de strategie op meer dan 80%. Deelnemers geven tevens een hoge tevredenheid aan t.a.v. de timing van de waarschuwingen. De doelstelling om eerder dan bij het basismodel te waarschuwen is daarom ook losgelaten. Ook is bevestigd dat de op rijstrookwisselingen gebaseerde control transition strategy kan worden geïntegreerd in geautomatiseerde filerijsystemen in combinatie met additionele waarschuwingssystemen. Door de deelname van verschillende bestuurderstypen is aangetoond dat de control transition strategy goed ontvangen wordt, onafhankelijk van rijervaring met ondersteunende systemen.

De voorgestelde control transition strategy geeft tevens inzicht in de (sensor)technische eisen benodigd voor het detecteren van rijstrookwisselingen. Tot slot biedt het bestuurders waardevolle ondersteuning voor zowel hedendaagse als toekomstige geautomatiseerde filerijsystemen.
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1. Introduction

1.1 Automated Vehicle Driving

Today multiple media sources including television broadcasters, newspapers, technical journals and scientific publications are all focusing on two key topics with regard to the future of individual transportation. One is the electrification of vehicle powertrains to promote the reduction of greenhouse gases by using renewable sources of energy. The other topic is vehicle automation; this theme is derived from advanced driver assistance systems (ADAS) and vehicle automation can be regarded as the natural evolution of the ADAS development cycle. In some publications the term “vehicle automation” is replaced by “autonomous driving” which refers to situations in which vehicles will move on public roads without a human driver and optionally without passengers. Recently, with the speculative involvement of non-automotive companies like Google, Apple, and Uber into the business of individual mobility and transportation, the public is becoming increasingly aware of autonomous driving and its potential application. (Ewing 2015).

Evolving technologies have a key role to open up the possibilities of driving automation in terms of a better future for transport systems. The automotive industry has concentrated its resources on computerization and automation more than ever before (McKinsey&Company 2014). Enhanced computing power and intelligent sensors have become more affordable in a way that the supplier industry can now offer them for ADAS applications to OEMs. Electrically controlled actuators like drive-by-wire accelerator pedals and electric power steering systems have already been standardized for longitudinal and lateral driving support in a wide range of vehicle products.

In Figure 1 an example of a roadmap for driving automation is displayed. Continental Corporation is the world’s third largest automotive supplier and they forecast in their Fact Book (ContinentalAG 2015) a double-digit growth for safety and comfort systems. Continental draws a parabolic line for the development of driving automation. In the time frame from 2015 to 2020 there is a dense accumulation of new functionalities being introduced to the market like traffic jam and highway assist (see Figure 1). An accurate forecast is difficult to construct because the influence from legal and social factors cannot be predicted from a contemporary viewpoint. However, the level of automation is anticipated to increase as well as the number of situations under which automated modes can be driven.

Governments around the world proclaim their supportive attitude towards the introduction of driving automation. E.g. some states in the U.S.A. like California now allow testing of highly automated prototype vehicles on public roads (DMVCalifornia 2015). Additionally, the German ministry of transport has recently issued a brochure “Strategy for automated and networked driving” which has the proclaimed objective to make Germany the lead market for automated driving (BMVI 2015). The ministry pledged participation and investments for a test area of automated driving on a motorway in Bavaria. To allow testing of cooperative vehicle automation a test site in the Netherlands recently has opened (DTICM 2016): It deals with a test track developed on public roads with intersections, city, intercity and highway elements.
There is a firm belief in the community of automotive engineers that these evolving technologies will support two visions on individual transportation (SAE, Advanced Safety Standards & Resources 2015): firstly to achieve a target of zero-fatalities and secondly to enable efficient and stress-less driving, thereby reducing drastically the high number of today’s congestions and traffic infarcts.

This thesis will focus on driving automation in its current development stage, on the borderline from assisted to automated driving functions. It will explore how, in this transition period, tools can support the driver by appropriate means in order to break through the threshold to a future driving experience that offers automated vehicle drive for individual transportation.

The vision of driving automation will not be realized in a single large scale accomplishment. A review of research and development efforts in automotive industries indicates a step-wise introduction of driving automation over the next decade as illustrated by Figure 1. In the coming years human drivers and automated driving systems will coexist and therefore they need to cooperate (van Waterschoot 2013). Successful introduction of driving automation will therefore critically depend on intelligent collaboration between the driver and the vehicle. The driver will have to be guided in this process to realize that his role in the driving task is going to change.

Within this collaborative approach the contribution of both the driver and the support tools is indispensable. Unless driverless taxis are available for individual transportation tasks and full autonomy of vehicles is achieved, the coexistence of drivers and automation systems will be a major subject in automotive research and science (Bengler, et al. 2014).

In situations where the human driver and support systems need to collaborate the driver must be aware of the distribution of work task responsibilities at all times. Analysis of research and development efforts reveals that support is only provided for specific task or under specific

![Roadmap from ADAS to Driving Automation (ContinentalAG 2015)]
circumstances. A crucial element for the collaboration consists in the transition phase from automated driving to manual driving. This thesis investigates precisely these transitions of vehicle control and elaborates a design proposal for user centered driver support.

1.2 Research Objectives

An effective policy to facilitate the first steps for driving automation on public roads is to invest in currently available ADAS products by combining them. Figure 1 illustrates this statement by showing an accumulation of introduced support systems in the years 2015-2016. The driver is to get a taste of driving automation while he is suggested to have more driving comfort but not in the sense that he is released from driving responsibility. A driver support is needed that makes him understand that his role in automated driving gets modified from a more activity related task to a more supervising and controlling task. Analogue to the introduction of electric vehicles, the social acceptance of automated driving functions will depend on efficient implementations that offer advantages and benefits for the driver with respect to ordinary day to day transportation tasks.

The question “Who is driving my car?” that builds the title of this thesis has an easy answer: “It is YOU!” This is true at least until the future point when fully automated vehicles will become available and are allowed to operate on public roads. Regarding the present research, it means that the main responsibility for the vehicle motion remains with the driver. Accordingly the objectives and tasks of this work are described by the subtitle of the thesis: Development and Analysis of a Control Transition Strategy for Collaborative Automated Congestion Driving. The driver needs support in the collaboration with an automated driving system while driving through traffic in a safe and efficient manner. This is a challenge that does not come with either easy answers and solutions or a fast realization.

For the present time the following research objectives are pursued in this work:

To assist drivers in their modified role, a tool for collaboration needs to be designed. The driver shall be aware of his responsibility for the motion of the automated car and must also be prepared to swap to manual driving at any time during vehicle operation. In automated mode the driver does not need to perform any physical action in the car. Mentally he has to be challenged to maintain a continuous awareness of his responsibility. Therefore, an appropriate driver support has to be provided in form of a strategy or a tool. For that purpose an innovative control transition strategy shall be developed. It is based on the fact that a vehicle that is driven in automated mode needs to revert back to manual driving mode at some point in time. The strategy consists of warnings that are issued while being in the automated mode: A differentiation of warnings is needed to either create awareness for a changing traffic situation without a formal risk and keeping the driver mentally in the loop (soft control transition) or alerting the driver to a traffic scenario that potentially is perceived as a threat (hard control transition) so that he wants to take over the driving control manually until the situation is cleared.

It has to be decided what instances of traffic scenarios the strategy shall be based on: a focus shall be put on lane changes that happen in the direct surrounding of the automated vehicle. A classification of lane changes goes along with an assignment to the proper type of control transition. Special
Introduction

attention is given to situations that represent a threat to the drivers and that are due for a hard control transition. Physical indicators are to be identified for a technical description of lane changes.

The subsequent objective is to create a model for the strategy that can make use these lane change indicators. The control transition model is to be divided into a warning model and a timing model. The warning model decides whether the occurrence of a lane changes shall produce a warning. It should limit the potentially excessive supply of warnings. The timing models objective is to identify a suitable timing to issue a warning while avoiding false warnings.

The challenge to develop the control transition strategy is connected with the approach of user centered design: The strategy will be developed with the target of high usability. It will also ensure that the warnings are provided at the correct time and that the warnings are free of errors such that false positive warnings are avoided.

The strategy shall be designed as a driver support tool. The tool shall also be optimized for a universal type of driver. It is the intent to conduct the experiments with different groups of participants, then to analyze whether these groups show a statistically significant difference when evaluating the usability of the proposed control transition strategy.

A further research objective lies in integrating the control transition strategy into holistic automated driving design. In this context the research will focus on an actual automated driving system that fits to the subject of a control transition strategy. A popular discussion in the field of automated driving is led about traffic congestions and infarcts, exemplarily in mega cities like London or Beijing (ERTRAC 2015). As a technology under investigation the previously mentioned traffic jam assistance system (TJA) is a candidate to offer the suitable subject for the intended research objectives, even though it is intended in first instance to provide functionality on motorways only. In such a support system the associated automation needs to be turned off at the latest when the traffic jam is finished or when the motorway ends. With these limitations it becomes clear that the driver has to be in the loop and also needs to come back to his task to manually drive the vehicle. Therefore a control transition strategy is definitely required.

The outcome of designing the control transition strategy should result in requirements that build a basis for specifying the driver support tool, with a focus on performance targets of image processing and object recognition technology. The strategy itself can serve as an initial input for software development. The basic functionality of the tool will provisionally be implemented and tested in a real-world environment to be able to meet the requirements of user-centered design rules. However, the tool itself is not assumed to be ready for production. Moreover, the claim has to be investigated whether the developed strategy fits well into automated congestion driving as an integral portion of a holistically design.

By working on these research objectives the thesis can contribute in an advanced manner that automated technologies, especially the relief of driving in traffic congestions on motorways, are positively influenced and guided by user centered product design. This is crucial for the success of technologies which will be acquired in future by customers on the automotive market. The success strongly depends on drivers’ appreciation of the new automotive products, just as we are in a transitional phase from assisted to automated driving.
1.3 Approach

The design of the control transition strategy is the central theme of all work activities in this study. In summary, several methods are used in this research in order to accomplish the research objectives and provide answers accordingly to research questions that are investigated in related chapters: data collection by means of a naturalistic driving study (NDS), post-processing by video coding techniques and data mining, literature studies, statistical analysis, mathematical modelling, driving simulator studies based on video presentation, survey methods including a questionnaire process, and finally a field test trial.

The methods of NDS data collection, video coding and data mining are linked with the research task to identify suitable indicators for a technical description of lane change scenarios. Mathematical modelling serves to generate the control transition strategy as a construct of logic operations. It is based on lane change indicators as input values. The model outputs warnings as a reaction to the control transition. It also provides the opportunity to enhance the strategy by updating the model input and by assigning new logical conditions in an iterative development process. Literature is studied for analysis of lane change maneuvers as well as for experimental design.

The simulator studies are set up as participant based testing in order to evaluate the user-centeredness of the developed strategy: They seek answers to objective ratings of usability, timing requirements and error-proneness.

Survey techniques are applied in parallel with the participant experiments in order to give answers to research questions about subjective ratings of the developed strategy. In an interview process they offer opportunities for the participants to revisit independent and creative ideas, e.g. by going beyond the established indicators that derive from the data analysis.

The field experiment links the research into a real-world environment. It supports the approach on user centered design for a trustful automated car driving event. Finally it provides the possibility to embed the control transition strategy into a real and holistic experience of automated congestion driving. The resume and conclusion debate the technical requirements for an implementation of the control transition strategy in future automotive products.

1.4 Thesis Outline

Following this introduction that summarizes its scope and research objectives, this thesis will continue with a literature study on the subject on driving automation. Chapter 2 introduces the subject of driving automation with a view to the past and projections into the future of vehicle development. It provides an overview of the on-going work within automotive industry and academia to define and categorize the levels of driving automation.

Chapter 3 reports about a dedicated automation system that will be under investigation in this work, i.e. automated congestion driving. The chapter clarifies the term “collaborative driving” and refers to
the proposed driver support for automated congestion driving in form of a control transition strategy.

Chapter 4 summarizes the research objectives in detail. It provides a direction for the research tasks and questions that are treated in the subsequent chapters 5 to 9 and it defines the approach of developing a control transition strategy with given limitations.

Chapter 5 presents the collection and recording of traffic jam data and it defines and describes different types of lane changes. It introduces the technique of video labelling and data mining as post-processing methods for traffic data. The quality of the labelling method is assessed by a conformance and coherence investigation in order to justify their further use as indicator signals for a characterization of lane changes. A common list of indicators from sensor and label signals is identified that are recommended for further modelling work.

Chapter 6 focusses on model development for the control transition strategy. A preliminary concept is proposed for issuing warnings to the driver regarding transition in control. The warning and the timing aspect of the model are elaborated in detail in order to implement the preliminary concept for a first experiment.

Within this research a suite of experiments shall be conducted to augment step by step the model validity by measuring the performance of the control transition strategy. Chapter 7 describes the setup of a pilot study and the core experiment conducted in a basic driving simulator. Performance criteria regarding usability, timing and error-proneness are addressed in order to verify the user centred design approach of the control transition strategy.

Chapter 8 revisits the development by refining the model, with additional indicators to support especially the warning model. In a next iteration a follow-up experiment is defined to understand the performance progress of the adapted model.

Chapter 9 describes the verification and final assessment of the control transition strategy within real-life congestion driving scenarios by means of a field test.

The closing chapter 10 summarizes main findings of this thesis research and concludes the achievements of the proposed control transition strategy. The application and impact of the control transition strategy within collaborative automated congestion driving systems are discussed as well as recommendations for future research are provided.
2. Driving Automation Systems

2.1 Introduction

Individual transportation by means of passenger vehicles has made its introduction in the early days of the 20th century. Since that time it is a privilege that humans cherish. The enthusiasm of men for individual mobility has brought up many variants of road vehicles which became mass products since Henry Ford has invented the assembly line more than 100 years ago.

Increasing population and wealth have led to a steep growth in the number of road vehicles. Combined with freight road transport this has resulted in significant problems regarding congestion and traffic safety since 1970 (Black 2004). So, the well-known downside of individual mobility consists of two main subjects: traffic congestions that lead to traffic collapses in big cities and secondly traffic accidents and road causalities.

Multiple efforts have taken place to counter this development: improvements have been made to all elements of the road transportation system, i.e. improvements to the road infrastructure, to vehicle technology as well as development of driver support. Just in the recent years a fourth element has been added which focuses on automation of the road transportation system, not only on private ground but predominantly on public roads.

2.2 History of driving automation

The illustration of Figure 2 was published as an advertisement of America’s Independent Electric Light and Power Companies (LIFE-magazine 1956). It expresses the vision of transportation in a passenger car that does not need a responsible driver. Transportation time of all passengers is used for playful entertainment. This kind of visions is experiencing a renaissance in today’s magazines, with the minor modification that the driving time is converted into working hours in a business office.

Figure 2: Vision of driving automation (LIFE-magazine 1956)
One of the first realistic technological considerations about robot vehicles on public roads was published in Prometheus project (Zimmer 1990) in Germany from 1987 to 1995. The project demonstrated with a famous prototype vehicle VaMP an automated drive from Munich to Copenhagen with a top speed of 175 kph and 158 km as longest distance without human intervention. Average intervention distance was 9 km.

A comprehensive summary of driving automation history is given by (Becker 2013) outlining e.g. the projects “no hands across America” (1995) and “California Path” (1997). In the framework of autonomous ground vehicles the DARPA projects are very well remembered and known from the years 2005 to 2007. With this competition the potential performance of autonomous cars was demonstrated to the public with the DARPA Grand Challenge first under safe conditions in the Mojave Desert in the USA. In a further step the DAPRA urban challenge, a competition in 2007, reached the status to drive simulated city cycles and special trajectories including parking scenarios (DAPRA 2007). This happened in a protected environment of a closed test track because the vehicles were driven without a human being on board.

INVENT was one of the first governmental funded projects for intelligent vehicles combined with an intelligent traffic system and was finalized in 2005. Amongst others a preliminary prototype study of a Traffic Jam Assistance system (TJA) was presented in the sub-project Traffic Performance Assistance which was based on telematics services (Scholl 2005). Some technical open issues were identified for telematics at that stage at the end of the project. Especially expressed was also the “unsolved legal situation” for automated driving.

Since 2010 awareness about automated driving comes to the media. This is because more driver assistance systems are on the vehicle market which fires the imagination about the future of vehicle driving. After introduction of ADAS in high-class passenger vehicles the systems are built into non-luxury cars and arrive in the mass vehicle segment so that a higher public interest is created. This leads to speculations and also expectations by the public that automated driving will be available for the mass market in the near future.

2.3 Related work

The compliance to enhance transportation safety on roads and to improve traffic efficiency is a widespread fact, especially in Europe where the governments and the European Commission have supported a series of research projects up to now. These have demonstrated a positive contribution of automated driving concepts to traffic safety and efficiency by proposing as step-wise introduction of automation and by starting with a so-called collaborative approach.

The following is a list of state-of-the-art projects with regards to automated driving functionalities with a connection to this thesis:

- **InteractIVe** started in January 2010 with a projected time line to November 2013 (interactIVe EU project 2013). It has a focus on accident avoidance by active intervention for Intelligent Vehicles and supports automotive development of next generation of ADAS that autonomously brake and steer by active interventions in critical situations. It integrates the information, warning and intervention strategies into the development process for active
safety systems. Another part of InteractIVe was dedicated to homologation issues for active brake and steering interventions. The distinction to this thesis is an emphasis on research of environmental sensor technology and accident avoidance rather than on driving automation.

- **HAVEit** took place from Feb. 2008 to July 2011 and dealt with highly automated driving application in highway scenarios under driver supervision (HAVEit EU project 2011). Queue assistance and temporary auto pilot were developed. The optimization of a shared driving task between the driver, the co-pilot system and the vehicle was researched. With *Figure 3* HAVEit visualizes the importance of driver and automation interaction as integral part of the human machine interface concept. This representation is a widely recognized framework to compare driver-automation-vehicle interaction schemes. It is also reused in (adapTIve 2016).

- **Sartre** (SARTRE EU project 2012) was rolled out from Sept. 2009 to Oct. 2012 and was focusing on safe road trains on public highways. This is also known as “platooning”: A professional driver controls the leading vehicle while following vehicles enter a semi-automated control mode with a virtual towing bar. It results in high fuel efficiency of the following vehicles generated by the positive aerodynamic effects. This automated driving technology obviously does not have commonalities with a collaborative approach except for the driver in the first vehicle who acts like a train conductor on the motorway and interacts with other road users.

- **V-charge** (V-CHARGE EU project 2011) is another project supported by the European commission; it is continuing until September 2015 and has a focus on fully automated valet parking as well as charging for e-mobility. Standard sensors and also innovative sensor systems with situation dependent sensitivity were researched. Again this is a project with the focus on fully automated driving in designated areas without the collaborative approach.
CityMobil, this project was conducted from May 2006 to December 2011 with a focus on automated vehicles in dedicated urban infrastructure (e.g. eLanes for road trains). Lane changes, however, were not investigated in this context (Citymobil EU project 2011).

EASY - Effects of Automated Systems on Safety - was initiated by the UK Engineering and Physical Sciences Research Council has a focus on a step-wise increase of automation (lateral control, longitudinal control and both), and researched situation awareness in high automation a and situation awareness with loading the driver by a secondary tasks (EASY 2010). In a related simulator experiment the drivers were asked to take over control based on fixed time periods of on dynamic intervals with the result that “dynamic intervals had a more pronounced effect on keeping the driver in the loop”.

All mentioned projects have demonstrated dedicated vehicle automation concepts in according environments and with special maneuvers, e.g. a correct and long lasting follow maneuver in a reserved lane. However, a research project with a mature concept for implementation of collaborative automated driving systems does not yet exist. It is still open to investigate what control transitions from automated mode to manual driving can be considered and which indicators for a control transition can be taken into account. Hence there is room for more detailed research work. The objective is to design automated driving systems in according traffic situations in order to execute automated maneuvering smoothly under real world conditions.

2.4 Prospect on Driving Automation

In the years 2011 to 2015 one perceives remarkable increase in publications about automated driving systems in the automotive world and related industries. A very high amount of public interest and publicity was given to the Google driverless car project (Fisher 2013). In 2012 the internet company has started a test fleet of some autonomously driven cars and collected data and experiences of over 500.000 miles without the need of human intervention. However, this success was obtained under protected conditions since only a limited number of US governments have allowed autonomous vehicles to be driven in dedicated regions like Nevada. (Moore and Lu 2011) made an assessment about the evolution of driving miles in relation to required human intervention that is represented in Figure 4. In fact Moore and Lu refer to the Google Autonomous Driving Project that has collected miles in test drives on American roads and has counted situations when the vehicle automation system failed to overcome an unusual situation and the driver had to intervene with a steering or braking action. In connection to the research of Moore, David Stavens suggested this number to be a required level of 1 million driving miles per one single human intervention. He projected that this could be achieved in the year 2025 in the automotive industry; in comparison the aircraft industry requires a safety level that of 1 billion miles per death.
At the one hand the public observes this step of autonomy technology with enthusiasm and fascination. At the other hand people are very skeptical about the performance and reliability in ordinary day usage and an adequate substitution of human control over a vehicle (Pritchard 2016). The current situation regarding driving automation is summarized well by (Winner and Wachenfeld 2015) with the following statement: “There will be no vehicle which is autonomously on the road everywhere at all times even in the next thirty years. These vehicles currently move back and forth on a trial basis in a specific network and are constantly monitored. So the vision of a vehicle which reacts intelligently in any situation will not occur so quickly; highly automated driving on certain routes, however, yes. ...the driver will have to take over the steering wheel if necessary, but may also deal with other things, for example process e-mails without paying attention to traffic – whilst the system prompts acceptance. So, at this configuration level the driver will not yet be completely released and able to fold down the steering column and sleep.”

This statement is in accordance with the research objective of developing a support tool that helps drivers of automated vehicles in their task to supervise the ride and gain an awareness of the remaining responsibility.

2.5 Definition of driving automation levels

Automotive manufacturers and related associations are issuing publications under the terminology of “automated driving technologies” instead of calling it autonomous technology. Autonomous driving is associated with driverless vehicles. But european OEMs (Original Equipment Manufacturer) prefer use of the term “driving automation systems” to indicate that they are focused more on the near- and mid-term implementation strategy rather than aiming for the uncertain target beyond 2025 (see Figure 1). Earlier implementation shall be achieved by implementing lower levels of automation.
In Europe one observes a trend to strengthen the efforts for legitimization and legal confirmation of automated driving functions. The German automotive association VDA (Verband der Automobilindustrie) has founded a commodity team that elaborated a position paper for the future of automated driving (VDA. 2013). It defines the steps of the evolution in driving automation and the according terminology. It was set up to promote and prepare the changes in the legal framework of regulatory law and registration law.

Table 1 provides the overview of driving automation levels. With relation to this work it needs to be distinguished between partly and highly automated systems. The table differentiates these categories by defining the role of the driver: In highly automated systems the driver will not be obliged to monitor the system constantly. In further statements it is said that the driver is allowed to draw his attention to secondary tasks. This term is not explained in detail and it can be speculated that a precise definition of allowed secondary tasks will be due at a later date. It can be assumed that for initial embodiments of highly automated systems it will deal with a controlled secondary task, hence a task that the automation system is able to supervise, to interrupt or stop completely. It is also indicated that the driver of highly automated systems will have sufficient time for the transition. A more precise specification of the expression ‘sufficient time’ has to be declared and a fair statement can be found in the study of (Petermann-Stock, et al. 2013): “Due to subjective requirements the transition time shall be at least 5 seconds with a maximum of 10 seconds.”

The terminology in Table 1 will likely be adopted as a European standard for classification of driving automation systems. It is in accordance with a definition paper that has been developed simultaneously in North America. (SAE, Taxonomy and Definitions for Terms Related to On-Road Automated Motor Vehicles 2014) defines an identical scale of automation levels where the level 3 - term highly automated driving is substituted by conditional automation but identical phrasing for the control task.
The US-organization ‘National Highway Traffic Safety Administration’ issued another definition for automated driving technology (NHTSA 2013). As presented in Table 2 it uses a similar terminology for the levels of driving automation. The ultimate level 4 includes both occupied and unoccupied vehicles. NHTSA avoids expressing that a driver is allowed to partially concentrate on non-driving tasks during the automated drive. In both the US and European classifications the lower automation levels demand the driver to be prepared to take over control in a specific time.

Below in Table 3 an overview of functions is provided describing these steps of automation in various examples. The levels of automation can be subdivided into these use cases:

- Slow maneuvering – driving function at low speeds (e.g. < 10 kph), e.g. automatic parking
- Maneuvers of limited duration – individual functions that are completed within seconds, e.g. changing lanes and overtaking
- Driving for long periods – function normally remains active over a longer period, e.g. longitudinal and lateral control on the motorway

Partially and highly automated functions require interaction with the driver:

- Partially automated – The driver has to supervise the system at all times. The system knows its performance limits and prompts the driver to take over.
- Highly automated – The system recognizes the limits of its effective range. Emergencies are mastered by the system, and managed in a similar manner as by a human operator. With a sufficient time reserve it calls the driver to take control over the vehicle.

Fully automated systems however do not define a driver take over as a crucial element in the sense of collaborative driving because they can cope with all situations within the use case. Only when the use case is terminated they prompt the driver to take control, see (VDA. 2013) and (Bartels, et al. 2013).

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDA German</td>
<td>Driver Only</td>
<td>Assisted</td>
<td>Partially Automated</td>
<td>Highly Automated</td>
<td>Fully Automated</td>
<td>Driverless</td>
</tr>
<tr>
<td>SAE English</td>
<td>Driver Only</td>
<td>Assisted</td>
<td>Partial Automation</td>
<td>Conditional Automation</td>
<td>High Automation</td>
<td>Full Automation</td>
</tr>
<tr>
<td>NHTSA English</td>
<td>No Automation</td>
<td>Function-Specific Automation</td>
<td>Combined Function Automation</td>
<td>Limited Self-Driving Automation</td>
<td>Full Self-Driving Automation</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Differences in nomenclature of automation levels (Gräter 2015)
Driving Automation Systems

<table>
<thead>
<tr>
<th>Partially automated (level 2)</th>
<th>Slow manoeuvring</th>
<th>Manoeuvres of limited duration</th>
<th>Driving for long periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Parking assistant</td>
<td>Automatic driver-initiated manoeuvring into and out of the parking space. Driver is outside the vehicle, must monitor the procedure constantly and interrupts if necessary.</td>
<td>Overtaking assistant Automatic driver-initiated overtaking (of one vehicle). Restricted to motorways. Driver must monitor the procedure constantly and intervenes if necessary.</td>
<td>Construction site assistant Automatic longitudinal and lateral control. Restricted to motorway construction sites. Driver must monitor the procedure constantly and intervenes if necessary.</td>
</tr>
<tr>
<td>Highly automated (level 3)</td>
<td>Lane change chauffeur Automatic driver-initiated lane change. Restricted to motorways. Driver does not have to monitor the procedure.</td>
<td>Motorway chauffeur Automatic longitudinal and lateral control. Restricted to motorways. Driver does not have to monitor the procedure, but is prompted to take control.</td>
<td></td>
</tr>
<tr>
<td>Fully automated (level 4)</td>
<td>Parking pilot Automatic valet parking and manoeuvring into and out of the parking space. No driver / driver leaves vehicle.</td>
<td>Automatic emergency stop Automatically returns vehicle to safe state when driver is unable to drive.</td>
<td>Motorway pilot Automatic longitudinal and lateral control. Restricted to motorways. Driver does not have to monitor and does not have to take control.</td>
</tr>
</tbody>
</table>

Table 3: Levels of automation vs. speed and duration (Bartels, et al. 2013)

The research and development of fully automated systems is an ongoing activity for more than a decade: (Saniee and Habibi 2004) report about automated highway driving using a fuzzy ranking method. They present a simulation system to guide an automated vehicle on the highway controlling its longitudinal movement and deciding about its operational lane to drive. In the current situation the crucial step from partial to high automation is debated. In public discussion it is expected to bring the right applications for highly automated driving into action. According to (Kämpchen 2011) and (Wüst 2013) the development from high to full vehicle automation will probably not constitute such a quantum jump like the step from partial to high automation in its momentary status. By reading Table 1 and Table 3 there is a choice of picking an appropriate system to support this crucial process for the evolvement of driving automation. One consideration is related to slow manoeuvring systems: In order to illustrate driving automation in some detail the following example describes an implementation of Remote Parking Assistance:

Parking functions that are in production today satisfy parking needs in which the driver stays in the vehicle and the vehicle is driven automatically into a parallel or perpendicular parking slot. Publications about the next steps in parking aid functions are demonstrated by the automotive manufacturer BMW. (Boeriu 2010) reports about the newly created Remote Parking Assistant that is
Remote Controlled Parking goes a step further, performing an entire parking manoeuvre – in this case forward perpendicular or garage parking – single-handedly. The driver does not even have to be sitting inside the vehicle. Crucial items for the realization of this technology are the transition from manual to automated mode and the collaborative and supervised driving which is a part of the remote control action. The driver needs to stay in the line of sight with the vehicle during the parking manoeuvre. The driver defines the demand for take-over from automatic mode back into manual control by an immediate interruption of the automated drive and the vehicle comes from slow manoeuvring speed to standstill. In a practical embodiment this transition is realized by the immediate release of a remote control button. In Table 3 this functionality is categorized as partially automated driving.

In summary, however, it cannot serve as a role model for collaborative automated driving in the context of this thesis; the driver has not only to observe, monitor and supervise the automatic drive but he also has a continuous operation task by pressing a so-called “dead man switch”. The vehicle is in automated driving mode but it is still manually controlled by a remote device. Hence, the importance of transitions from automated to manual driving is not straightforward in this case. Consequently the automated parking technologies are not seen as a suitable subject in this work that intends to concentrate on automation with authentic transitions from automated to manual driving.

The previously mentioned feature “Traffic Jam Assistance” TJA is not listed in Table 3. As an assistance system with longitudinal and lateral support it is presumably counted to the partly automated category. Technology-wise it offers full automated drive with longitudinal and lateral control which points into the direction of motorway chauffeur in Table 3. This belongs to the highly automated category (level 3). It is important to note that the driver of a motorway chauffeur system will be prompted to take over control. This is a clear hint that the driver needs to collaborate with the automation system in a way that he has to activate the system and also to come back to manual driving. Therefore it requires an according control transition strategy. TJA is an automated congestion system for motorway driving that is to be associated with a collaboration concept. It represents a suitable example for collaborative automated driving with transitions of driving control. TJA points out to be the appropriate object for further and deeper investigation in this thesis because it deals with a driving automation system that interacts with the driver in a collaborative way. The role of the driver changes from being the operator of the vehicle towards a supervisor who has to take over the driving task just on request of the automation system. The consequences of being a supervisor and owning responsibility for the vehicles motion need to come to the driver’s awareness. This will be treated in more detail in chapter 3.
2.6 Conclusion

This chapter reviewed automated driving technology in past and present times. It served to manifest an overall position of this technology and to identify the current need in research and development. Researching the related state of the art made apparent that much supporting research work has been conducted to describe, characterize and prepare the analysis of automated driving systems.

Within the automotive industry automated vehicle driving is differentiated into five different levels. In the coming years full automation - represented in level 4 - will not yet be feasible. The current situation represents an interim status between partially and highly automated driving, described by level 2 and level 3. Both levels are characterized by involvement of the driver and they require collaboration between the vehicle and the driver. In the current definitions of automation levels 2 and 3 a distinction is made that secondary tasks that are not related to the driving task are either prohibited or allowed. The driver has to supervise the system either permanently or transiently. In both cases a control transition strategy is required that keeps the driver in the loop and reminds him about the collaboration task and the responsibility for the vehicle’s motion. The control transition strategy will be the main subject in this thesis.

Research on automated driving systems is motivated by the ambition to introduce more systems of level 2 and level 3 in a mid-term timing of five to eight years in order to pave the way for fully automated driving that will be established thereafter. The research presented in this thesis supports this ambition by considering partial and high automation as its scope, i.e. the levels of automation when the driver is still in the loop as an essential controller of the vehicle and where he needs to be assisted in this task.

A suitable automation system that fits into the focus of this research is identified: A congestion driving support system, generally called traffic jam assistance (TJA), is defined for collaboration between the vehicle and the driver while driving on motorways. Transitions in driving control from the system to the driver take place as part of the collaborative driving effort. Solutions for supporting this challenging task will be investigated. At this stage it is known that driver and automation need to collaborate in controlling the vehicle. Unknown is how a supporting control transition strategy has to be designed in order to assign the driver a supervising and collaborating role that he accepts.

The next chapter defines in detail the context of automated driving and the collaborative approach in which the research objectives will be established.
3. Collaborative Automated Congestion Driving

3.1 Introduction

Recent publications describe the traffic jam assistance system TJA as a natural evolution of the Adaptive Cruise Control feature ACC: Since the start of production of ACC in the year 2000 many drivers learned that longitudinal vehicle control can trustfully be handed over to a driving robot. The drivers also learned about the weakness and limitations of ACC knowing that the braking capacity is not capable to perform an emergency stop and that the radar sensor measures the headway only to the leading vehicle in the lane while ignoring complex scenarios in which several vehicles are involved. For maintaining a smooth driving style the driver has to complement the intelligence of the ACC system by intervening from time to time with the accelerator or brake pedal and by using a resume button. ACC has been improved over years through the cross-functional combination of driver assistance systems. The work of (J. Freyer 2007) shows that ACC benefits with the inclusion of a lateral assistance system named Lane Change Support.

An extension to the embodiment of ACC was launched in 2010 known as ACC Stop&Go, e.g. in BMW 5 and 6 series cars. (Schaller, Gradenegger and Schiehlen 2008) report that they are “capable of braking the car until standstill. However, the remaining lateral control task in traffic jams has to be done by the driver. This task points out to be uninteresting but nevertheless it demands constant attention from the driver in order to benefit from an increased level of assistance in these situations and to reduce his workload”.

A workload reduction can be achieved when the driver is released from the lateral control task as well. Hence, a TJA system shall also take over the control of the steering wheel. In order to complement the driving automation (Schaller, Gradenegger and Schiehlen 2008) postulate that the system needs to “keep the driver in the loop for adequate reactions in critical situations.” The demand comes from the recognition that the environment sensing technology at today’s level is error-prone in comparison to human capabilities under highest attentiveness.

This chapter provides an overview of the state-of-art of automated driving in traffic jams on highways. It provides information on methods of control transitions from automatic mode to manual driving which underlines the collaboration task of the human driver with the automation system as a central theme for this research.

3.2 TJA functionality

The character of collaborative driving is well expressed with the driving automation system Traffic Jam Assistance (TJA). Exemplarily the car manufacturer Audi has demonstrated at the Las Vegas Consumer Electronics Show CES in February 2013 a prototype vehicle with automated highway driving functions, explicitly named as a Traffic Jam Assistance feature. Other manufacturers like BMW invest in similar research and development activities regarding highly automated congestion driving on motorways as published by (Kämpchen 2011).
An important step for TJA-like driving features was made with the start of production of Mercedes E- and S-class vehicles in 2013. These vehicles dispose a function called Distronic+ and Lane Assist to drive automatically under special conditions. The German magazine Der Spiegel (Wüst 2013) reports about these vehicles:

“In traffic jam driving at walking speeds the system allows the driver to take his foot from the pedal and his hands from the steering wheel... The legal framework is still unclear for this kind of operation. This autonomous driving at low speed rates of the S-class will be a borderline mission for the existing certification guideline. The luxury vehicle operates in a legal gray zone.”

This kind of manoeuvring allows the driver to take his feet from the pedals and keep his hands off the steering wheel while driving in a traffic jam so that he is principally enabled to perform a secondary task that is not related to the driving task. The system follows the leading car in front without overtaking and steers automatically into the centre of the lane, marked by lines on the right and the left side. The sensors used in conjunction with a TJA system are located in the front of the vehicle and can consist of e.g. camera, radar, laser and ultrasonic technologies.

(Schaller, Gradenegger and Schiehlen 2008) describes in this matter a practical version of TJA that offers two main modes of assistance:

Longitudinal assist – like the known ACC Stop&Go function it supports the driver to take his foot away from the pedals and it maintains a follow speed from e.g. 40 kph to standstill. At higher speeds a take-over demand is generated. At standstill an advice asks the driver to resume the follow drive.

Lateral assist – the driver takes his hands of the steering wheel and - in order to stay in the middle of the lane - he lets TJA steer automatically in given boundaries, like maximum steering angle and also maximum follow speed of 40 kph.

In early 2016 an explicit TJA technology is not yet on the consumer market, presumably because the legal framework still needs to be adapted for a roll-out of this feature. In the framework of the ongoing European project (adapTIve 2016) TJA functionality is notably mentioned as a use case in congestions on motorways by following the lead vehicle in a lane with stop&go activity. Regarding human-vehicle interaction, the preference is given to a collaborative option: "The human and automation can both participate in the control through some sort of partnership.”

With this approach TJA is classified as ‘supervised automated driving’ and it differs from the description of a motorway chauffeur system in Table 3 which is assigned to highly automated driving. In this context it can be assumed that the TJA has to be considered as an assistance system at partial automation level because the drivers shall not be allowed to perform a secondary task. However the borderline to highly automated driving systems is blurred, regarding the allowance to drive hands-off and to execute a secondary task. The duration of control transition times is not yet proposed or specified in publications. With respect to the time span between transitions (Naujoks, et al. 2015) presents in an experimental design of different TJA versions with either 10 or 120 seconds of taking the hands off the steering wheel. One crucial aspect to evolve automated driving systems from partially automated (level 2) to highly automated (level3) will consist of an extended duration of hand-free driving, e.g. 3 to 5 minutes or even longer.

The level of automation for traffic jam systems that the automotive industry will presumably offer for motorway driving in the near future depends on the progress of on-board sensor technologies: On the one hand engineers are very excited and fascinated by the performance of the newest sensing
technologies. (Kuffner, et al. 2012) report that “the different sensor principles complement each other in terms of range, resolution, light intensity and weather robustness”. On the other hand the scepticism remains also in the engineering field whether it can adequately replace a highly attentive human sensor and data processing system. Figure 5 shows the environment sensor systems in a contemporary mid-class vehicle and a representation of their fields of view. Although there is some redundancy by the overlaps of fields intensive research work has to be continued in order to strengthen the reliability of environment sensing.

(Kämpchen, Aeberhard, et al. 2012) states about the current performance of automotive sensor systems: “Obstacles like lost charges on the lane are not always identified or lately...There is room for further research activities”. This makes clear that the human supervision of automated drives will exist unless a flawless environment sensing system has been developed.

![Figure 5: Example for Environment Sensor Systems in a Contemporary Vehicle](image)

### 3.3 Human cognition and reaction

A complementary element of technical environment sensing is the human perception of the same environment. For a driving automation system it is essential to establish a balance between the efficiency of automation and the performance of human cognition and reaction. Exemplarily (Moravec 1998) handles it as a competition to compare the potential of human senses and brain with the increasing performance of sensor technologies like image processing systems and according computing power. In literature the efficiency of human senses and brain is discussed controversially. (Broadbent 1958) stated that the human perception is an apparatus with limited capacity of a single-channel processor, proven by an listening experiment conducted by (Cherry 1953): If a test person is presented two messages simultaneously but separate on each ear only one message is given attention.
In a later investigation from (Wickens 1992) the human information processing mechanism is described as a complex interaction system with the long-term memory storage. Outside stimuli go first through a short term sensory store. The perception in the working memory is formed by including data of the long term store before a decision is built for response to the stimuli and execution.

(Vollrath and Krems 2012) explain how close the subject of driving is connected with seeing, visual perception and attentiveness. The human eyes perceive a visual field with a horizontal extension of about 180°. Only a small portion can resolve a detailed picture, this is 2 degrees represented by the area of fovea. In a traffic situation the flood of information exceeds the capacity of the visual system and the human brain filters the information by selecting the relevant object or image section. This happens by eye movements, so called saccades that control the fixation of the fovea and serves to scan in sequence all relevant objects in a traffic scenario. Beside the foveal perception there is also peripheral perception that supports the driver in his control task to keep the lane and the correct lateral direction of his vehicle.

The driver’s holistic perception leads to situation awareness. (Endsley 2000) created a model for situation awareness that represents three levels: Perception of elements, understanding of the situation and anticipation into the future. Figure 6 shows a part of Endsley’s model with the feedback loop of the driver’s reaction.

This representation of situation awareness builds on a continuous vigilance of the driver. For collaborative driving systems the model needs to be enhanced because it has to take into account the inattentiveness of a driver at any time especially when highly automated drive systems are in operation. The advancement of the awareness model shall be elaborated in the next sections.
3.4 The collaborative approach and driving awareness

The terminology of collaboration in conjunction with automated driving can be confusing unless specifying its meaning precisely. In this research the terminology “collaborative automated driving” is used to indicate that there is a clear borderline to fully automated driving (Level 4) in which a driver interaction is no longer required. The term “collaborative” is applied to indicate exactly the instance that the driver collaborates with the automated vehicle system by observing and supervising the surrounding traffic and being prepared to take over control himself if deemed necessary. In contrast the term “Cooperative Driving” is used differently in the literature, e.g. in studies of vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication for automated driving systems. It is also applied to explain the communication of vehicle drivers with other traffic participants with eye contact or gestures. In this work however the term “collaborative” is exclusively employed in the above sense to differentiate it from cooperative systems.

The collaboration between the TJA automation system and the human driver exists in different steps: Firstly the driver hands over the driving control to the automation system, then the driver has to maintain an awareness about his supervising task and the preparedness to take over control and ultimately the driver has to service the transition from automated driving back into manual driving. In this way supervision and readiness pave the way for the final hand-over to manual driving. Conclusively the collaboration task for the driver needs to be supported: he shall be informed and sensitized about the traffic situation in which he is involved and then - just in case - he can be urged to take over the control.

The term collaborative approach in conjunction with driving automation can be explained by the demand that both partners, the automation system and the human driver shall work together, hand-in-hand. The collaboration concept has clearly to define which partner actually has the authority for driving, either the human or the automation system. The major collaboration part consists in the readiness for hand-over from automated driving to manual driving. The hand-over itself can literally happen by taking the steering wheel back into the hands or by operating the pedals. This is either the acceleration pedal or, even more pronounced, the brake pedal to decelerate the vehicle and minimizing a potential risk of the current situation.

The importance of the human factor for the collaborative approach and especially the before mentioned transition are researched in several publications. A summary of related publications is given by (Merat and Lee 2012). Their summarized judgment is that “high level of automation combined with drivers’ tendency for distraction will result in lower levels of situation awareness.” If a driver needs to retake control due to a transition need these are likely situations where rapid action is required, in terms of milliseconds. However in some cases the driver may need some seconds to reenter the control loop. (Merat and Lee 2012) call it an irony that “periods when drives are most likely to fully rely on automation – highway driving – also require the most rapid reentry of drivers into the control loop... Technology that people view as taking on the role of the driver will likely exacerbate distraction and the tendency for other roles to displace the person as driver, leaving people vulnerable to situations the automation cannot handle.”

(Rauch, Gradenegger and Krueger 2007) investigated situation awareness of a driver who works on a secondary task while driving. The new projection in their study allowed test persons to handle the secondary task self-responsibly and to operate with anticipation in order to compensate situation
awareness. Rauch does not report explicitly in the context of automated driving, however, the subject of a secondary task is strongly related to driving automation. One detail of his study that is of interest for the collaboration approach shows the behavior how the driver’s view is redirected from the secondary task back to the road, see Figure 7. Depending on the situation (study 1 and study 2 have different secondary tasks and driving situations) the percentage of road views varies in the left diagram between 18-43%. This means that the drivers remain in a mode of “blind flight” for up to 80%. The duration of these road views varies in the right diagram between 250-600ms. The study concludes that surprisingly this small amount of time satisfies the driver for ensuring him situation awareness. Based on these findings it is advisable that a driver of an automated system (secondary tasks are only allowed in level 3 systems) shall be made aware about all relevant changes in a static traffic situation in order to meet the collaboration task with the automated driving system.

An assessment framework for situation awareness under conditions of collaborative automated driving is investigated by (van den Beukel and van der Voort 2013):

“The automotive industry’s current focus for automated driving is on developing congestion assistance providing automated lateral and longitudinal control during low speeds on motorways. Due to this application, transitions between automation and manual driving occur regularly: For example when traffic speed exceeds the low speed threshold, a take-over will be requested by the system. However, during automation a driver is placed remote from the control loop. Likely, this causes slower reaction times and reduces driver’s awareness of the situation”.

In the study van den Beukel investigates accident avoidance within time-critical situations in automated drives i.e. the time to react after an alarming sound. Time to collision was varied to simulate different levels of criticality. Reaction timing was exemplarily set to 0.5, 1.0 and 1.5 seconds. Depending on the analysis method for situational awareness— SAGAT and SART were applied - the results show with a light ambiguity that situation awareness has a positive correlation with successful driver-take over.

The importance of situation awareness is also stressed with the work of (Spießl 2012). He researches the effect when the automation system does not work resiliently as desired. In this case the driver’s permanent supervision becomes necessary despite of a secondary task that he performs. “...a complete failure of an automated system is not the worst case, because there is a good chance that this can be detected and the driver can be warned and prompted to take over. The most difficult case is when the automation seemingly works fine, but actually does not perform as supposed to. For instance, erroneous sensor or camera data can lead an automated lane keeping system to believe
that the vehicle is right on course, when it actually is not, which can result in unintentional lane departure.”

(Johansson 2014) reports in the European project interacTive about the term of collaborative automation in the following statements: “By collaborative automation we mean that this implies that the automation and the driver have complementary skills. And we should see if we could use these complementary skills together to achieve one common goal... The basis here is continuous communication in some way and continuous interaction between two partners.”

Conclusively it appears that situational awareness is a core element for the collaboration task of the driver in automated driving modes. Situational awareness is strongly related to oncoming research questions and research tasks because it is closely linked to transitions in control that drivers of automated systems need to be prepared for.

### 3.5 Transition between automation and human responsibility

Research on transitions between automated and manual driving is comprehensively presented in the work of (Flemisch, et al. 2003), supported by Figure 8. Starting with a similar interpretation of levels of automation as presented in Table 1 and Table 3 he declares that transitions are possible from every stage to another. And the possibility of initiating the transition is given to both participants of the drive, the automation system and the driver himself. This relationship is graphically presented in the figure below.

![Figure 8: Seamless transitions between automation levels, redrawn from (Flemisch, 2003)](image)

This perspective derives from the H-Metaphor, the so-called horse metaphor: The horseback rider can ride the horse with tight or loose reins. The looser the reins are the more he lets the horse control the ride trusting in the intelligence of the animal (Damböck, et al. 2012).

With reference to situation awareness and the collaboration task this implies that there is certain adjustment and tuning possible for the creation of the automated system in general as well as for a supporting tool in special.
What can be learned from the aviation industry?

(Merat and Lee 2012) identified a prominent example of transitions from automated to manual control in the aircraft industry. Passenger airplanes are in control of 2 educated pilots, the captain and the co-pilot. A third controller can be activated and deactivated by these 2 human pilots, it is called autopilot. It has several embodiments; generally it cooperates with the flight management system that informs about the desired flight direction and flying altitude. Amongst others it automatically controls the jet engine and the pitch elevator.

(Young, Stanton and Harris 2007) reported about a comparison of driving automation to the aviation industry. They investigated whether two different philosophies from the companies Airbus and Boing, named hard automation and soft automation, can be transformed into the world of road vehicles. In hard automation the pilot is overridden by the automation when the aircraft exceeds protection envelope. Comparably, an ABS system in a vehicle can be considered as a hard automation item; it has ultimate authority not to block the wheels and can only be deactivated by disconnect the electric supply or pulling the according fuse. For soft automation the driver is enabled at all times to override or to shut-off the automation system. Soft automation is in most cases the comparable method for automotive driver assistance systems. They can be activated and deactivated by choosing the options in the control panel menus.

Automatic aircraft starts are not intended by auto-pilot. Also for the landing from a certain altitude it is mostly controlled by the pilots to maintain a continuous human expertise with the captain and his co-pilot especially for bad weather conditions. Only a small amount of landings is handled by the autopilot. In parallel the human pilots retain responsibility for lane centring on the landing runway.

In the automotive domain it can be considered to offer an automation system like TJA only in specific areas of the road infrastructure. Even in a limited selection of motorway areas could be regarded. It is a field of open research to understand whether users of driving automation would be in accordance with such kind of limitation.

Due to (Young, Stanton and Harris 2007) the learning process from aviation for vehicle automation led to the insight “that high levels of automation autonomy, coupled with a great deal of automation authority could be problematical for the pilot”. This is well understood in the automotive industry that a stepwise introduction of vehicle automation is necessary and that prior to high and full automation the open issues of partial automation systems needs to be overcome.

Overall – this example from the aviation industry cannot be directly transferred onto driving automation of road vehicles: First of all, the skills needed to fly an aircraft include a huge level of abstraction to operate in a three-dimensional domain while car driving in normal conditions can be considered as a two-dimensional domain.

Secondly, pilots are highly educated and trained for their professional work. A long lasting education and a continuously recurring training in new aircrafts and flight simulators are mandatory. Moreover, the conventional driver on public roads does not maintain a permanent consciousness of his own driving skills. With an average education of three months and a singular examination he obtains a life-long lasting driving license. In case that he comes in touch with new assistance systems like ACC in a newly bought vehicle he has to educate himself via “learning by doing” how to make beneficial use of it.

Thirdly, the density of traffic in terms of time and space is much higher for road transportation than in the air. In case of changing conditions it challenges the driver with a more prompt and timely
execution. Driving e.g. on motorways with up to 5 lanes in one direction and with lane changes that are initiated either by the ego-driver himself or by the surrounding drivers requires discipline, concentration and mutual collaboration from traffic participants. This can be compared to the tasks of aircraft pilots after landing and before take-off which are sophisticated and complex.

The analogy of automated systems in aviation industry - buzzword autopilot - and road vehicle automation seems to be clear at first glance and is therefore commonly compared in media. The differences that are found, however, are huge and the learning effect for partially and highly automated vehicle systems (level 2 and level 3) is relatively small. It is a fact that civil aircrafts have two pilots on board, a pilot and a co-pilot. Usually the presence of a co-pilot contributes in situational awareness of the pilot and supports him in control transitions. For drivers of automated vehicles who in contrast perform their task as soloists a supporting control transition strategy will be of high importance in order to perform in their job with comparable precision and perfection.

3.6 Warning Concept for Control Transitions

Rough concept ideas for control transitions in collaborative driving exist in various versions. These mainly concentrate on the transition from automated to manual driving. In Figure 8 this is represented by unidirectional arrows highlighted in the lower part of the drawing, independent if a traffic jam assistance system is regarded as a partially or a highly automated driving system.

In a description of the TJA system by (Schaller, Gradenegger and Schiehlen 2008) the transition from automatic to manual driving was initiated by an alarming sound that urged test persons to take over the control as quickly as possible. If longitudinal or lateral control of the automatic system is asked to exceed certain limits of braking and steering capacity it will issue a hand-over warning. Their concept also maintains a soft take-over request in case of reaching a maximum speed in the traffic jam which was 40 kph.

Another example of awareness control is known from the railway industry. The feature is called “vigilance control” or “dead-man-switch”. (Newman 2010) reported about its efficiency. The transition consists in a sign of life of the train engineer: he has to press the dead-man-switch in response to an alerting signal that is issued randomly in a few minutes.

(Naujoks, et al. 2015) and (van den Beukel, van der Voort and Eger 2015) report about two different forms of warnings and transitions that can be used in the framework of automated driving:

1. A soft transition that is equivalent to an awareness alert. The driver will take notice of the warning but no immediate reaction is required. It can be compared to an outside temperature warning: The driver is alerted that driving conditions will become more dangerous if the road surface becomes wet.
2. A hard transition consists of a clear request to the driver to take over control from the automated vehicle and dominate the longitudinal and lateral movement by conventional manual control.
<table>
<thead>
<tr>
<th>Possible traffic scenario, causal context for warning</th>
<th>SOFT TRANSITION (awareness alert)</th>
<th>HARD TRANSITION (take-over request)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A constant situation to follow permanently a leading vehicle is interrupted by lane changes e.g. cut-in and cut-out manoeuvres from other vehicles.</td>
<td>Another vehicle from a neighbouring lane performs a close cut-in manoeuvre that is perceived as a threat to the driver.</td>
<td></td>
</tr>
<tr>
<td>A leading vehicle cuts-out with no replacement or a new object is not detected because of limited sensor range.</td>
<td>A leading vehicle decelerates sharply and becoming an emergency situation.</td>
<td></td>
</tr>
<tr>
<td>Lane markings are not fully recognized.</td>
<td>Lane markings are lost, the traffic jam ends, the sensor system fails.</td>
<td></td>
</tr>
</tbody>
</table>

| Possible warning methods | Light chimer or haptic feedback like vibration in the seat or in the steering wheel. An according symbol in the instrument cluster is displayed. | Buzzer with loud and escalated sound. Blinking warning bulbs, head-up display warning in red colour |

| Automation system reaction | The automation system remains active. | The system switches off or ramps down its automation function. |

<table>
<thead>
<tr>
<th>Consequences for the driver, driver action</th>
<th>Driver focusses his attention back on the road to regain situation awareness.</th>
<th>Driver has to take over control immediately by operating the steering wheel with his hands and the pedals with his feet.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optional: Driver pushes a resume button or touches the steering wheel.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4: Definition of control transitions including context, warnings, reactions and consequences**

*Table 4* uses elements from proposals of (Naujoks, et al. 2015) and (van den Beukel, van der Voort and Eger 2015) with regards to soft and hard transitions. In their research these are called soft and hard warnings. They are subject of a physical refinement of warnings and an investigation of drivers’ reaction. The research of this thesis, however, concentrates on the new aspect of control transitions: How can the driver be at all times prepared and supported for a physical take-over of the vehicle control?

*Table 4* also defines two different variations of a control transition in the context of TJA, a soft and a hard control transition. It is a double-tracked warning concept which can also be regarded as a two-step alerting system in case that first a soft and then a hard alert is issued. The described conditions and values are exemplary and non-exclusive. Warning for transition might have several root causes. Fundamentally soft transitions do not reference a critical traffic scenario and thus they do not require physical driver action in terms of taking over the controls of the vehicle. In form of an
awareness alert they request the driver solely to regain awareness of the actual traffic situation in that he resides. A confirmation of his awareness can optionally be expressed by a light driver action like an intended button press or by putting the hands back on the steering wheel for a short moment. In contrast, a hard transition requires a real and immediate action from the driver because the automatic system will switch off its support in a defined time span. By means of a take-over request the driver is urged, especially by the escalated warning method, to take over full responsibility of the vehicle motion as quickly as possible. He has to control the vehicle again, namely through manual operation on the steering wheel and the pedals. Most relevant is the brake pedal to decelerate the vehicle immediately.

The double-tracked control transition strategy can be realized by soft and hard warnings: they are designed in order to remind the drivers about their responsibility for driving and to gain situation awareness and willingness for a sudden transition back to manual driving. The soft warning expresses a kind of mental take-over of vehicle control while the hard warnings mean a real and physical take-over. The reasoning for issuing a hard warning can be various as listed in Table 4, i.e. lane changes, occurrences of “loss of lane markings”, “sensor system failure”, “end of lane”, “end of motorway”, “constructions site”, “end of traffic jam” or “driver’s presence in doubt”.

### 3.7 Relevance of Lane Changes for Automated Congestion Driving

The need for transitions in control either comes from the system meeting its boundaries or changes in the surrounding traffic situations. With respect to the latter, lane changes are expected to be the major cause for needed transitions in control. (Larsson, Kircher and Hultgren 2014) investigate ACC systems and state that for cut-in events they “might in some cases even behave in a counter-productive way...In this kind of event the ACC is not always able to identify and lock onto the new lead vehicle straight away, but initially reacts as if there is now no obstacle in front.” A patent of (Labuhn, Chundrlik and Rush 2001) also refers to adaptive cruise controlled vehicles that “respond to capture of new in-path vehicles which violate a predetermined inter-vehicle spacing to attenuate unnecessarily aggressive deceleration responses”. As for ACC these system boundaries will apply in a similar manner to collaborative automation systems. They are a major motivation to develop a control transition strategy in order to make drivers aware about system limits and the related responsibility issue.

The work of (J. Freyer 2008) investigates a driver assistance system that enhances the known functionality of ACC with a lane change support system. His research is focussing on lane changes of the ego vehicle and not of surrounding traffic and it deals with higher vehicle speed. From his work it can be learned what motivates drivers to perform lane changes and how lane changes can be anticipated time-wise (see also chapter 5.3).

Although the relevance of lane changes for automated congestion driving is clear, little research is performed regarding the impact of lane changes by surrounding vehicles in traffic congestion, especially in relation to driving automation systems that are designed for driver collaboration and the need of a control transition strategy.

(Pe and Xu 2006) investigated lane changes in traffic jams with speeds below 10 kph from the bird view perspective. They adopt rules from game theory for the manoeuvres. The indicators for a lane change were based on drivers’ cooperation tactics with space and time, i.e. they do not reference an
ego driver or a foreign driver. In difference to this thesis the availability of their indicators goes beyond real data of sensor systems and lane changes only happen at creeping speed and not in the relevant range of velocities in traffic congestions.

For this research in particular the determination of indicators for identification of lane changes is relevant that require transitions in control. Moreover for the research in this thesis, it should be noted that traffic situations around an automated vehicle can be highly dynamic. The cause for transitions in control can be due to sudden dynamic traffic impulses, hereby transiting from an alertness request to a required take-over.

Figure 9 illustrates vividly the differences between a static and a dynamic traffic jam situation. The left picture represents a constant and stable traffic flow with no need for any warning or even driver action because no obvious or sudden changes are expected. In the right picture one recognizes a high level of fluctuation and agitation because of the lane changes of other drivers. This will most likely require the attention or eventually intervention of the driver in the ego-vehicle.

This research will focus on the development of a control transition strategy in cases of lane changes under conditions of collaborative automated congestion driving. As a first step an analysis of real driving data will be performed (chapter 5) to investigate the relation between lane changes by surrounding traffic and the need for transitions in control. Furthermore the optimal timing and form of warnings will be researched: Which of the two warning variants - if any - is to be generated in current specific traffic situation and when - at what actual point in time - shall the warning be issued?

During an automated vehicle drive, the driver should be (made) aware of lane changes that are relevant for a control transition. Referring back to the situation awareness model presented in Figure 6 the hard and soft transitions can be included in the flow diagram, resulting in Figure 10. While the soft transition influences the perception of situational elements, a hard transition directly affects the decision to act and its execution by the driver. Figure 10 shows the enhanced awareness model with the points of application for soft and hard transitions. The difference of the two transitions is underlined by the fact that a soft transition starts deeply inside the situation awareness block.
whereas a hard transition is directly linked to a driver’s planning and action. Timing-wise the soft transition has a larger gap to a driver’s reaction. It also depends on the planning and decision phase if an action will take place at all.

Figure 10: Enhancement of situation awareness model for collaborative driving

In the context of the previous discussion it plausible that the success of collaborative automated driving depends on the quality of control transitions and an according warning concept. Within this research a control transition strategy shall be developed in line with the double-tracked warning approach proposed in Table 4, i.e. offering a soft warning and a hard warning.

3.8 Conclusion

This research will focus on Traffic Jam Assistance TJA as an instantiation of an automated congestion driving system with collaborative approach. Traffic Jam Assistance can be considered to be both a partly (level 2) and a highly (level 3) automation system depending on the permission of a secondary task and the allowed duration of the automated mode. While driving with TJA, the driver needs to monitor the system either permanently or occasionally; because the driver’s presence and supervision is required in automated driving mode special attention is given in this research to the collaboration task of the driver. A comparison with the aviation industry revealed that the automation of road vehicles has a different approach that cannot be simply copied. Especially the transitions in control are of particular importance for the driver who drives without a human co-pilot. The objectives of the present research are directed to define a control transition strategy based on a double tracked warning system. It offers, when appropriate, either a soft or hard transition to the driver while being in the mode of automated congestion driving. Most relevant for the issuing of alerts is the dynamics of the congested traffic situation around the automated vehicle. Lane changes are a major contributor to this traffic dynamics and have been chosen as the central topic for developing a desired driver support in form of a control transition strategy. This research aims to develop a control transition strategy for TJA systems that in particular aims to support the driver by
means of warnings in taking back control of the vehicle when required in situations of lane changes under conditions of automated driving in traffic jams.

For a holistic control transition strategy, traffic or vehicle situations other than lane change manoeuvres will be of influence. Although beyond the scope of this research, the occurrence of such situations is acknowledged and, where feasible, represented in the assessment framework of the control transition strategy.

The next chapter will describe the objectives of this research as well as the chosen approach in more detail.
4. Research Objectives and Methods

Previous chapters explain the context and background for this thesis with a summary of the history and state of the art as well as categories for driving automation. Automated congestion driving was selected as the specific instantiation of collaborative automated driving this thesis will focus on. The automated congestion driving functionality can be classified as either partially or highly automated driving system. The core aspect of these vehicle automation systems is a modified role for the driver. To support the driver in his new role of supervision with instances of intervention, the collaborative automated congestion driving system will generate warnings to keep the driver in the loop. To issue these warnings a control transition strategy is required. In this research a model for the control transition system will be developed and evaluated for an automated congestion driving system (also referenced as TJA) with a particular focus on transitions in control that are required due to occurring lane change manoeuvres of surrounding traffic. As a baseline a control transition strategy is proposed that issues hard and soft warnings in order to emphasize the fact that the driver remains responsible for the vehicle motion and he can be urged to take over the driving control at any time.

This chapter will provide a detailed description of the research objectives of this study and the research questions it will address. Additionally the methods that will be applied to pursue the research objectives are introduced. The detailed process of modelling and set-up of experiments will be described in subsequent chapters.

4.1 Research Tasks and Objectives

Based on the background and context described in chapter 2 the focus of this research is defined as the development and evaluation of a control transition strategy for an automated congestion driving assistance system with a particular focus on transitions in control evoked by occurring lane change manoeuvres of surrounding traffic. These traffic circumstances imply transitions from automated back to manual driving mode which requires keeping or regaining the driver mentally and actively in the loop.

First objective for this research is to confirm and justify this research focus through the analysis of driving events recorded under real-life conditions of automated congestion driving. The occurrence of lane change manoeuvres will be analysed in comparison to other scenarios that are due for a warning in order to explain the concentration on these types of traffic situations in automated driving mode. The intended outcome of the traffic data research is a list of indicators for (anticipated) transitions in control that are recommended for the development of the control transition strategy. Furthermore identified lane change manoeuvres will be assigned to one of the warning types (i.e. hard and soft). The list of indicators will allow describing these lane changes based on according indicator values.

The presented study concentrates on a control transition strategy that is based on surrounding lane changes that commonly occur. Contradictory to other research, e.g. (de Waard, et al. 2000) and (Mok, et al. 2015), the present research does not focus on emergency situations and warnings for automated driving.
Rather, it serves the driver to regain awareness of his responsibility as well as to react to traffic situations that relate to a transition in control. The control transition strategy will therefore be developed as a model and implemented as a tool for driver support in collaborative automated congestion driving.

The modelling shall make use of the list of indicators as input and firstly develop algorithms in order to determine the issuing of warnings as an output. Secondly the model will work out a timing proposal to anticipate at which point in time during the course of a lane change a warning shall be given to the driver.

In the strategy development an iterative user-centred approach will be applied during which evolving versions will be generated and assessed from the perspective of the driver. The assessment will in particular focus on three main criteria:

Usability
The aim is to create a control transition strategy that has a high level of usability. According to ISO 9241-11 usability is defined as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.” High usability means that the control transition strategy for automated congestion driving effectively alerts and warns the driver (effectiveness) in case of relevant traffic scenarios, while limiting the number of warnings at the same time without compromising provided support (efficiency) and ensuring that circumstances under which warnings are issued are in line with drivers’ expectations and acceptance (satisfaction).

Correct Timing of warnings
The objective is to issue warnings at the exact point in time when the drivers expect an appropriate support in form of soft or hard warnings. The hypothesis that has to be tested is that drivers desire the warnings to be issued as early as possible. Within the context of surrounding lane changes that (might) require transitions in control, this implies that relevant lane change maneuvers have to be identified in an early phase of execution.

Error-avoidance
Warnings are issued with the intention to indicate relevant lane changes in the surrounding traffic to the driver. However cases will occur when the driver does not identify a lane change that caused the warning because it was for some reason interrupted and not finalized. As a result a warning is issued without the driver being able to associate a valid reason for it. The assessment on error-avoidance aims to avoid these so-called false positive warnings. The hypothesis is that drivers desire a full error-free control transition strategy with the assumption that false positive warnings are perceived as an annoyance and will not be accepted by drivers of an automated congestion system. This hypothesis will be tested.

A series of experiments shall be conducted in order to assess evolving versions of the control transition strategy and the assumptions in respect to these three criteria. As a principal measure the levels of driver agreement shall be explored and evaluated for both soft and hard control transitions. The end-objective of this iteration process is to test and assess a prototype version of the control
transition strategy, i.e. to implement it in an instrumented vehicle, under real-life circumstances of automated congestion driving.

The design of control transitions shall be applied to different groups of participants. A recurring differentiation of groups for driver assistance research is a classification of experience with and without ACC driving, compare (Young and Stanton 2007), (Strand 2011) and (Larsson, Kircher and Hultgren 2014). By investigating differences of groups this gains an understanding whether the chosen design is robust against variations of driver types and if it is generally applicable to drivers of cooperative automation systems.

The design of a control transition strategy that is based on lane changes is considered to have a significant impact in the development of automated congestion driving; therefore it shall be investigated how the integration of the control transition strategy in an enhanced context of automated congestion driving works out, e.g. in conjunction with other warning systems. This investigation serves to assess whether the warnings can be embedded in parallel with other supporting strategies for automated driving.

Collateral outcome of this research will be additional requirements for technical equipment that is used in the according driver support system. This serves as an assessment framework for system capabilities of sensors which are currently included in prototype versions of automated vehicles, i.e. radar, image processing units and near-field sensors (e.g. ultra-sonic and Lidar sensors). This framework will be supportive to the practical and technological implementation of the control transition strategy in automated congestion driving.

### 4.2 Approach

The research objectives lead to a development process that comprises of complementing data analysis, literature study, modelling work and experimental studies to conclude in a control transition strategy. Table 5 provides an overview on the defined objectives and the according research methods.

The research process starts with data recording of traffic scenarios that are relevant for the proposed development of the control transition strategy. A naturalistic driving study NDS shall be used to classify relevant driving scenarios. A literature study on lane changes will support the classification by identifying the characteristics and the detailed structure of such kind of traffic manoeuvres. In NDS the categories of available signals are typically a mixture of sensor data and observation data. By methods of data mining (Fayyad, Piatetsky-Shapiro and Smyth 1996) and statistical analysis (MINITAB 2007) the NDS data base will be explored to identify indicators for lane change manoeuvres that require transition in control. If technical signals measured within the driving study reveal to be insufficient for full manoeuvre identification, post-processing of the NDS data by means of manual video coding, generally referred to as labelling, shall be introduced to generate additional indicators. These labels have to be validated in terms of consistency in order to use them trustfully in conjunction with technical signals.
<table>
<thead>
<tr>
<th>Research objectives</th>
<th>Chapter Task /Questions</th>
<th>Method</th>
</tr>
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<tbody>
<tr>
<td>Traffic jam data analysis</td>
<td>Ch. 5</td>
<td>NDS data collection</td>
</tr>
<tr>
<td>Lane change classification</td>
<td></td>
<td>Video Coding: Labelling</td>
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<td></td>
<td></td>
<td>Literature study</td>
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<tr>
<td></td>
<td></td>
<td>Consistency analysis</td>
</tr>
<tr>
<td>Nomination of modelling indicators</td>
<td>RT5.4</td>
<td>Data mining</td>
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<td></td>
<td></td>
<td>Stat. analysis</td>
</tr>
<tr>
<td>Modelling of control transition strategy</td>
<td>Ch. 6</td>
<td>Separation into warning and timing model</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Math modelling using indicators and log. operations</td>
</tr>
<tr>
<td>Model simplification</td>
<td>RT6.2, 6.4</td>
<td>Main indicator research</td>
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<td></td>
<td></td>
<td>Literature study</td>
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<tr>
<td>Assess usability of control transition strategy</td>
<td>Ch. 7 RQ7.1-7.4</td>
<td>Participant based experiment</td>
</tr>
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<td></td>
<td></td>
<td>Basic driving simulator setup</td>
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<tr>
<td></td>
<td></td>
<td>Stat. analysis, literature study</td>
</tr>
<tr>
<td>Participant dependency</td>
<td>Ch. 7 RQ7.5</td>
<td>Stat. analysis of experiment and survey</td>
</tr>
<tr>
<td>New Indicator research</td>
<td>RQ7.6</td>
<td>Survey, questionnaire process after simulator experiment</td>
</tr>
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<td>Model enhancement</td>
<td>Ch. 8 RQ8.1</td>
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</tr>
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<td>Reassessment of model</td>
<td>RQ8.2, 8.3</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Stat. analysis</td>
</tr>
<tr>
<td>Participant dependency</td>
<td>RQ8.4</td>
<td>Survey, stat. analysis</td>
</tr>
<tr>
<td>Real driving validation Consistency of data to NDS</td>
<td>Ch. 9 RQ9.1</td>
<td>Field test</td>
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<td></td>
<td></td>
<td>Stat. analysis</td>
</tr>
<tr>
<td>Final assessment of usability</td>
<td>RQ9.2 – 9.5</td>
<td>Stat. analysis of field test</td>
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<tr>
<td>Integration into framework</td>
<td>RQ9.6 -9.8</td>
<td>Survey</td>
</tr>
<tr>
<td>Participant dependency</td>
<td>RQ9.9</td>
<td>Survey, stat. analysis</td>
</tr>
<tr>
<td>Derived technical requirements of the control transition strategy</td>
<td>Ch. 10</td>
<td>Assigning strategy requirements to object detection and recognition performance</td>
</tr>
</tbody>
</table>

Table 5: Research methods linked to objectives
The control transition strategy will be initially developed as a model that is split into a warning and a timing model. Respectively it is setup as a mathematical construct in order to principally support an automated computation for the suggested strategy in form of software logic. It will be advantageous to develop a basic model environment in the first instance of the process. This can be achieved by concentrating the warning model on one principal indicator if such can be found and by building the timing model on a fixed rather than a variable point in time. An iterative modelling process will be applied in which the model will evolve based on the outcome of a series of participant-based experiments.

The experiments will be conducted to understand the usability of the model and the according strategy. As experimental environment, a basic driving simulator will be used that offers the possibility of viewing traffic videos from the perspective of a motorway driver. The simulator study is complemented with a survey as the survey will enhance the objective analysis of driver agreement in the driving simulator tests with subjective answers of individual participants. A consistency of objective and subjective usability ratings can be addressed in this way. The reasoning to select in first instance a simulator study as experimental research set-up is founded in its high controllability and reproducibility as well as lower complexity. Ensuring participants’ safety is a further reasoning for choosing a simulation environment for the first experimental part of the present research. In contrast, a field or full-scale study involves high complexity with low controllability as indicated in Figure 11. To achieve a higher level of validity assessment of the control transition strategy within a complementary field trial is therefore anticipated. Multiple simulator experiments with evolving versions of the control transition model are conducted up till the point that the usability of the strategy is ensured and a suitable version is available for an assessment in a field trial.

The field study shall be used to finally assess the usability of the proposed control transition strategy under real-world conditions, i.e. within a holistic environment of automated congestion driving. This kind of experiment is labour intensive and needs a supporting infrastructure. The field study will in addition specifically address the research question regarding the strategy’s integrateability into a cooperative automated congestion driving system.
In a final consideration the claims of the control transition strategy for future technological development of automotive sensor systems will be summarized.
5. Naturalistic Driving Study and Data Analysis

5.1 Introduction

This chapter describes the first step of the research approach, which is real-life data collection and analysis of collaborative automated congestion driving on motorways. The data collection derives from a naturalistic driving study (NDS). Practical data capturing consists of a time-continuous stream of signal records. For this study, those parts of the NDS data will be considered that can be related to the control transition strategy, especially the according lane changes. The chapter starts with a description of the prototype vehicles that maintain an initial version of automated congestion driving (TJA) and that are used for the collection of driving data. It shall lead to an understanding what type of data is available for the development of the control transition strategy and what data still has to be added.

An in-depth study of lane change manoeuvres follows by researching literature and by categorizing them into three classes: normal cut-in, close cut-in and cut-out scenarios are considered. A time partitioning into phases of the manoeuvres aims at the timing objectives of the research. After collection of NDS data, data mining is used to provide a most complete description of lane change manoeuvres in collaborative automated congestion driving on motorways. Extraction of all relevant signals is pursued, even the ones that cannot readily be collected by sensors in the instrumented vehicles. To this purpose, lane changes recorded within the NDS are analysed by means of video coding techniques. The video coding process serves to enhance the availability of potential indicators. This post-processing work is called labelling. Labels are generated manually by human cognition, thus by nature they are not fully free of errors. Their practicability shall therefore be evaluated by conformance and coherence analysis. If practicability of labelling can be justified a cooperative application of both, technical signals and label data, is pursued as input to the development process of the control transition strategy. In a later stage the label data is targeted to be replaced by more advanced sensor signals.

The signals will be evaluated as indicators of lane changes, i.e. whether they are applicable to differentiate the lane change scenarios. At the end of this chapter the list of relevant indicators for lane change manoeuvres shall be presented, which will serve as a starting point for the preliminary modelling process of the control transition strategy.

In summary there are five research task (RT) to proceed in this chapter:

RT5.1: Categorise lane changes into differentiated manoeuvres and provide an appropriate time resolution for these events.
The task supports the research objective by addressing traffic scenarios which are considered for the control transition strategy and by discussing associated time partitioning of manoeuvres.

RT5.2: NDS data are to be post-processed with a video labelling method to enable data analysis for signals of surrounding lane changes.
A labelling tool and according rules have to be defined. Manually created labels that are in line with RT1 shall be added. In conjunction with the recorded sensor signals they describe lane change manoeuvres in detail and can be applied for extraction, data mining and further analysis.
RT5.3: Determine conformance and coherence of label data.
Labels are generated as part of the post-processing of NDS data. This task pursues to understand the robustness of the generated labels in terms of conformance. A comparison of the labelling by team members with that by a master labeller is proposed in order to determine the conformance. In terms of coherence it is also necessary to have an understanding about the reliability and consensus regarding lane changes that represent a threat to drivers. In the proposed control transition strategy a threat will lead to the issuing of a hard warning and a take-over request. This research task will investigate the coherence in perception between a normal lane change and a ‘threatening’ lane change and whether close cut-in lane changes can be distinguished by means of available sensor signals.

RT5.4: Determine to what extent surrounding lane changes are dominating the interruption of static flow in automated congestion driving.
This task will reveal the relevance of lane change occurrences in comparison to other events that are potentially due for a control transitions and associated warnings. With the data mining method it is possible to extract all events from NDS data that interrupt the static flow of a traffic jam drive. As comparison variable the time density of events is chosen. The proposed control strategy concentrates on surrounding lane changes as a predominant cause for warnings. This research task clarifies to what extent the concentration on lane changes is justified.

RT5.5: Provide a list of preferred indicators to be used as a starting point in the preliminary modelling process of a control transition strategy.
By these indicators the control transition strategy will need to distinguish lane changes of other road users in the surrounding environment. Statistical analysis shall be used to understand how indicators differentiate between manoeuvres accordingly.

5.2 Vehicle Equipment and Data Collection

The drive data that are used in this thesis derive from test drives in two passenger cars, with an initial prototype functionality of automated congestion driving. The two vehicles (type: Ford Focus and Smax) are elaborately described in detail by (Tröster 2012), especially the sensors and the measurement equipment for the setup of the test drives.

Figure 12 gives an impression of the vehicle equipment in the trunk compartment. It comprises a car PC with MS operation system, a dSpace autobox backed-up with energy from a supplementary battery mounted in the trunk, as well as CAN gateways (x-bus simulator, AGOSTEC) and break-out boxes. Monitors of the car PCs are mounted nearby the passenger front seat displaying software tools from companies Vector and dSpace. The front camera is supplied by MobilEye, a radar system from Delphi, ultrasonic sensors from Valeo and a Lidar system from Continental.
Figure 12: Test equipment of a TJA vehicle

The test drives were conducted in autumn 2012 in several places in Europe. In sum there is data of approximately 30 hours of traffic jam driving available. The definition of a traffic jam in the context of recorded data is aligned to the vehicle speed. Generally the data logging was paused when the TJA vehicle exceeded a speed of 50 kph. While a TJA car was in follow mode on the motorway and the leading vehicle drove faster than 50 kph the TJA drive was considered to be interrupted per definition. Table 6 provides an overview of the gathered records in the different cities. Obviously the city of Paris has facilitated the recording of the comparably highest data volume.

<table>
<thead>
<tr>
<th></th>
<th>Stuttgart</th>
<th>Bruxelles</th>
<th>Paris</th>
<th>London</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60,6 km</td>
<td>137,8 km</td>
<td>103,8 km</td>
<td></td>
<td>302,2 km</td>
</tr>
<tr>
<td></td>
<td></td>
<td>79,1 km</td>
<td>102,6 km</td>
<td>76,3 km</td>
<td>258,0 km</td>
</tr>
</tbody>
</table>

Table 6: Drive data collection in European cities summed up to ca. 30 hours and 560 km

The instructions for the driver was to search a traffic jam e.g. by radio traffic announcements and find a way to append to the end of the congestion. Most of the records were taken during the morning and evening periods when lots of traffic jams occur due to the rush hour. The vehicle teams were built by a driver and a measurement engineer who supervised the equipment to start and stop the data recording.

The data records consist of vehicle CAN and video data. Both data types were combined and referenced to a common time scale as they were logged simultaneously. The CAN channels contain vehicle and environment sensing signals; most relevant are ego vehicle speed and steering wheel angle, distances to the leading car and some vehicles on neighbouring lanes and lane width information. Two cameras were used, one internal camera with audio trace (to record driver comments) and one external camera representing the driver’s frontal view through the windscreen.
At the start of a test the drivers selected a lane of the traffic jam, they switched the vehicle to automated driving mode and stayed in the lane with this mode as long as possible. The data records were divided into time portions of 5 minutes of traffic jam driving in order to provide single data files a manageable size. These portions were placed into a folder structure in order to identify the vehicle, the city, the dedicated traffic jam and time and date of recording.

**Characteristics of data records**

Generally for driving records a distinction is made between data of Naturalistic Driving Studies (NDS) and data of a Field Operational Tests (FOT). NDS data are collected when the drivers are left in their naturalistic environment with ordinary day regular driving. (Lietz, et al. 2011) describes the essence of the NDS characteristics to be very close to reality – in contrast to investigations from laboratories that are manipulated by instructions or do have some artificial constraints. NDS serve sometimes to compare different trial conditions or different trial groups like drivers from various geographic regions. On the other hand FOT data are generated when the drives are influenced by testing new driving features and functionality in relation to information and communication technology. This definition and the characteristics of a FOT process are well documented, e.g. in the Euro FOT project (Etemad 2012).

With these definitions there is an ambiguity about the used data in this thesis whether it deals with NDS or FOT data: On the one hand it comprises a novel driving automation technology that is introduced on public roads, i.e. the prototype vehicles maintained an initial version of automated congestion driving. The activation of TJA made the data collection independent from different driving styles of individual test drivers and also unambiguous between the two vehicles in use. The distance control of in the applied version of TJA was subjectively rated by the test drivers as defensive, i.e. that they perceived the distance as large. It was argued amongst the test drivers that a later version of automated congestion driving with an optimized parameterization for distance keeping might lead to a slightly modified behavior of the surrounding traffic. The argument is considered valid and it unveils a weakness of the recorded data that shall be taken into account for the evaluation of results. For example one can assume that the number of threatening lane change will either raise or drop down if the distance keeping algorithm is adjusted in a way to support a smaller distance to the leading vehicle.

However, all other traffic participants on the motorways performed their usual and common drive style as every day. The characteristics of a lane change manoeuvre that allow the differentiation between normal lane changes and ‘threatening’ lane changes are expected to be largely unaffected. The natural behavior of surrounding road users gives this data collection the gloss of NDS data. The research paradigm in this thesis treats the acquired driving data in the sense of a naturalistic driving study and section 5.5 explains known methods to process NDS data.
5.3 Lane change prediction and indicators

This subsection serves to find references to lane change research in the literature that addresses driving behaviour and drivers’ motivations in traffic jams and possible indicators for lane changes.

A topical issue in the human driving behaviour is the influence of phone and internet connectivity in vehicles. (Angell, et al. 2006) published a workload study of drivers in different environments, amongst others on interstate highways. Depending on the workload type they measured unintentional lane departures of participants. (TextingThumbBands 2013) reported about the fact that novice drivers (18-20 years old) are highly attempted to text and drive. And even 27% of adults admit to send or read text messages while driving. This has a severe influence on situation awareness and traffic safety; so (Wilson and Stimpson 2010) concluded that 16,000 drivers were killed in the U.S.A. by handset use between 2001 and 2007. These facts are mentioned to sensitize the understanding of surrounding traffic: Actions of road users might be hard to predict and to understand because some drivers are highly distracted from their primary driving task. One possible consequence in a traffic jam can be that vehicles are drifting out of their lane without realizing it in an early stage.

In context however the research is directed onto human behaviour in order to understand, anticipate and predict the lane change manoeuvres with a connection to the outside driving environment as well as human tactics. Unintended lane change behaviour as described above could potentially influence the control transition strategy by issuing a false positive warning based on an interrupted lane change manoeuvre. A summary of lane change motivation is given in Table 7.

<table>
<thead>
<tr>
<th>Approaching lane change</th>
<th>Navigation lane change</th>
<th>Cooperative lane change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speediness lane change</td>
<td>Emergency lane change</td>
<td>Unmotivated lane change</td>
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</tbody>
</table>

Table 7: Categories of lane change motivation in traffic jams

- An approaching lane change happens if e.g. a leading car decelerates to standstill and the following car wants to go around this obstacle to continue the drive on the other lane.
- A navigation lane change is associated with the intention of the driver to prepare himself for an exit ramp or the correct lane in an intersection area, indicated by the traffic guide systems above the lane.
- A cooperative lane change appears if the driver sees another road user on the neighbour lane who needs a lane change e.g. for navigation to the correct lane that indicates his direction. Without jeopardizing his own navigation plans he cooperates and give him the gap that he needs.
- A speediness lane change happens if the driver sees that the neighbour lane maintains a higher speed than his own lane that forces low speed or even standstill. The driver waits for the next gap in the neighbour lane queue that he can fill in at no or low risk. The danger exists that he annoys the other driver who has to decelerate his car in order to let the lane changer come up to the new lane’s speed.
Naturalistic Driving Study and Data Analysis

- An emergency lane change occurs if an emergency vehicle comes from behind with flashing lights and siren that the driver wants to give way.
- The unmotivated lane change is present in case that none of the before mentioned motivations can be identified. Some drivers make use of this just because they want to overcome the monotonous and boring situation in a long lasting congestion drive (Angell, et al. 2006).

A small thought experiment can be conducted with respect to the research objective to identify the earliest point in time to feed the control transition strategy with a changing traffic scenario: If it was possible to read the mind of drivers in surrounding traffic then a relevant driving situation could directly be connected to a control transition. Figure 13 picks up this idea and sketches a complex traffic situation with thought bubbles. The ego vehicle is running in automated driving mode and the driver overviews the intentions of the other traffic participants. Now he could be supported by a control transition in order to take over full control of the vehicle for an interim period. In the sense of cooperative driving he would slow down, notably because vehicle 5 is going to perform a close cut-in manoeuvre. This unrealistic thought experiment leads today to real automotive research known as vehicle to vehicle (V2V) technology. One idea is to let the surrounding vehicles know about a lane-change intention when hitting the turn indicator switch or by steering angles that let the car drift out of the lane. (Azimi, et al. 2011) reported about V2V to make vehicles safely navigating at intersections. This is potentially applicable for TJA use cases on motorways. V2V is a direct way to predict lane change manoeuvres. It was not available for the work presented in this thesis.

Figure 13: Imaginary scenario and thought bubbles in a traffic congestion
Lane Change Prediction Methods

The work of (J. Freyer 2008) has relevance in respect to lane change prediction because he investigates methods for the lane change prediction in a field operational test FOT on highways at speeds at 90 to 150 kph. The objective of his research is an improvement of an ACC system including a support of lane changes during the ACC ride. He observes the lane change behaviour of the ACC driver who intends to keep his target speed and therefore wants to change lane in appropriate situations. (Harms and Tönross 2004) explained that drivers who perform a lane change manoeuvre reprioritize for a moment their objectives: They keep a target speed in lieu of keeping a target distance. The on-hand thesis, however, concentrates on lane change behaviour on motorways at lower speeds which are in the nature of traffic jams at 0 to 50 kph. Another crucial difference is that the lane change behaviour of surrounding vehicles is studied and not lane changes by the ego-vehicles. This is in line with a TJA system as defined by (Schaller, Gradenegger and Schiehlen 2008): there is no scope and no intention to change lanes automatically. TJA is supposed to keep a specified target distance and to adjust the speed always to the leading vehicle. In spite of these differences (J. Freyer 2008) can be considered as an eligible study in terms of lane change investigations. It declares several items as being relevant indicators for lane changes:

**Turn signal flasher**

Before a lane change can be started the driver shall announce this by activating the turn indicator lights. This rule is anchored in the traffic regulation laws, e.g. in Germany in (StVO kein Datum) and conforms with: “The cut-out for overtaking and the according cut-in have to be signalized clearly and in time; for this the turn indicator lights have to be used.” (Stengl 2007) found in a study in Germany that one third of drivers who perform a lane changer manoeuvre do not use the turn indicator as required. The data material of this work has an opportunity to compare the percentage with the lane change discipline in other European countries. In contrast to that figure Freyer found in test drives that he researched a turn indicator usage of 92 % and stated this to be an artificially high percentage because the test drives were conducted under the supervision of a test engineer at the passenger seat. The effect deals with an unintentional and unconscious high attentiveness of the participants during the drive, similar to a test situation with the presence of an examiner. Freyer came to the conclusion that the turn indicator flasher signal can be used to predict a lane change 1,5 seconds prior to the line crossing in those cases where the turn flashers are applied.

**Lateral velocity**

(Sporrer, et al. 1998) found that the lateral speed signal reveals a characteristic signal shape for lane changes. Freyer’s experiments revealed that during lane changes at motorway speed a minimum lateral velocity of \( v_{lat} = 0,3 \text{ m/s} \) differs from normal oscillation within the drive lane and can be associated with an intention for a lane change. In the according investigations this value was reached at 1,5 seconds prior to the line crossing, many of the test drives reached 0,6 m/s at the point in time of the line crossing itself.

**Time to Line Crossing**

Indicator TLC defines the time to line crossing as time that the vehicle will need with an unchanged driving situation to reach the lane marking. TLC depends on the distance to line crossing (DLC) and is defined as \( TLC = DLC/v_{lat} \). TLC as an indicator for a lane change intention stabilises in results of (J. Freyer 2008) at a value of 1 second before the lane change itself.
In the context of high speed motorway driving Freyer came to the conclusion that with these indicators a prediction of the ego-driver’s lane change can be made in the area of 1,5 seconds prior to the line crossing. Table 8 shows a summary of his findings. It has to be noted that all indicators are measured with on-board sensor systems of the lane-changing vehicle. Again it is recognized that V2V technology would be an enabler to transfer this information to all other affected road users.

In contrast the indicators are not available with NDS data that delivers only on-board measurements of the TJA vehicle. As a conclusion the proposed indicators cannot be used in this thesis but can be recommended for future research because it enhances the research of lane change indicators.
5.4 Classification of relevant traffic categories

The previous section revealed that earlier research of lane change behaviour does not support the identification of indicators as needed in this study. An identification and early detection of lane changes is a declared research objective and needs to be followed up by means of the naturalistic driving data. For this purpose the driving team reviewed the NDS data base with examples of dynamic events which resulted in the following classification of relevant scenarios according to research task RT5.1. The described manoeuvres are always observed from the ego vehicle (TJA vehicle) with a view on the surrounding traffic. For TJA functionality to be activated and executed, the ego vehicle always has to identify a primary object (PO), i.e. a leading vehicle in the ego vehicle lane. This PO is continuously tracked by the sensor systems in the TJA ego vehicle.

Normal cut-in manoeuvre

For normal cut-in scenarios the TJA vehicle identifies a PO and in addition on the neighbour lane a most relevant vehicle as Secondary Object, called SO. This secondary object is important because it is going to change its lane position; hence it performs a cut-in into the ego lane of the TJA vehicle and becomes the next primary object. This is subdivided in several time phases: The first phase is a “potential” cut-in and is related to a secondary object movement toward the line marking. This can be connected in some cases with flashing indicator lights. The second phase, called “in progress”, starts when a wheel of the secondary object crosses the line marking and ends when it overlaps the forward looking path of the ego vehicle. At this point in time it becomes the primary object. This again represents the start of the third phase, named “lane change completion” which ends when the other side of the object leaves the line marking and it is fully in lane. The manoeuvre is sketched in Figure 14 which is also applicable for related close cut-in manoeuvres.

Close cut-in

Close cut-in manoeuvres are a special form of cut-ins because the distance from host to target vehicle is felt subjectively by human perception as very tight and as a possible threat. The sequence of three phases is identical to normal cut-ins as sketched in Figure 14. However, phase1 does not always exist because in some cases the SO comes into the driver’s view when the line marking is crossed already. It deals with very tight manoeuvres that happen mostly at low vehicle speeds. In these instances the cut-in starts with phase2, as soon as the vehicle is in the field of view of the driver.

Figure 14: Three phases of a cut in manoeuvre
Multiple cut-in

*Figure 15* shows a multiple cut-in scenario. This scenario starts always with a single cut-in as explained above. Meanwhile a second or even third object performs another cut-in. The definition of the transition from a secondary to a primary object depends on the distance of the object to the ego vehicle. The primary object is always to be defined as the closest in the path and it has to be a single object. Multiple cut-in situations like this appear relatively rarely and they are treated identically to conventional cut-ins in this work because a differentiation means no added value for the control transition strategy. So far cut-ins shall be distinguished whether they are normal (conventional) or close-cut-ins.

Cut-out manoeuvre

The cut-out manoeuvre represented in *Figure 16* has a three-phase partitioning that is similar to the cut-in situation as described above. It starts with an identification of a “potential cut-out” that is recognized by an initial movement of the primary object PO towards the lane markings. The phase finishes when a wheel crosses the left or right line of the lane. The second phase is called “Lane Cut-out in Progress” and lasts until the PO gets out of the path and loses its status as a PO. Consequently the third phase is opened and it ends when the past primary object is fully out of the lane. The easier handling of the cut-out manoeuvre in comparison to the cut-in manoeuvre results from the early and unambiguous identification of the relevant vehicle, the PO.

The presented manoeuvres described in this section are to be considered for data analysis and research of lane change indicators according to research task RT5.2. Optionally the list could contain emergency situations in a cut-out manoeuvre, e.g. a leading vehicle that performs a sudden cut-out and unveils a still-standing vehicle in front. However, analysis of the 30 hours of NDS data revealed that such an emergency situation has not been recorded. To capture only one of these emergency manoeuvres within a naturalistic study a much larger amount of traffic hours likely has to be recorded. Consequently critical manoeuvres that come out of a cut-out lane change scenario exists but cannot be treated in this study.
5.5 Post-processing, Video Labelling

After exemplary inspection of the recorded drive data and the classification of manoeuvres the analysis team came to the conclusion that available sensor data (mainly velocity and range signals) will not be sufficient to describe the lane change scenarios to a level that is required for the intended research tasks. The resolution of a lane change manoeuvre as referenced in the prior sections cannot be achieved: e.g. the identification of primary and secondary objects is not feasible with a three-phase partitioning and the according timing. For the present time this can only be achieved by observing and coding the appendant video data and by assigning labels and time-stamps to the phases, which is in line with research task RT5.2.

In naturalistic driving studies sensor data and observation data are usually mixed. The latter are generated by post-processing. NDS methodology seemed to be well applicable to the research objectives and therefore it was decided to start a resource-intensive manual labelling work to support the NDS method.

Technique of naturalistic driving studies (NDS)

According to (Lietz, et al. 2011), within NDS studies additional observation data are generated with post-processing methods. Visualization and coding tools are required and there is a need for a trained evaluation team. A fixed set of rules has to be applied by this team to write down the observations. It is indicated that such a method requires resources and is quite time-consuming because of a high amount of manual work.

In the present application case the method to label video data consisted of the following steps:

1. Define structure and rules for labeling/coding.
2. Educate the coders
3. Measure coders’ performance

For the first step it was crucial to be as precise as possible to avoid misunderstandings and misinterpretations of the rules in order to achieve a consistent labelling throughout the labelling team. Therefore a training session with all involved team members was conducted and exemplary some coding work was discussed until a common sense was generated. The third step focussed on rating the correlation amongst the observers in the team. This so-called “Inter-rater reliability” deals with the objectivity of the generated label and coding work. In some NDS the correlation is calculated between a “coder” and a “master coder” who is considered to be the reference to all other coders from the team. This was applied in the so-called 100-Car study of (Dingus, et al. 2002). In this study the rating for correlation of objectivity was measured with Cohen’s kappa $\kappa = 0.65$ in an interval from $[0..1]$ which is graded as acceptable correlation of coders and master coder due to (Grewe and Wentura 1997).

To set a target for the level of inter-rater reliability, other studies applying video coding techniques were consulted. (Stutts, et al. 2003) reported about an agreement of 65-70% (number of matches / total number matches plus errors) in their team after training. This was rated as mediocre correlation and explained by the subjective nature of labels that were defined. In their case they created a label for the dawn that got attributes from light to grey. The perception of brightness might be subjective and will be different for the individual labeler even with the existence of rules to objectify the
assessment.  
It is an ambitious but fair and realistic target setting to postulate that in this thesis a label conformance should therefore be above 65%.  
The inter-rater reliability due to (Stutts, et al. 2003) shall be applied to the video-coding process in this work in order to judge the success of labelling efforts. It is aimed for proving a high reliability level of the manually and subjectively created coding data.  

Data labelling by human observation  
A group of twelve engineers was formed with the task to review the NDS material and assign relevant labels to the traffic jam manoeuvres. A set of rules was defined by the team to ensure the subjective labelling work for each individual team member to be as precise as possible. By applying the process instructions a new set of label signals was generated to complement the set of NDS sensor data.

Figure 17: Result of labelling 5 minutes of traffic jam  

*Figure 17* shows one resulting example of the labelling work which was handled in time portions of five minutes of driving. The timeline is represented in the lower area with different bars. These illustrate the manual coding work of the labelling team. The small cursor line at the end of the time scale pinpoints the current situation as a traffic snapshot. It showcases a follow manoeuvre of a passenger car while a cut-in of another passenger car happens that has used its left turn indicator beforehand. The three phases of lane change events have different shaded bars. The current cut-in manoeuvre is in its progress phase (phase 2).  
The line of cut-ins counts five events, the first three display a beginning cut-in with only a phase 1 label. The PO_Type bar represents the label of primary objects. It indicates that passenger cars have been leading vehicles during the complete time. It is noted that motorbikes can also be referenced as PO or SO. Further important labels are the turn indicator signals of primary and secondary objects. With the EH label the neighbour lane is marked in the current situation as an on-ramp to the motorway.
Lane change labels

An according representation of lane change manoeuvre signals that derive from the labelling is shown in Figure 18: the phase values have been assigned to a typical cut-in situation. This is one possible sequence of phases in a lane change manoeuvre. (Other options are listed in section 6.4, Table 14: Sequences for lane change manoeuvres and lane change indices. The turn indicator is not applied by all drivers for a lane change, as indicated with lane change index d.) Also, a cut-in is normally started with phase 1, however, it sometimes happens that the driver has changed his mind and returns into the original lane. This is an interrupted lane change that has an effect to the control transition strategy in terms of false positive warnings.

![Figure 18: Phases of a cut-in manoeuvre with turn indication, (Tröster 2012)]

Rules for the labelling work are explained exemplarily for cut-in manoeuvres: Table 9 gives precise instructions in at which point in time the label with its values, called sub-labels, shall be set. The instructions of label setting for three lane change phases and the turn indication are in line with Figure 18.

On-ramps and exit ramps

Occurrences of on-ramps and exits on motorways are visually recognizable by human observation. Technically there are also traceable by satellite and map based technologies, e.g. GPS. In literature, e.g. (Bechtolsheim and Dorum 2002), the technology is referenced as electronic horizon (EH) technology. This technology was not available on-board of the prototype vehicles at the time when the NDS was conducted. Therefore the labelling rules apply here with a precise definition of the start and the end-points. E.g. an exit ramp starts at the first point of lane separation at the edge of the video frame; it stops at the point that is no longer possible for a driver to enter the exit ramp. The reasoning for these labels is associated with an upcoming research question. Like in aviation (see chapter 3.5) the automated ride can potentially be switched-off in certain sections. The area of ramps on motorways is specifically being considered for this exemption.
<table>
<thead>
<tr>
<th>Cut-In label</th>
<th>Sub-label</th>
<th>Instructions</th>
</tr>
</thead>
</table>
| SO Turn Indicator (Phase0) | left or right blinking | Visual indication of SO turn indicator  
*Label ends, when Cut-In is completed (vehicle fully in lane) OR Turn Indicator is switched off* |
| Hazard Lights blinking | | Visual indication of SO hazard lights |
| Cut-In | Potential Cut-In (Phase1) | Potential Cut-In identified, based on SO movement e.g. yaw angle, distance to line, lateral speed, other traffic behaviour (the traffic situation allows cut-in) |
| | Lane Cut-In in Progress (Phase2) | Label starts, when SO outer front wheel (inner side), crosses line marking. SO becomes PO directly after that point. |
| | Cut-In completed (Phase3) | Label starts, when new PO outer front wheel (inner side) comes in predicted path. (first point where you would collide with Cut-In vehicle)  
*Label ends, when Cut-In is completed (vehicle fully in lane)* |

Table 9: Rules for setting labels of a cut-in manoeuvre

**Object type labels**

In the labelling process a distinction is made between object types, i.e. primary and secondary object (PO and SO type) in order to understand potentially different traffic jam behaviour of different vehicle types. Furthermore three main road vehicles were differentiated:

1. Passenger cars  
2. Trucks  
3. Motorbikes

From the ordinary day experience one knows that motorbike drivers behave differently in traffic jams, e.g. they drive on the line markings without the intention to change lanes. Therefore they need a special treatment in the data analysis, see section 5.8.

**Lane and line labels, end of traffic jam**

A standard lane width on motorways in Europe differs from country to country but is usually on average 3 meters. As soon as this width diverts significantly a lane irregularity is identified, e.g. at construction sites the lane width can sometimes shrinks to 2 meters. An identification of a wide lane of e.g. more than 4 meters applies accordingly. A lane’s end means in most cases that the vehicle has to execute a cut-in manoeuvre to the neighbour lane. A similar notification exists if the neighbour lane merges into the host lane, often applicable at on-ramps.
The line marking on the right and left side of the lane should be recognisable for human cognition alike for cameras with image processing capabilities. They serve as borders for the lane, independent whether they are solid or dashed, thin or bold. If either the right or the left line or even both disappear this is identified as a line irregularity. All of the mentioned irregularities of lanes and lines can affect the automated congestion driving functionality and are therefore labelled.

The label “end of traffic jam” is assigned when the speed of the TJA vehicle exceeds 50 kph or the congestion disappeared. These labels serve to understand the percentile occurrences in comparison to lane change events on behalf of research task RT5.4.

Labelling process iterations

*Figure 19* illustrates the applied process for data labelling by means of a flow chart. The process had been described by (Tröster 2012). The left side of the flow chart shows the iterative labelling process that led to the data basis including label signals for the complete NDS. The work load of labelling traffic jam data was divided equally amongst a team of twelve engineers. Depending on the experience of the individual engineer and the nature of traffic jams the labelling of a five minute video was estimated to require on average 30 minutes of manual processing. Each engineer was assigned a defined work book of data files. The team itself developed and refined the labelling rules in a democratic way. Detailed questions were discussed and agreed and finally each individual of the team committed to the set of rules.

During the period the team members worked on their individual labelling package, the team came together at intervals to compare notes and - as a result - to extend the definition of rules and add comments for clarifications of ambiguities in which the rules were not applicable or even misleading.

![Figure 19: Initial Process of labelling and comparing NDS data](image-url)
5.6 Conformance of manual labels

To ensure the quality of the labelling data, the conformance and coherence of the labelling data was analysed as outlined in the introduction with research task RT5.3.

For the analysis of data labelling quality, a master labeller was added to the team. The master labeller joined the team as an experienced analyst of NDS data and has been educated with the same labelling rules without being assigned a portion of the team’s workload. In the process he is represented in the right branch of Figure 19. The master labeller serves as a unique reference to all individual team members. It does not mean that he is an error-free provider of labels. However, he can be referenced as one reproducible source of labels with a constant mind-set.

The data that is due to comparison is randomly chosen from the NDS. The amount of compared data from every team member is equally set to five minutes as indicated in Figure 17. In this way the work of the master serves as a reference to the labelling team as a group and not to the individual labeller.

As indicated in the beginning of this section, a minimal coherence of the team in label data of 65% is pursuit in line with (Stutts, et al. 2003) in order for the data labelling to be used in further research.

Comparing the lane change labels

*Figure 20* shows exemplarily one result out of twelve comparison studies. On the X-axis there is a time line of five minutes (3000 sec) of TJA recorded traffic data. On the Y-axis the comparison of eight pairs of labels is presented, starting with the cut-in label at the bottom. The grey signals were generated by the original team member while the black signals are created by the master labeller. The comparison of all cut-in situations confirms that six instances have been commonly identified by the team labeller and the master labeller. Therefore the quantitative measure for identification of cut-in manoeuvres lies at 100% for this portion of the analysis. An example of a mismatch is visible with the identification of close cut-ins: four are found with the labeller and only three with the master which results in a conformance of 75%.

![Figure 20: Example of label comparison between coder (dashed) and master (solid)](image-url)
The single phases of the cut-in manoeuvre, however, are assigned at slightly different time stamps. These time differences serve as a measure of timing quality for the comparison of cut-in labels.

In the further process a comparison of the generated labels in line Figure 20 is applied to the selection of twelve TJA records coded by the individual coders. A comparison of conformance of identified events (quantitative) as well as of conformance of timings (qualitative) is pursued in the following analysis. Exemplarily the quantity of cut-in records is counted at the coder and the master labeller. In Table 10 it leads to a result of 100% conformance because the overall identification of 37 cut-in labels with each 3 sublabels is identical at both.

However, the timely order of three-phase cut-in process was mixed in some cases. This affects the quality of the labels that is measured with the time difference between the master and the coder. The left plot of Figure 21 represents the qualitative conformance of cut-in labels of 148 according time stamps (4 per each event). One recognizes that there are some extreme values that show a quality difference of the master to the labeller in a range from 2 to 18 seconds for the start as well as for the end of a label tag.

These extreme time outliers have been investigated and the following causes are found:

- The traffic jam was in standstill on all lanes. The coder has discovered a movement of the front wheels of a vehicle that intends to cut-in. The master labeller has tagged the potential cut-in much later when the traffic jam came out of the standstill situation. In worst case this was 18 seconds of time difference.
- The congestion moves at very low speeds (\(<\ 5\ \text{kph}\)) on all lanes. Some cutting-in vehicles drive a long time on the line marking before they make a clear turn into the new lane. So the tags for cut-in labels differ from 2 to 10 seconds from the master to the coder.
- The loss of line markings is another effect that leads to timing mismatches of labels. When the line marking is no longer visible in the video, the human perception tries to continue an imaginary line to maintain the lane borders. Even if the tag for a potential cut-in does not differ significantly in the comparison it happens that the tags for “cut-in in progress” and “cut-in completion” are interpreted differently between the master the coder. This aggravates at very low speed to extreme time differences above 12 seconds.

The analysis of timing conformance due to RT3 aims at the development of timely warnings within the control transition strategy. In traffic jam scenarios at standstill or very low speeds of the TJA vehicle the timing aspect of the control transition strategy moves to the background because there might be no criticality or even no interest in these events. In this context it deems feasible to exclude the extreme outlier values with more than 2 seconds difference from the further analysis which were explained with the above effects.
Exclusion means in this case that they shall not be accounted for the qualitative comparison analysis. The comparison is based on values without extreme outliers as presented in the right boxplot of Figure 21. The same handling was applied to cut-out manoeuvres. Conformance values are presented in Table 10 as percentages of inter-rater reliability.

Table 10 shows the main categories of labels. The 2nd and 3rd column present the amount of labels rated by the master and by the coders. The 4th column represents the conformance in quantitative and qualitative format. The conformance ratio (in %) is built with the maximum number of events in the denominator, independent from the originator - master or labeller.

The quantity targets for the labelling work which were set at 65 % are nearly achieved in all areas with the exception of the close-cut-in labels with only 58 %. (Side note: the calculated ratio results from 12 events that were rated overall as close cut-ins but only 7 events are rated in common.) As this label has a tendency towards subjective perception, it needs special treatment in the on-going work.

Also labels for on-ramps and exits roads leave room to improve the conformance score of 71 %. Further analysis revealed that the master labeller has proven a superior performance because he identified correctly all on-ramps and exits in the videos that he had to work on. A probable root cause for this could be that he had a lower work-load than the coders. The workload per coder should therefore be monitored closely in future work.

The quality of labels was not set as an upfront target. Literature does not report about such a measure. The qualitative measurement of time tags is shown with mean values and standard deviation. Standard deviation rises up to ca. 800 milliseconds in some cases. This has implications for the timing of warnings in the control transition strategy if it is intended to base them on the recognition of lane change phases. It means for the robustness of timely warnings that this level of time variation has to be tolerated.
<table>
<thead>
<tr>
<th>Event</th>
<th># Labels master</th>
<th># Labels coder</th>
<th>Conformance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean value</td>
</tr>
<tr>
<td>Cut-in</td>
<td>37</td>
<td>37</td>
<td>100%</td>
</tr>
<tr>
<td>Close Cut-in</td>
<td>8</td>
<td>11</td>
<td>58%</td>
</tr>
<tr>
<td>Turn indication</td>
<td>27</td>
<td>27</td>
<td>100%</td>
</tr>
<tr>
<td>Cut-out</td>
<td>14</td>
<td>14</td>
<td>100%</td>
</tr>
<tr>
<td>Turn indication</td>
<td>14</td>
<td>14</td>
<td>100%</td>
</tr>
<tr>
<td>Secondary Object</td>
<td>65</td>
<td>60</td>
<td>92%</td>
</tr>
<tr>
<td>Passenger car</td>
<td>29</td>
<td>27</td>
<td>93%</td>
</tr>
<tr>
<td>Motorbike</td>
<td>31</td>
<td>28</td>
<td>90%</td>
</tr>
<tr>
<td>Truck</td>
<td>5</td>
<td>5</td>
<td>100%</td>
</tr>
<tr>
<td>Primary Object</td>
<td>14</td>
<td>14</td>
<td>100%</td>
</tr>
<tr>
<td>Passenger car</td>
<td>12</td>
<td>12</td>
<td>100%</td>
</tr>
<tr>
<td>Motorbike</td>
<td>1</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Truck</td>
<td>1</td>
<td>1</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Table 10: Quantitative and qualitative label conformance (inter-rater reliability)

**How to improve conformance of label data?**

Regarding the resources of the labelling process this work can be called labour- and time-intensive. With the new experiences one can recommend the following improvements for labelling work in future with the target to achieve higher conformance values than in the on-hand study. The
The proposed improved labelling process is visualized in Figure 22 and recommended for future work on related video coding tasks.

The main differences to the applied process are that the team should set clear and ambitious targets for quantitative and qualitative measures of label conformance and that an iterative process with several loops has to be anticipated upfront in order to achieve the desired targets.

5.7 Coherence of close cut-in labels

It is crucial for the control transition strategy to confine and differentiate the characteristics of normal cut-ins from those of close cut-in manoeuvres. Unfortunately the previous section revealed that the conformance of close cut-in label identification does not fulfil the target of exceeding 65%. This mismatch of individual team members with the master labeller is very clear and has to be explained with some more detailed information on the labelling process: The team members stated that in several cases the decision to label a close cut-in manoeuvre was difficult. If another member
defended a labelling decision with good arguments he could convince the team of his choice. The perception of a threat with cutting-in manoeuvres was subjectively rated by each individual labeller. For enhanced objectivity it could have been stabilized in a team decision. Time and resource-wise this was not possible.

(J. Freyer 2008) reports in his study about close cut-ins of ACC test drives: A professional driver rated close cut-ins as critical manoeuvre scenarios for the test participants. The participants however rated these close cut-ins differently. In contrast to the professional driver a surprising low percentage of only 28% felt a threat. It underpins that there is possibly a weak point of close cut-in labels in the NDS data and a dedicated investigation on the coherence of close cut-in labels with subjective sensor data is to be considered.

For the development of the control transition strategy it is intended to make use of close cut-in labels from the NDS data records because they are closely linked to perception of a threat by drivers of a TJA vehicle. A threatening manoeuvre however is assigned to a hard transition as explained in Table 4 of chapter 3. In this view the importance becomes clear to separate close cut-in labels from the remaining control transition strategy that is concentrating on soft transitions. In order to justify and confirm the further use of close cut-in labels as identified in the manual data labelling process, a distinction between normal and close cut-in manoeuvres is sought by referencing objective sensor data. For understanding the level of label objectivity a unique coherent connection of close cut-in labels and related sensor signal is researched.

<table>
<thead>
<tr>
<th>Normal cut-ins</th>
<th>Close cut-ins</th>
<th>Cut-outs</th>
</tr>
</thead>
<tbody>
<tr>
<td>470</td>
<td>108</td>
<td>317</td>
</tr>
<tr>
<td>All cut-ins</td>
<td>All lane changes</td>
<td></td>
</tr>
<tr>
<td>578</td>
<td>895</td>
<td></td>
</tr>
</tbody>
</table>

Table 11: Number of lane changes in recorded data

Table 11 declares the total numbers of labels of completed lane changes that have been identified by the twelve members of the labelling team in all cities, showing 18.6% of cut-ins are rated as close cut-ins and they cover 12.5% of all lane changes. The numbers are extracted in a data mining process that only considers lane changes that are completed, i.e. the sub-label of phase3 is assigned to the manoeuvres.

With Table 12 the following hypotheses for characterization of close cut-in labels are under investigation. They are generated with the knowledge of the labelling team and test driver team. The labelling rules for close cut-ins formulate that a threat is perceived. The team members who have gained good experience with the subjective observation of cut-in manoeuvres tried to translate this into technical signals that are measureable by sensors:

<table>
<thead>
<tr>
<th>A differentiator for close cut-in labels in comparison to normal cut-in labels is</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. a lower threshold of minimum range to a cutting-in vehicle during the course of the manoeuvre, measured with near field sensors</td>
</tr>
<tr>
<td>2. a lower PO range value (measured with primary sensors) at the end of a cut-in</td>
</tr>
<tr>
<td>3. a higher time headway THW</td>
</tr>
<tr>
<td>4. a lower TTC (time-to-collision) measured with primary sensors</td>
</tr>
</tbody>
</table>

Table 12 : Hypotheses to distinguish close cut-in labels
Remembering the research objective to design a control transition strategy as a support tool for automated vehicle driving it will be advantageous to concentrate on the investigation of technical signals that can directly be used in a real-time calculation without post-processing methods. However, for the research task in this section to identify first indicators for the strategy the labels represent are preferred signal format because they are easy to handle in a subsequent modelling and experimental work. Later-on the connection of label and sensor signals is resumed in the discussion.

Moreover, the use of sensor data is crucial in this context. The radar and camera system are so-called primary sensors, they are supposed to detect the entire frontal environment of the TJA vehicle. The used primary sensors had a weakness in measuring the near-field range of because of blind spots in this area. Therefore the distance measurement is supplemented by the frontal near field sensors, based on Lidar and ultrasonic technology (d < 12m, d < 5m). The near field sensors are presented in Figure 23 and serve to detect a close cut-in characteristic of a lane change manoeuvre by neighbouring vehicles. The lateral ultrasonic sensors as of Figure 5 are disregarded in the measurements in order to avoid conflicting sensing with situations from narrow lanes and construction sites.

In the TJA prototype vehicle the near field sensors did not influence the distance keeping algorithm but they are added to the measurement equipment in order to scan the closer environment at all times. For the near field value the minimum vehicle distance, represented in Figure 23, during phase 2 and phase 3 of the lane change manoeuvre is calculated. The data mining tool translates this into an algorithm for the data extraction:

\[
\text{Nearfield\_range} = \text{MIN(nearfield\ sensors)} @ \text{cut\_in (in\_progress, complete)}
\]

The other hypotheses in Table 12 are based on primary sensor signals: The signal 'PO range rate' represents the speed difference of the TJA vehicle and the PO vehicle; it is stabilized in the third phase of the cut-in event, namely “cut-in complete”. The measurements for cut-in manoeuvres with primary sensors are therefore taken at the end of this phase because now the sensors are aligned.
about the detection of the relevant PO. For the investigation with primary sensors these definitions apply:

\[
P_{\text{range}} = \text{range} @ \text{cut}_\text{in} \text{ (complete)}
\]

\[
P_{\text{range}}_\text{rate} = \text{relative speed (primary sensors) @ cut}_\text{in} \text{ (complete)}
\]

\[
THW = \frac{P_{\text{range}}}{\text{vehicle speed @ cut}_\text{in} \text{ (complete)}}
\]

\[
TTC = \frac{P_{\text{range}}}{P_{\text{range}}_\text{rate}}
\]

The following plots serve to investigate the hypotheses of Table 12 in order to distinguish normal and close cut-in manoeuvres:

Figure 24 illustrates the results for hypothesis 1 in a boxplot and individual value plot. One observes that the near field measurement is limited in exactness. A high sensor noise rate is perceivable for cut-in events. It is noticeable that there is an accumulation at 1200 cm in the normal cut-in data. The near field sensors come up against their measurement limits; in reality it represents a distance greater than 12 meters. Mann-Whitney U-testing (MWU) shows a significant difference in minimum distance between the TJA vehicle and the leading vehicle for close cut-ins and normal cut-ins (W = 24309 ; P = 0,000). This verifies hypothesis 1.
In contrast hypothesis 2 is built on primary sensor measurements. Also the primary sensor system in the prototype vehicle is not fully reliable with regards to the cutting-in vehicles; some values are generated while still using the previous objects rather than the most significant vehicle (PO) in front, so they are superposed by noise factors and represent higher distances than in reality because of failures with the correct object selection. The right part of Figure 25 shows a boxplot of the range of cut-in manoeuvres with median values of 24 and 17 m. Application of the MWU-Test shows a significant difference in range for close and normal cut-ins \((W = 22562; \ P = 0,000)\) and verifies hypothesis 2.

In addition the investigation of time headway THW due to hypothesis 3 is represented in the left part of Figure 26. Again the MWU testing states a significant difference \((W = 123977,0; \ P = 0,000)\) and supports the statement of hypothesis 3. For reference a plot of vehicle speed is also displayed in the figure because this signal is related to THW and range.

The analysis for hypothesis 4 is summarized in the right boxplot of Figure 26: It represents the time-to-collision measurement (TTC) without outliers. The medians show a difference in sign: -2,5 s for normal cut-ins and 0,5 s for close cut-ins. The positive TTC median value for close cut-ins indicates that the relative motion between the TJA vehicle and the cutting-in vehicle is a rapprochement: A vehicle performing a close cut-in decelerates strongly in order to avoid an accident with the leading car while the TJA vehicle maintains its velocity. The TTC values support the subjective impression of the test drivers and the labelling team: during close cut-in manoeuvres there is a tendency of a closing gap while normal cut-ins are more characterized by an opening gap, especially during the end of the manoeuvre; this is also characterized by the negative sign of the TTC median value for normal cut-ins.

In contrast to the subjective impressions, a MWU-Test shows a non-significant result for this statement \((W = 27232 ; \ P = 0,112)\). This result does not verify hypothesis 4.

---

**Figure 26: Boxplot - THW and TTC of normal and close cut-ins**

Overall, the range measurements with both sensors types, primary and secondary sensors, and the vehicle speed signal support hypotheses 1, 2 and 3. Herewith a significant distinction of close cut-in labels from normal cut-ins is proven. The subjective label work performed by human labellers is acknowledged by objective sensor measurements. This encourages making further use of close cut-in labels to specify these specific lane change manoeuvres and to include them as indicators into the future design of a control transition strategy.
5.8 Search for Lane Change Indicators

This section investigates lane change manoeuvres of surrounding vehicles in the neighbourhood of a TJA vehicle in order to support research task RT5.5: Indicators for the description of lane changes shall be derived from vehicle sensor signals combined with signals of the labelling work.

Two hypotheses about indicators for lane changes are based on the background experience of TJA test drivers: The first hypothesis deals with the ego speed of the TJA vehicle during lane change manoeuvres: TJA test drivers relate close cut-ins to low TJA speeds, normal cut-ins to medium speeds and cut-out manoeuvres to higher TJA speeds. The second hypothesis assumes increasing distances (Range to the primary object PO): short, medium and long ranges corresponding to close cut-ins, normal cut-ins and cut-outs.

The analysis of vehicle speed and object range signals show the following results: Figure 27 represents the boxplots of speed and range investigations. In the left diagram a one-way ANOVA test is conducted for the different speed distributions and a significant difference is found for the three types of lane changes (F = 20,04; P = 0,000). Mann-Whitney-U tests for each pair also revealed significant differences for all comparisons (W = 18794 ; P = 0,000 | W = 18699 ; P = 0,000 | W = 175400 ; P = 0,004). This result proves that the ego speed of the TJA vehicle can be used as one differentiator for lane change events. Surprisingly cut-out velocities are in average below normal cut-in speeds. A motivation for a cutting-out lane change manoeuvre can be that the driver perceives the speed as too low in comparison to neighbouring lane speeds.

The right boxplot of Figure 27 shows that normal cut-in ranges exceed cut-out ranges for the median and the average value. The Mann-Whitney-U test proves a significant difference (W = 182590 ; P = 0,000). From Figure 25 it is known that close cut-in ranges also differ significantly from normal cut-in ranges, hence it can be concluded that normal cut-ins are different to cut-outs and close cut-ins. Despite the fact that lane changes do happen at all TJA driving speeds (0 – 50 kph) and at a wide interval of ranges one recognizes that there are preferred ranges within these signals that can be used as potential indicators for lane change prediction. These indicators thereby form a potential input for the development of the control transition strategy.
Reflections about the density of lane changes

*Table 13* presents a further outcome of NDS data mining. With this extraction results it can be anticipated how lane change labels potentially influence a related control transition strategy. In a hypothetical consideration it is assessed how often the driver would be advised time-wise for collaboration if every lane change issues a warning on. This would happen if no specific control transition strategy existed. As a reminder it shall be noted that the development objectives of the control transition strategy are not linked to a quantity of warnings but to user centred design rules, see chapter 4. Moreover, the quantity reflections help to gain an understanding that not every manoeuvre will need a control transition.

A qualified measurable for the density of lane changes is connected to the time and not to mileage. Further on it is recommended to quantify the lane change density by time (counts per minute). If one assumes that all completed normal cut-in plus cut-out events generate a soft warning this would mean that in about 2 minutes (0,31 + 0,21) min⁻¹ there is a soft transition. Further a hard transition shall be connected with a close cut-in which would mean that a hard transition with hand-over scenario happens about every 14 minutes (0,07 min⁻¹). If a cut-in lane change was already announced with phase 1 it would nearly double the number of completed lane changes (1072 vs.578) which is mainly caused by motorbike drivers, predominantly occurring in Paris. These events were judged as irrelevant by the team and shall not be considered for the control transition strategy. The availability of vehicle type labels supported to filter out motor-bike events that only provide phase 1.

<table>
<thead>
<tr>
<th>Event</th>
<th>CITY</th>
<th>Brussels</th>
<th>London</th>
<th>Paris</th>
<th>Stuttgart</th>
<th>Overall</th>
</tr>
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<tbody>
<tr>
<td>All CUT-INS</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
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<td>108</td>
<td>829</td>
<td>19</td>
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<tr>
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<td>356</td>
<td>19</td>
<td>578</td>
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<td>77</td>
<td>74</td>
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<tr>
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<td>0.41</td>
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<td>0.81</td>
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<tr>
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<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
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<td>79</td>
<td>81</td>
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<tr>
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<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
</tr>
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<tr>
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<td>0.09</td>
<td>0.21</td>
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<tr>
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<td>0.35</td>
<td>0.42</td>
<td>0.36</td>
<td>0.45</td>
</tr>
</tbody>
</table>

*Table 13: Results of lane change labelling (discussed numbers in bold)*
With reference to research task RTS.4 the density of lane changes reveals a dominant value of 93.7% for lane change events that come into consideration for the control transition strategy in automated congestion driving. The density of other relevant traffic situations like e.g. “end of traffic jam”, “loss of lane markings” and “lane end” is at a 0.04 min\(^{-1}\) and represent 6.3 % of relevant events with the given data base. These values derive from the NDS and are influenced and determined by current sensor limits of the prototype system (lane recognition of the image processing system was at an interim level) and the tuning of maximum TJA velocity. This is set at 50 kph and could be considered at 60 kph in future applications. With evolving camera technologies and an enhanced TJA speed threshold it can be projected that the event dominance of lane changes come to the foreground with above 95%.

Regarding turn indicator labels a hypothesis is that turn flasher lights announce lane changes early and reliably. The labelling data however reveals a third of missing turn flasher lights as well as misleading turn-indicators which is fully in line with the findings of (Stengl 2007), see also chapter 5. Especially with cut-outs 43% of the used turn flasher lights are not related to a completed cut-out. The hypothesis is thereby falsified. Nonetheless, when considering the timing tags of lane changes in phase 1 to phase 3 the turn-indicator labels will be supportive and are therefore added to the list of recommended indicators.

Another hypothesis that was tested is that the density level of lane changes increases at certain motorway sections, namely next to on-ramps and exits. The NDS data confirms this: there is a tripling of cut-ins (0.33 to 0.96 min\(^{-1}\)) compared to regular motorway sections (in Table 13 named “non-ramps”). Hence the control transition strategy could take the motorway infrastructure into account to determine the relevancy of warning generation and to avoid over-informing the driver. The increased density levels at ramps and exits are also found for close cut-outs. In Brussels a peak value of 0.54 min\(^{-1}\) occurred. In London a high ratio (factor 7) is found with 0.22 min\(^{-1}\) compared to 0.03 min\(^{-1}\) on non-ramps. The on-ramp and exit-ramp labels are useful indicators to continue further research of a control transition strategy.

The last potential indicator relates lane change density to geographic location. Table 13 clearly illustrates this relationship. Unambiguously Paris maintains a high score of a combined lane change density (0.81 min\(^{-1}\)) while Stuttgart is below average with 0.25 min\(^{-1}\). However, a development of the control transition strategy to adopt to the traffic situations within different countries might be technically feasible but it is beyond the scope of the present research.
5.9 Nomination of Indicators for a Control Transition Strategy

Previous sections conducted an analysis of the NDS records with available sensor and observation data. As an interim result of the analysis it is proposed to make use of indicator types, both, the sensor signals as well as the video label signals. The usage will lead to potentially combine indicators and vary their parametrization to support the modelling of a control transition strategy.

Regarding research task RT5.5, true candidates for indicators due to the analysis are:

1. The speed signal of the TJA vehicle
2. The range signal that represents the distance to the leading vehicle.
3. Labels that announce areas of on ramps and exits on motorways; it is technically supported by signals from a navigation system.
4. The close cut-in labels as an indicator for control transitions that need immediate attention (so-called hard transitions).
5. The lane change labels for cut-in and cut-out manoeuvres, with an inclusion of the sublabels of 3 phases; “potential”, “in progress” and “completion”.
6. Turn indicator labels (also referenced as phase0) to support a timely warning, i.e. a warning in phase 1.

Technically the use of e.g. lane change and turn signal labels approaches a future sensor system to deliver these signals reliably. The challenge will be to generate the label signals with equal or even higher quality than the human labels that can also guarantee a 3-phase resolution of a lane change event in order to establish a reliable and accepted control transition strategy.

5.10 Conclusion

This chapter described the data collection of traffic jam drives in prototype vehicles and presents the according data analysis. The investigation of indicators for required control transitions in automated driving was defined as the prior-ranking target of this chapter.

Two vehicles equipped with a preliminary version of an automated congestion driving system were driven on different motorways near European major cities in traffic congestions. In a naturalistic driving study (NDS) they recorded ca. 30 hours of technical data. It was intended to learn about events that interrupt the static flow of automated congestion driving and that are relevant to a control transition strategy. Lane change manoeuvres in the surrounding traffic of the automated vehicle turned out to play a major role in this regard.

The literature study about lane changes revealed that signals of neighbouring vehicles were not explicitly explored. With the captured sensor signals of the automated vehicle the surrounding manoeuvres could not fully and completely be captured. The description of lane changes needed to be enhanced with additional signals. Based on the NDS data analysis a classification of relevant traffic scenarios was defined by indicators that differentiate between cut-out and cut-in manoeuvres. Close cut-in lane changes play a special role for the control transition strategy because they are closely
linked to hard transitions in the control transition strategy. For the research of relevant indicators lane changes are defined as scenarios with three time phases. A video labelling method was introduced that provided a detailed resolution of traffic jam manoeuvres. The labels were added to the data records in post-processing work by a labelling team of 12 members and a master labeller. The process of labelling was developed and with the learnings from video coding an improved work flow could be suggested. In order to ensure its quality and recommend further use, the labelling data was subjected to a conformance and coherence analysis.

The outcome of the declared research tasks of this chapter can be concluded as follows:

**RT5.1:** The task demanded for categories of lane changes and a suitable time resolution. The classification of lane changes into normal cut-ins, close cut-in and cut-out was be achieved along with an effective description of the timely sequence which is itemized into three phases: Potential lane change (phase1), Lane change in progress (phase2) and Lane change completion (phase3).

**RT5.2:** The task focussed on the application of a post-processing tool that can be used to prepare indicator analysis for a description of surrounding lane changes. Indicators derive either as technical signals of automatic sensor systems or they are manually generated as label signals. The label tool exposes labelling rules that distinguish lane changes and their phases according to RT1. A turn flasher label is optionally added to the lane change. Further useful labels like “motorway exit”, “lane markings” “vehicle type” were assigned. The latter one helped to recognize e.g. motorbikes that play a special role for lane change events because they rarely perform a complete manoeuvre. Some handling rules for lane-change labels in the data mining process were learned, e.g. to disengage labels from the strategy when the traffic jam is in standstill.

**RT5.3:** In this task the robustness and reliability of manual post-processing labelling work was investigated. The task aimed to claim the conformance and coherence of labels which were created by team individuals. In terms of conformance the labelling of team members were compared to a master labeller. The comparison of labels showed satisfactory results in inter-rater reliability (92-100%) except the agreement about close cut-in signals which was lower and conflicts with a 65% target. The timing conformance of lane change labels was characterized with a standard deviation of about 800ms. This has to be taken into account when a timing strategy is designed on the basis of NDS data.

A coherence analysis was applied to close cut-in manoeuvres because of the above mentioned conflict of team members and the master labeller. Close cut-in labels are strictly connected to the perception of a threat which will lead to immediate control transition. Close cut-ins were researched by statistical testing (MWU) of NDS sensor signals. As a result a significant difference of close cut-ins and normal cut-ins was found with the sensor signals near-field distance and time headway. For the first concept of the control transition strategy the use of close cut-in labels as indicator is still recommended as they support an initial concept for hard control transitions. The perception of close cut-ins and the use of sensor signals as indicators will however be focus of further research in upcoming experiments.

**RT5.4:** With this task the density of distinct traffic scenarios was researched that interrupt a static flow in congestion traffic. The dominance of lane change density in comparison to other events that can potentially be considered for a control transition is proven. Cut-in (0,31 min⁻¹) and cut-out (0,21 min⁻¹) manoeuvres happen frequently, while events like “lane end”, “loss of lane markings” or “end of traffic jam” occur less often. Close cut-in situations were found to have a density of 0,07 min⁻¹ on
average, predominantly influenced by test drives around the city of Paris. The NDS data that were recorded with an initial prototype version of automated congestion driving revealed that ca. 94% of potential required transitions in control between the driver and automated vehicle can potentially be based on surrounding lane changes. This confirms the importance and dominance of lane changes for a control transition strategy and justifies that further research work concentrates on the development of a strategy that uses lane change events as prior-ranked input.

RT5.5: For the development of a first concept of the control transition strategy a list of indicators was requested that differentiate surrounding lane change manoeuvres. An analysis of indicators was performed and in summary the sensor signals Speed and Range were identified as relevant differentiators. Furthermore the lane change label signals are considered relevant, including previously defined sublabels: potential lane change (phase1), lane change in progress (phase2) and lane change completion (phase3) can be used for timing objectives.

Even though the conformance of close cut-in labels was low a further use was recommended because the coherence with technical signals (like e.g. near-field distance) was demonstrated. Additionally turn indicator signals and labels for motorway exits and on-ramps are identified as considerable indicators.

The identification of indicators is based on the NDS records driven with prototype vehicles that performed an initial version of automated congestion assistance with a safety-oriented tuning of distance keeping. Having the reliability of label data in mind both data types - label and sensor signals - are intended for a combined usage as indicators in the proposed control transition strategy and the corresponding warning model. It was also recognized that label signals will be a challenge for a future technological execution of the strategy: They would be demanded in a real-time manner instead of availability through post-processing. Additionally their technical quality would need to meet or exceed the quality of human perception (Urhahne, Steiger and van der Voort 2014).

This chapter concluded in section 5.9 with a list of relevant indicators for lane change manoeuvres, which will serve as a starting point for the preliminary modelling process of the control transition strategy, described in the next chapter.
6. Concept for a Control Transition Strategy

6.1 Introduction

This chapter describes the development of a first concept for the control transition strategy. The development shall build on the naturalistic driving study data that provided a classification of lane change types and corresponding indicators consisting of sensor signals and post-processing label data.

This first concept is preliminary because an iterative development approach will be pursued in which the proposed control transition strategy will be enhanced through a series of evaluative experiments. At this stage it is intended to keep the model simple and use the indicators revealed by the naturalistic driving study.

The main research objective for this chapter is therefore to develop a first concept for the control transition strategy based on the indicators identified in chapter 5. Overall aim for the control transition strategy is that it should detect the potential need for transitions in control from the automated vehicle back to the driver timely and should classify the urgency of the transition correctly by generating the appropriate type of warning (i.e. soft vs hard).

While meeting this overall aim, the first concept should address two additional aims:

First, the control transition strategy should contain a warning model. The warning model serves to avoid generating large amounts of warnings in order to achieve high driver acceptance for the strategy and to maintain the comfort and benefit of an automated congestion driving system. In this way the warning model prevents to over-inform the drivers. This aim applies for the generation of soft warnings (i.e. the request to pay attention) only. In the process of limiting the issuing of soft warnings the objective is to maintain only those warnings that are seen as necessary and that are therefore accepted and appreciated by the drivers. Hard warnings, i.e. the request for manual takeover of control, are directly linked to the driver’s sense of safety and will therefore not be limited in this first concept. Later development iterations in this thesis will assess the validity of this decision by experimental studies.

Second, drivers need time to follow up on the warning they receive. Regarding the timing of warnings, one principal objective for this first concept of the control transition strategy is therefore that warnings shall be issued at the earliest possible point in time.

On the other hand the control transition strategy claims for the objective to avoid error-proneness, in particular false positive warnings. From the naturalistic driving study it is known that there is a remarkable number of lane change instances (i.e. soft warnings) which were started but not finalized. Generating warnings in such lane change scenarios should be avoided.

For hard warnings it is questionable whether a fully error-resistant strategy for aborted close cut-in events has to be offered: If a lane change manoeuvre presents a threat to the driver and he is willing to take over control until the situation has cleared there may not be added value to suppress the warning. As a result, in this first concept hard warnings shall be issued directly at the instance of a close cut-in detection.
In summary there are three research tasks (RT) aimed for in this chapter:

**RT6.1:** Create a first concept for a control transition strategy that generates warnings for soft and hard control transitions according to lane changes in surrounding traffic.
This first concept of a preliminary warning model shall be based on indicators identified in chapter 5.

**RT6.2:** Limit the generation of soft warnings by identifying a principal indicator for lane change manoeuvres for which the issuing of warnings can be acceptably and safely discarded.
Proposing a principal indicator for the initial model approach shall ease the application of the control transition strategy in a first experimental step. This will be the basic model scope at first which is able to be enhanced in a later version.

**RT6.3:** Build a timing model that fulfils the requirements to issue soft warnings as early as possible in the course of a lane change manoeuvre while avoiding false positive warnings.
The two requirements need to be balanced for an effective implementation of the timing model in an experimental setup.

All three research task shall be approached by developing a first concept of the control transition strategy based on the indicators identified in chapter 5. In the modelling of the control transition strategy these indicators will serve as input, whereas the appropriate warning format (i.e. no warning, soft warning, hard warning) will form the output. The method of model creation is to identify math rules in form of logical operations to connect input and output values. In particular threshold values of indicator will determine when and what type of warning should be issued. This preliminary concept of the control transition strategy shall also serve as a preparation for the first upcoming experiment.

### 6.2 Warning model

The introduction of this chapter puts the modelling of the soft control transitions into the foreground. A proposal for the generation of soft warnings shall be developed based on Vehicle speed and Range signals as suggested indicators for lane changes. The task is to identify mathematical expressions e.g. with individual thresholds for these signals that characterize according lane change manoeuvres.

The following argumentation is used to apply thresholds to Speed and Range signals:
The lower the TJA vehicle speed and the higher the distance to the leading vehicle is, the less important or interesting a lane change manoeuvre might be for a driver to receive a soft warning. The attributes ‘important’ and ‘interesting’ are used here also in the sense of safety relevance. A related reflection is how closely to a threat are the manoeuvres that have been labelled as normal cut-in or cut out.
Events that present a threat to the drivers shall only be found with close cut-ins. These are treated separately in the first concept (see chapter 7) and will be strictly linked to the close cut-in labels as assigned in the NDS data record.
Figure 28 summarizes the preliminary warning model, presented by (Urhahne, Piastowski and van der Voort 2015). Lane change manoeuvres classification, i.e. LC labels, are shown as an input; it deals with the labels for the manoeuvre itself (normal cut-in, cut-out and close cut-in) as well as the sublabels for phase1, phase2 and phase3. For occurrences of lane changes the model provides options for choosing or combining indicator thresholds and declaring the issue of a warning. This can be a hard warning, a soft warning or a non-warning. The figure also illustrates that the input values for the modelling is a mixture of manually created, post-processed labels and objective sensor signals.

6.3 Definition of indicator Q

Research task RT6.2 was defined with the idea to develop a warning model that is easily applicable, anticipating that it will be involved in the setup of a participant based experiment. To combine several indicators into one new indicator can support this idea.

Figure 29 represents the lane change types, normal cut-ins and cut-outs, with scatterplots and regression lines. They suggest a quasi-proportional relationship. The Pearson correlation of speed and range indicators is at \( r = 0.64, p < 0.01 \) for normal cut-ins and at \( r = 0.67, p < 0.01 \) for cut-outs.
Side note: In the statistical evaluation of indicators the outliers will be disregarded. Due to previous analysis it is known that outliers exist in the data repository and can be explained by provisional sensor maturity, especially for distance measurements, in the test vehicles. Outliers are calculated within the application of the statistical tools of (MINITAB 2007): Outliers are observations that are at least 1,5 times of the interquartile range (Q3 – Q1) from the edge of the box.

It is anticipated that the quotient of Speed and Range signals tends to a fixed (constant) parameter value. The quotient summarizes the characteristics of the two indicators into only one indicator Q.

\[
Q = \frac{\text{vehicle\_speed}}{\text{PO\_range}} = \frac{1}{THW}
\]

Justification for the usage of this indicator goes along with the following reasons:

The lower the quotient Q is, the less interesting and safety relevant a lane change manoeuvre might be for a driver to receive a soft warning. In other words: a low value of Q matches with a low Speed and/or a high Range value. The indicator Q is equivalent to the inverse of the time headway THW (Ishida and Gayko 2004). In investigations of congestion drives it is beneficial to use Q instead of THW because vehicle speed is low and sometimes reaches the value 0 kph which leads THW towards infinite values. For practicality reasons the unit of Q is chosen to be kph/m. Herewith a value of 1,0 kph/m represents a situation when e.g. the TJA vehicle speed is at 10 kph with a range of 10 meters, or speed at 40 kph while the distance to the leading vehicle is at 40 meters.

The German traffic regulation by (BMJ 2013) is aligned with laws of several European countries. In (StVO §4 Abs.1) it requests the driver to keep a safety margin to a leading vehicle at all times. The applied rule of thumb for city traffic at and below 50 kph is a time headway of ca. 1 second equivalent to a quotient Q = 3,6 kph/m at a distance of 13,9 meter. On rural roads this rule of thumb changes to a byword “halber Tacho” that represents a quotient Q = 1,8 kph/m. These values of Q for safety standards will be taken into account when defining thresholds for the warning model.

It can be assumed that the relevance of a soft warning to the TJA driver differentiates for a normal cut-in and a cut-out situation:

In a progressing cut-in manoeuvre the range is to be halved whereby the quotient Q is doubled. An example: driving at 30 kph with a distance of 20 m results in a Q of 1,5 kph/m in phase 1. After cut-in completion in phase 3 the range could be well at 10 meters or less; this brings the quotient to Q = 3,0 kph/m or higher and it comes into an area in which full attention is already required from a normal driver due to the postulation of the traffic law.

In contrast to cut-in a completed cut-out manoeuvre extends the gap to the next leading vehicle. As a consequence the TJA vehicle performs acceleration in order to readjust to a standard distance. This can directly be perceived by the driver. At the same time the bigger gap might inspire some other drivers from the neighbouring lanes to use this gap for a cutting-in lane change.

A distinction of normal cut-in and cut-out manoeuvres seems to be desired for the above mentioned reasons. At this stage it cannot anticipated how the driver will comply with certain thresholds of the indicators, especially with thresholds of Q. It needs to be investigated in a participant based
experiment. The next section will discuss the determination of the levels for the indicator thresholds within the first concept of the control transition strategy.

6.4 Effects of the warning model to NDS data

Assuming that all completed lane changes in the NDS data base, represented as normal cut-ins and cut-outs, issue a soft control transition, this would result in in a number of 787 soft warnings and a soft warning density of 0.52 min⁻¹ (compare Table 13). The development and labelling team that has been involved in the NDS found this level of warning density subjectively too high to be in a comfortable zone for TJA drivers. This supports the aim to consider only those lane change manoeuvres for a warning that are of interest to a driver.

NDS data purification

For further investigations the NDS data were purified: The aim was to only consider plausible lane change sequences of normal cut-ins and cut-outs as summarized in Table 14. Acceptable and according sequences of events are assigned to lane change-indices (LC-index a to d).

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</tr>
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<td>1. Turn indicator set (Phase0)</td>
<td>Nominal sequence, starting with turn indication</td>
</tr>
<tr>
<td></td>
<td>2. Potential lane change (Phase1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Lane change in Progress(Phase2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Lane change Completion (Phase3)</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>1. Potential lane change (Phase1)</td>
<td>turn indication comes in phase 1</td>
</tr>
<tr>
<td></td>
<td>2. Turn indicator set (Phase0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Lane change in Progress(Phase2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Lane change Completion (Phase3)</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>1. Potential lane change (Phase1)</td>
<td>turn indication comes late in phase 2</td>
</tr>
<tr>
<td></td>
<td>2. Lane change in Progress(Phase2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Turn indicator set (Phase0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Lane change Completion (Phase3)</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>1. Potential lane change (Phase1)</td>
<td>Lane change without turn indication</td>
</tr>
<tr>
<td></td>
<td>2. Lane change in Progress(Phase2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Lane change Completion (Phase3)</td>
<td></td>
</tr>
</tbody>
</table>

Table 14: Sequences for lane change manoeuvres and lane change indices

Wrong sequences as well as doubled labels have been detected in the NDS data and were removed from the data set. In practise it meant to rework or delete a few instances in which the sequence was mixed up or a single occurrence of phase 2 or phase3 was labelled falsely. It has to be stressed that these errors are due to manual labelling work. Further data purification was achieved by identifying and removing occurrences of lane change with high ranges (> 80 m) because these events indicate a situation outside the scope of a real traffic jam. Furthermore some values for non TJA-speeds (>50 kph) have been captured and removed from the data analysis because the TJA system that was applied during the data collection was deactivated above 50 kph. The purification led to a reduction of the overall number of completed normal cut-in manoeuvres and cut-out manoeuvres, that is:

\[ N_{\text{nomal cut-in}} + N_{\text{cut-out}} = 379 + 277 = 656 \]
With the remaining time valid for traffic jams it is equivalent to a density of 0.44 min⁻¹. This is considered as a new density reference value (100%) for soft warnings. The same kind of purification was applied to close cut-in manoeuvres while reducing the number from 108 to 102 with no visible effect on the density of 0.07 min⁻¹ for hard transitions (compare Table 13).

Figure 30 presents the distribution of lane changes according to the three proposed indicators - Speed, Range and Q. Each of the histograms shows the indicator values at the beginning of phase 3 (lane change completion) which is equal to the end of phase 2 (lane change in progress). The histograms contain normal fits, according mean values and standard deviations. The mean values provide an initial assessment at which particular thresholds a reduction of about 50% of soft transitions could be achieved which would result in a theoretical warning density of 0.22 min⁻¹ or lower.

Figure 31 outlines in more detail the assessment how the quantity of transitions can be influenced by varying the thresholds for the indicators Speed, Range and Quotient. Soft transitions are divided into normal cut-ins and cut-outs in order to support different strategies for both types of lane changes.
Driver perception of using indicator thresholds to determine the issuing of soft warnings has to be tested in the experimental part of this work.

As explained before the reduction of hard warnings is not pursued as these directly relate to close cut-ins that require a direct response by the driver.

The question remains which soft warnings are requested by drivers and what are desirable thresholds for indicators. The dependency effect of using thresholds of three indicators Speed, Range and Q on the warning density is represented in Figure 32. A free selectable reduction of warning quantities is possible by indicator thresholds. It is shown how to limit soft transitions up to 100% by setting indicator thresholds to a requested value. The reading of the diagram can be illustrated with two specific examples: A reduction of ca. 70% of warnings for normal cut-ins is achieved if those manoeuvres with a quotient $Q < 1.2 \text{ kph/m}$ are neglected. Secondly it is possible to avoid ca. 48% of soft transitions from cut-out manoeuvres if no warning is given for cut-outs that are performed with a range of more than 20 m.

The model for soft warnings can flexibly be used with these indicators in the oncoming tests. Dependent on the chosen threshold the model predicts if a lane change shall issue a soft warning or not. As a first proposal only a threshold for $Q$ shall be used because $Q$ accounts for the other indicators Speed and Range as well. In the first concept it is aimed to limit the issuing of warnings to about half of NDS lane changes. For both types of lane changes the thresholds are selected in the area of median and mean value:

$$Q_{\text{cut-in}} = 1.0 \text{ kph/m} \quad Q_{\text{cut-out}} = 1.1 \text{ kph/m}$$

These values are below the safety standards as referenced in section 6.3. It means that a warning is issued well before a safety margin is reached. The question remains whether these indicator thresholds of $Q$ will agree with the requirements for soft transitions set by the drivers. Presumably agreement to these thresholds will not be equal for all individual drivers. Agreement to the warning
model will therefore be investigated by means of participant-based evaluative research in the next step.

Figure 32: NDS data with warning limits by indicator thresholds
6.5 Timing model

The preceding section about the warning model is built on the assumption that the warnings are issued at a point in time when a lane change manoeuvre comes to an end, e.g. at beginning of phase3 of the lane change. This implies that the lane changes were completed. For the warning model development only these instances in the NDS data base were considered that have gone through phase3 of a lane change manoeuvre. These warnings can be given by avoiding a “false positive” error which is declared as one preliminary objective of the control transition strategy. Due to task RT6.3 the research is now directed to find the earliest point-in-time for soft control transitions when a warning is issued and simultaneously meet the objective of error-resistance. For the creation of a timing model NDS lane change data is to be considered that includes the instances of lane changes that were started but not finalized, i.e. they do not end-up in phase3.

A separate consideration for warnings in phase1 of a lane change should be made. If the driver regains situation awareness due to a soft warning and there is no relation to an upcoming lane change then the warning will be misunderstood and can decrease the trust in a reliable automated congestion driving system. In worst case the driver will adapt his behaviour and learns to ignore the warnings. This is to be avoided. In contrast this reflection cannot be transferred to phase2, where a direct visible relation between a warning issue and the movement of a vehicle to the other lane exists. Therefore false negative warnings in phase2 will most likely not lead to distrust of the control transition strategy. This consideration will have to be confirmed in oncoming experiments. The reflection motivates to develop a basic timing model that rejects the need for warnings in phase1.

Basic timing model

When considering a basic solution for the timing model regarding soft warnings it is recommended to trigger a warning latest at the beginning of phase 2. This is the point in time when the first wheel of the lane changing vehicle touches the line marking of the lane as shown in Figure 33 from the perspective views of the TJA driver and from a bird view. The recognition of this exact moment will be a high requirement for the sensor system. From the conformance investigation in chapter 5 it is known that human labelling was prone to identify these time stamps with an average deviation of 800 ms which gives a certain tolerance for the automated detection.

There is a risk that this basic model generates false positive warnings when the lane change manoeuvre is aborted and not continued into phase2 or phase3. Presumably, for soft transitions, the driver will excuse a false positive warning in case that a lane change manoeuvre is started visibly. In contrast the driver will not have a sympathy if a warning is given without a visible indication, namely at the beginning or during the early course of phase1. In the basic timing model the warnings are therefore only issued at a fixed point in time, that is when the lane changing vehicle is about to cross the line marking. An earlier warning, i.e. in phase1 of the lane change manoeuvre, is not considered in this model. Also a later warning than the beginning of phase2 is neglected. This implies that the basic model will not meet the requirements to completely avoid any false positive warning and accepts error-proneness to a certain extent. It will require the acceptance of the driver for some false positive warnings(< 5%). Nonetheless this version of a timing model shall be pursued within the oncoming experiments to understand whether a balance between the two requirements correlates with user agreement.
Enhanced timing model

The enhanced timing model is linked to the research objective to issue warnings as early as possible. This model creates a proposal for earlier timing of warnings, i.e. in phase1. It also aims for the approach avoiding false positive warnings. In case the participant-based experiments reveal that false positive warnings need to be avoided at all costs and earlier timing of warnings is desired, an enhanced timing model is needed.

For this combined target an investigation of lane changes within the NDS data in phase1 (with the exclusion of motorbike events) and phase2 is conducted in order to understand if early warnings can be given without generating them falsely.

In contrast to the basic timing strategy the objective becomes that the earlier a warning can be announced the higher the quality of the warning is rated. The driver benefits from an earlier awareness of the situation. Consequently a longer reaction time for any kind of driver response is provided. While pursuing this objective with the development of an enhanced timing model it will be focus of the first participant based experiment to reveal whether the drivers agree to this assumption.

A method to identify the earliest point-in-time for the transitions with soft warnings is applied by (Henel 2014). His work is based on the same NDS data as in this study. The lane changes are extracted and assigned into groups. These groups are divided into completed lane changes and aborted lane changes. Abortions are lane changes that are started with either phase 1 or phase 2 but they are not running through phase 3. So the lane change is planned but not really executed. In case of abortions no warning shall be given. Otherwise it is considered as an undesired false positive warning.

With regards to soft warnings Table 15 and Table 16 were applied. The tables represent groups (group names in upper case letters) and appropriate counts of lane changes. Additionally an
investigation of the influence of the turn indicator signals is pursued. Table 15 refers to soft transitions for lane changes which are aborted, divided into groups with (I,K) and without (C,G) turn flasher signals.

<table>
<thead>
<tr>
<th>Normal cut-ins</th>
<th>Abortions in phase 1</th>
<th>w/o turn-indication</th>
<th>w/ turn indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) 136</td>
<td>(C) 119</td>
<td>(I) 17</td>
<td></td>
</tr>
<tr>
<td>Cut-outs</td>
<td>(E) 57</td>
<td>(G) 50</td>
<td>(K) 7</td>
</tr>
</tbody>
</table>

Table 15: Groups of aborted lane changes for soft transitions

Table 16 shows completed lane changes and distinguishes the use of the turn indicator signal in phase 1 and 2 based on the lane change index as presented in Table 14. Relevant are lane changes that include the turn indicator signal (LC indices a and b) as well as manoeuvres without turn indicator signal (LC index d).

<table>
<thead>
<tr>
<th>LC-Index</th>
<th>a</th>
<th>b</th>
<th>Sum a+b w/ turn indication</th>
<th>c</th>
<th>d w/o turn indication</th>
<th>sum a+b+c+d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal cut-ins</td>
<td>232</td>
<td>71</td>
<td>(J) 303</td>
<td>2</td>
<td>(D) 74</td>
<td>(B) 379</td>
</tr>
<tr>
<td>Cut-outs</td>
<td>156</td>
<td>47</td>
<td>(L) 203</td>
<td>6</td>
<td>(H) 66</td>
<td>(F) 275</td>
</tr>
</tbody>
</table>

Table 16: Groups of completed lane changes for soft transitions

(Henel 2014) investigated indicators like Q, Speed and Range signals that serve as differentiators e.g. between groups C and D for lane changes without turn indicator signal as well as groups I and J for lane changes with turn indicator signal. In his work he found that it was not possible to identify significant differences between the respective groups by applying standard tests for parametric and non-parametric data. He developed and applied the method of difference quantities for a distinction of groups based on NDS data. It provided an auxiliary option to design an enhanced timing model upon indicators and served as a probabilistic framework to prevent false positive warnings in case of aborted lane changes by using a non-standard method.

Indicator thresholds $S_S$ for the timing model were identified to issue soft warnings correctly in phase 1 of the lane change based on difference quantities of groups A-L.

In the enhanced timing model presented Figure 34 early warnings in phase 1 are proposed. A practical example can be described: For normal cut-ins with turn flasher signal and the Range threshold $S_2$ were found as principally differentiating indicators. If a vehicle starts to cut in and has not set a turn-flasher signal the warning shall be issued at that time in phase 1 when the distance to the leading vehicle exceeds Range threshold ($S_2 = 33.4$ m). NDS data analysis shows that the commencing lane change will likely be finalized and therefore the early warning is correct and is not
Concept for a Control Transition Strategy

turned into a false positive warning. For cut-in lane changes with turn flasher signal the model uses combined indicator thresholds of \( Q \), Range and Speed \( (S_3 - S_5) \) to generate an early warning. According to (Henel 2014) cut-out manoeuvres are proposed for warnings in phase1 if specific upper and lower thresholds of Range values \( (S_6, S_7) \) are passed. No likewise distinction with the turn-flasher signal is suggested here.

If the enhanced timing model cannot suggest a warning in phase1 based on these thresholds it issues the warning at the beginning of phase2 which corresponds to the basic timing model.

![Enhanced Timing Model for soft warnings (Henel 2014)](image)

The enhanced timing model does not ensure that the research objectives are fully met: There is no guarantee that an early warning can be issued as well as that any false positive warning is completely avoided because an abortion of the manoeuvre cannot fully be excluded from warnings in phase1 and phase2.

Both timing models have to compromise the settings of objectives. The enhanced timing model however supports the earliness of warnings better.

As stated in introduction of this chapter hard warnings shall always be issued as soon as a close cut-in label can be assigned. According to NDS data this happens either in phase1 or in phase2 of the manoeuvre. Avoidance of false positive warnings is not pursued by the timing model because a close cut-in is a potential threat to the driver. Concerning hard warnings therefore no difference exists between the basic and enhanced timing model.
6.6 Conclusion

In this chapter a first concept for a control transition strategy could be delivered in form of a preliminary model that uses indicators developed in the analysis of real driving data in chapter 5. The concept aims to provide driver support for automated congestion driving system by detecting a potential need for control transitions during the automated ride.

The concept was developed as a warning model and a timing model. First, the warning model was created which impacts the appropriate issue of warnings by distinguishing hard and soft warnings. Hard warnings in the preliminary model are directly linked to close-cut-in manoeuvres as identified in the NDS data analysis. The modelling efforts were focussed on soft warnings. The issuing of soft warnings can be limited for those instances that are assumed to be supportive and accepted by drivers of an automated congestion driving system in order to fulfil the research objectives for usability of the control transition strategy. A principal indicator (Q) with threshold values was identified to be used in a first experimental trial of the concept.

Second, the strategy includes a timing model that decides the point-in-time when a warning is issued. Lead motivation for the build-up of the timing model was to find the balance between the earliness of warnings and the avoidance of false positive warnings. For the start of experiments the application of a basic timing model is determined that compromises both aspects best. An enhanced timing model exists in the background to focus on earliness of warnings if required.

The three research tasks as defined in the introduction of this chapter were processed in the modelling work and revealed the following outcome:

**RT6.1:** This task pursued the creation of a preliminary warning model. The model is delivered in form of a logical construct. Input variables for the model are adopted from the lane change indicator research described in chapter 5, consisting of lane change labels and signals Speed and Range. The model output decides which warning shall be issued and whether a warning is suppressed depending on threshold values of the indicators.

**RT6.2:** To limit the generation of soft warnings a principal indicator for lane change manoeuvres was identified for which the issuing of warnings can be acceptably and safely discarded. This limitation related only to soft warnings for normal cut-in and cut-out lane changes. As principal indicator the quotient Q was nominated that represents the inverse of the time headway and thereby combines the two indicators Speed and Range. An acceptable and safe limitation of soft warnings is expected to be achieved by setting a threshold value of Q for the two types of manoeuvre, initially proposed as $Q_{\text{cut-in}} = 1.0 \text{ kph/m}$ and $Q_{\text{cut-out}} = 1.1 \text{ kph/m}$.

**RT6.3:** The timing model aimed to issue warnings as early as possible in the course of a lane change manoeuvre while avoiding false positive warnings. A basic model is proposed that issues warnings at a fixed point in time during the course of a lane change, which is the moment when the first wheel crosses the lane marking. This timing can be applied to all instances of lane changes. Full avoidance of false warning, however, cannot be guaranteed.

In a proposal for an enhanced timing model earlier timings in phase1 of a lane change manoeuvre were addressed. As a most effective input thresholds for Range indicator were nominated in conjunction with the turn-flasher label. The output enables an early warning only for those instances of lane changes that fulfil the threshold conditions of the enhanced timing model. Again, these
instances are not fully error-resistant against false warnings.
A compromise in the strategy requirements for timing and error-proneness is to be negotiated. For a first use of the timing model in a participant based experiment the basic model is recommended for its simplicity. This first concept can then be used to determine to what extent early warnings as well as the avoidance of false positive warnings are strictly demanded by users of automated congestion driving support.

In summary for the issuing of soft warnings the principal indicator Q with threshold values serves as a decisive element whereas for timing a fixed point in time is nominated. The issuing of hard warnings is directly linked to the label of close cut-in manoeuvres and their timing to the first instance of a close cut-in label can be generated.

In the further course of the research an experiment will be setup to evaluate and validate the first concept for the control transition strategy.
7. Evaluating the First Concept of a Control Transition Strategy

7.1 Introduction

In the previous chapters a first concept for the control transition strategy was presented. It is based on the analysis of real driving data of prototype vehicles with an automated congestion driving system. The next step will be to evaluate this concept against the expectations of drivers in order to understand the validity of the modelling of the control transition strategy. This evaluation is called “core experiment” of this work and will be conducted by means of a driving simulator test. It involves potential drivers of an automated congestion driving system as participants.

As described in Chapter 4, the control transition strategy will be developed by approaching a user centred design which is oriented on customer expectations and requirements. From this perspective the validity and quality of the control transition strategy will be assessed with regards to usability, correct timing and error-proneness.

Usability comprises of three aspects: effectiveness, efficiency and satisfaction. The warning system is considered to be effective if it provides the type of support that the driver needs, expects and accepts. The type of support is given in form of either hard warnings or soft warnings. The control transition strategy is considered to be efficient if the quantity of support is perceived by drivers as sufficient. This means that the amount of warnings and non-warnings for surrounding lane changes has to be well-balanced to be accepted by drivers. The control transition strategy is considered to satisfy drivers if they value the proposed model as an integral part of an automated driving experience.

For correct timing the model suggests a basic solution to warn exactly at the border between phase 1 and phase 2 of a lane change. This shall be used in the experiment setup while observing whether the enhanced timing model would better meet the expectations of participants.

Error-proneness needs to be balanced with the approach of early and timely warnings: The target of error-proneness tries to avoid false positive warnings that can occur because of aborted lane changes. The experiment seeks an answer to the question whether the earliness of warnings and error-resistance can be comprised to a certain extent by users of the control transition strategy.

Based on these criteria the research questions (RQ) for the core experiment can be formulated as follows:

RQ7.1: To what extent do participants agree with the warnings issued in specific traffic scenarios, for both soft warnings and hard warnings?

This research question will be answered by evaluating the responses of participants to warnings which are issued as part of a driving simulator experiment. The levels of agreement will be calculated based on the responses (warning is either correct or incorrect) and shall be used to determine the effectiveness and efficiency of the warnings in the core experiment. The strategy is effective if it clearly distinguishes hard and soft warnings and it is efficient if it limits the warnings to those instances that are relevant to the drivers.

RQ7.2: To what extent are participants satisfied with the proposed control transition strategy?
By means of a questionnaire participants will be asked about their opinion on issued warnings. Their subjective impressions shall be employed to determine their satisfaction with the proposed control transition strategy.

**RQ7.3: To what extent do participants agree with the proposed timing of the warnings, for both soft warnings and hard warnings?**

In the driving simulator experiment warnings will be issued in video records of a lane change manoeuvres. In accordance with the basic timing model of the proposed control transition strategy, these warnings will be issued exactly at that point in time when the manoeuvring vehicle touches the line marking for a lane change. All traffic scenarios presented in the simulator experiment are constructed this way. The levels of agreement are calculated from the response by participants whether the timing is perceived as just right, too early or too late. These ratings shall be used to determine the validity of the proposed timing model.

**RQ7.4: To what extent do participants expect the timing model to be error-free?**

With reference to the previous mentioned timing model it is feasible to warn the driver in the early phase of a surrounding lane change. However, early warnings come with a probability that the lane change will in fact not be completed and the warning was given unnecessary. This might lead to confusion or even mistrust of the control transition strategy by the driver. This question of error-proneness of the model is also related to error tolerance of drivers towards the timing model. To address this question in the driving simulator experiment the participants will be presented a series of lane change manoeuvres that are interrupted in order to issue false positive warnings. The questionnaire is applied to understand the participants’ level of agreement to false positive warnings.

**RQ7.5: Do participants with experience in driving with advanced driving assistance systems judge differently about the usability of the proposed control transition strategy?**

The question serves as a usability assessment of the strategy for different types of drivers. Two groups are to be compared in the core experiment: drivers with and without ACC driving experience. This grouping is a preferred setup for investigation in automated vehicle driving, see (Naujoks, et al. 2015) and (Larsson, Kircher and Hultgren 2014). Desirably there will be no differences between ACC drivers and non-ACC drivers in the perception of the proposed warning model. This would support a more general approach for the usability of the strategy. The hypothesis is that there are significant differences of the groups regarding the judgement of the warning system because of different preconditions in driving experiences. The method to determine a possible difference is to compare the level of agreement in the two groups by means of statistical analysis methods.

**RQ7.6: Can the first concept of the control transition strategy be enhanced and if so, what are potential improvements?**

The first concept of the control transition strategy is based on the data analysis of a naturalistic driving study and a literature research regarding lane change manoeuvres. With the core experiment it will be investigated whether unbiased participants have further ideas or suggestions on how the control transition strategy can be improved. This investigation will help to develop the control
transition strategy into an enhanced version that can be evaluated in a subsequent iteration. One potential enhancement will be investigated specifically: From the NDS data analysis it is known that the density of lane changes and related warnings is comparatively high in the areas of motorway on-ramps and exit ramps. By means of the questionnaire and video examples it will be investigate to what extent participants consider switching off the functionality of the congestion assistance system around on- and off-ramps as a potential enhancement that improves driving comfort by avoiding an excessive warning density in these areas.

This chapter describes the complete execution of the driving simulator experiment, including the experiment setup, the conduction of a pilot-study and the evaluation of the results. The following section establishes the method applied to address all of the above research questions for the core experiment.

### 7.2 Method

The method of this experiment will be twofold. It is constructed as a participant-based driving simulator test that uses video streaming and a questionnaire process that hooks up with the video tests. Both support the objective to find answers to the dedicated research questions RQ7.1 - 7.6.

The method to use driving simulators in automotive research for driver assistance systems is common practice since several years. Sophisticated facilities that simulate not only the driver’s visual perception, but also the haptic perception of vehicle movement, already exist around the world at automobile manufacturers, e.g. Daimler-Benz (Wolff 2010) and Ford (Gitlin 2015). Also structures in research institutes, e.g. TNO and at university level like IKA Aachen (Pudenz 2013) offer future possibilities to simulate dynamic driving experience. In this research however a basic driving simulator serves the need to assess the usability of the proposed strategy in first instance.

In a cognate research project (van Driel, Hoedemaeker and van Arem 2007) and (Brookhuis, et al. 2008) reported about a driving simulator experiment for a congestion assistant system that gives warnings for upcoming traffic jams. Warnings consisted of text messages that came up before a traffic jam started and an active pedal that warned by means of a counterforce in the gas pedal lever. Subsequently a stop-and-go functionality was activated. In contrast the on-hand research work deals with a driving support system that offers a temporary automated drive without driver action on the pedals and on the steering wheel.

In many cases of automotive research it is recommended to start experimenting within a simulator environment. (van den Beukel, van der Voort and Eger 2015) present a framework for investigations of partially automated driving where using a driving simulator that comprises 180° viewing angle with 3 projection screens.

The common element of driving simulators is to play videos of driving situations. A general endorsement of the video experiment method for product design purposes is described by (Buur, et al. 2010): Buur claims “that for the purpose of user-centred design, video may be regarded as part of the design process itself.”. And he restricts: “… video cannot in itself set requirements for the performance of a new product; such measures need to be negotiated between members of the development team. What video can do is provide very strong support for the negotiation of requirements.”
Evaluating the First Concept of a Control Transition Strategy

The extension of external validity for a study normally serves to generalize the findings of research. A driving simulator cannot fully replace road and vehicle reality and therefore the external validity is often criticised. (Aronson, Wilson and Akert 2008) see the highest danger for external validity of laboratory experiments in an artificial setup.

In order to avoid artificiality and to learn for a smooth conduction of the core experiment a pilot study is conducted before the core experiment is started. Pilot studies are frequently used in medical research (Hulley 2007). They serve as a small scale preliminary study in order to evaluate amongst others feasibility, time, cost and adverse conditions of the core experiment. A pilot study in the context of this research also helps to avoid misunderstandings between the participants and the responsible organizer of the experiment. Misunderstandings lead to failures in the setup and conduction of the experiment. They potentially jeopardize the success of the research approach in the core experiment. This can be avoided by collecting experiences with the practical exercise and a first-step analysis of a smaller amount of data.

The following guidelines will be used in defining the set-up of the driving simulator experiment:

Realistic scenes from the NDS data repository shall be applied in order to construct lane change videos. They are available from the data pool that was also used for the generation of the first concept of the control transition strategy.

The video experiment shall be divided into a training part and an execution part in order to guide the participants and give them a comfortable and safe feeling throughout the experiment.

The sequence of the test is firstly to fill in the assessment sheet during the course of traffic jam videos. Secondly the participants are demanded to fill in the questionnaire at rest, with no time-stress.

Participants

In the pilot-study the selection of participants does not put an emphasis on customers of automated congestion driving systems but the participants shall be selected randomly. Typical customers are e.g. businessmen and women with a high yearly travel mileage, they are used to frequent driving in traffic congestions as well as using ADAS systems like ACC. Untypical customers are identified with young people, e.g. students that usually do not yet have a lot of driving practice and experience with driver assistance systems. However, for the core experiment a balanced ratio of ACC drivers and non-ACC drivers has to be found in order to achieve a fair distribution for the comparison of both groups due to research question RQ7.5.

The pilot-study was arranged with an acquisition of 6 persons. The persons were chosen randomly in the council of the Ford development centre in Cologne. The age span was from 33 to 62. Only one person had experience with ACC systems. For the core experiment it meant that a random selection of participants was not leading to an almost fair ratio of the two groups.

In the core experiment itself a number of 25 participants was aimed for which is aligned with other driving simulator studies, compare (Naujoks, et al. 2015) and (van Waterschoot 2013). (ITU-R 2012) describes a test environment from TV research and recommends a minimum of 15 participants for video experiments. A high number of participants for the video experiment is also beneficial for the questionnaire process.
The profile of the participants is discussed in Figure 35 with the pie charts of age distribution, gender and ACC driving experience. A fair gender distribution was achieved and a majority age group of 41-50 is based on the fact that they build the generation of baby-boomers with a high percentage in today’s society. Experienced ACC drivers were accounted with 56% which almost meets the envisioned target of 50%.

All participants are selected on a voluntary basis, no financial or other reward for participation is offered.

**Equipment**

This experiment makes use of a low level driving simulator as presented in Figure 36. The simulator is located in a separated space that avoids acoustic and visual distraction of the participants. In the beginning of the experiment planning it was considered to use a vehicle mock-up body, a steering wheel and a real vehicle seat. In the pilot study the participants were asked whether such a setup was supportive for the task. They generally appreciated and preferred the low-level setup to concentrate on the video analysis with the task to fill in the assessment sheet. A steering wheel seemed also not necessary to them because it is not used during automated driving. Based on the mounting location of the supporting camera the videos support a viewing angle that is equivalent to a nearly full view through the windscreen from a central position between the front seats of the vehicle. The single videos of lane change scenarios had time durations of ca. 40 seconds. The actual lane change manoeuvres were placed in the interval of [15sec..35sec]. At the end a five second “pause screen” requested the driver to assess the scenario on the sheet with the referenced number (e.g. A1). The interrupt button replaced the computer mouse and was used to stop the video sequence at any time in order to conveniently fill in the assessment of a lane change manoeuvre without hectic or stress. This happened preferably during the pause screen was displayed. It was not possible to replay the scene a second time with this device. Each participant should observe a scenario only once before he gave an assessment.

The acoustic scene was composed with some driving noise that represented running combustion engines and rolling tires, audible through a closed window. This was superposed with chimes for soft and hard warnings that are generated for a related lane change according to the basic timing model, when a manoeuvring vehicle hit the lane marking with a wheel. The soft warning chime resembled a pleasant quiet gong, hit shortly. The hard warning chime was like a pungent escalated siren.
Procedure

The procedure as well as the whole test setup is regarded with a special view on the experiment’s validity. Internal validity of a simulator study is constructed consciously in the experiment. (Shadish, Cook and Campbell 2002) and (Krauth 2000) describe factors for internal validity that have been taken into account: disturbance variables have to be eliminated by providing equally a steady and stable environment for all participants. Figure 36 and Figure 37 document how environmental conditions and the sequential process of the test are constantly applied to all participants. The process in the pilot study and in the core experiment is identical. It starts with a briefing to introduce the participants into the subject of automated congestion driving and the collaborative approach. The control transition strategy and the characteristics of both warning types have been explained and demonstrated:

Hard warnings are proposed for situations in which the lane changes of a cutting-in vehicle become a threat to the driver. With reference to system reliability the driver instantaneously takes over control of the vehicle.

Soft warnings in contrast are intended for lane changes that are related to dynamic situations in the near environment of an automated vehicle. They shall raise awareness of a driver that a traffic jam is not a static but a dynamic flow of vehicles that cut-in and cut-out with regards to the own driving lane. These do not indicate a threat and do not request the driver to immediately react with a manual take-over. However - soft warnings underline the characteristics of collaborative automated driving by making the driver aware that he is fully responsible for the ride of the vehicle at all times and he has to be prepared for hard warnings and a hard control transition at any time. The principal questions to the participants are: Depending on their individual rating, which of the presented lane change manoeuvres are due for an according warning? Is the time of warning chosen correctly?

An exercise with four examples of cut-in manoeuvres was then demonstrated in the simulator, followed by 19 video scenes that the participant had to handle on his own. For cut-out manoeuvres a similar sequence with three exercises and nine scenes for the participants is applied. The final task consists in filling-in the questionnaire. The assessment sheet as well as the questionnaire sheet of the core experiment is attached in the appendix section of this work (see appendix B). The assessment
The sequence of cut-in scenarios (close cut-in and normal cut-in) is separated from that of cut-out scenarios. The participants were informed how a cutting-out lane change differs from cut-in manoeuvres by enlarging the gap to the leading vehicle that is then closed again to the normalized distance. They could adjust their evaluation for the control transition strategy accordingly.

The experiment applied the rules of counter-balancing separately to both types of lane changes. *Table 17* shows the chosen sequence of scenes in the core experiment. Static sequencing is avoided by a rotation principle for the lane change videos. (Pelham and Blanton 2013) describe the different options of counterbalancing. In this study it was decided to use partial counterbalancing as a feasible method to avoid that participants start prediction of what is going to happen after a certain time. This would presumably affect those scenes at the end of the video exercise. With partial counterbalancing the sequence of presented videos was changed at every new participant.

<table>
<thead>
<tr>
<th>Cut-in Sequence</th>
<th>Cut-out Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 1</td>
<td>A1-5 B1-5 C1-5 D1-4 E1-3 F1-3 G1-3</td>
</tr>
<tr>
<td>Participant 2</td>
<td>B1-5 C1-5 D1-4 A1-5 F1-3 G1-3 E1-3</td>
</tr>
<tr>
<td>Participant 3</td>
<td>C1-5 D1-4 A1-5 B1-5 G1-3 E1-3 F1-3</td>
</tr>
<tr>
<td>Participant 4</td>
<td>D1-4 A1-5 B1-5 C1-5 E1-3 F1-3 G1-3</td>
</tr>
<tr>
<td>Participant 5</td>
<td>A1-5 B1-5 C1-5 D1-4 F1-3 G1-3 E1-3</td>
</tr>
<tr>
<td>……………………</td>
<td>……………………</td>
</tr>
<tr>
<td>Participant 25</td>
<td>A1-5 B1-5 C1-5 D1-4 E1-3 F1-3 G1-3</td>
</tr>
</tbody>
</table>

*Table 17*: Partial counterbalancing of video sequences

For the timing of the procedure it can be reported that all participants had to reserve about one hour of testing time, from briefing to filling-in the questionnaire. The majority of them ended up with ca. 45-50 minutes of lead time.
7.3 Experiment stimuli

In the driving simulator experiment the selection of video scenes was divided into the 3 known categories: Normal cut-ins, close cut-ins and cut-outs. Table 18 provides the compilation of the selected lane changes with the characteristics described by indicators applied in the control transition strategy. A wide variation in indicators values was chosen to open the opportunity to investigate the indicator thresholds in relation to the requirements of participants.

<table>
<thead>
<tr>
<th>Scenes</th>
<th>Speed</th>
<th>Range</th>
<th>Quotient</th>
<th>Turn-I</th>
<th>Warn P1</th>
<th>Speed</th>
<th>Range</th>
<th>Quotient</th>
<th>Near f</th>
<th>Warn P1</th>
<th>Speed</th>
<th>Range</th>
<th>Quotient</th>
<th>Turn-I</th>
<th>Warn P1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>31</td>
<td>23</td>
<td>1.35</td>
<td>x</td>
<td>A5</td>
<td>18</td>
<td>27</td>
<td>0.67</td>
<td>148</td>
<td>x</td>
<td>E1</td>
<td>12</td>
<td>15</td>
<td>0.80</td>
<td>x</td>
</tr>
<tr>
<td>A2</td>
<td>25</td>
<td>36</td>
<td>0.69</td>
<td>x</td>
<td>B5</td>
<td>20</td>
<td>12</td>
<td>1.67</td>
<td>186</td>
<td>x</td>
<td>E2</td>
<td>30</td>
<td>20</td>
<td>1.50</td>
<td>x</td>
</tr>
<tr>
<td>A3</td>
<td>37</td>
<td>26</td>
<td>1.42</td>
<td>x</td>
<td>C5</td>
<td>35</td>
<td>20</td>
<td>1.75</td>
<td>820</td>
<td>x</td>
<td>E3</td>
<td>36</td>
<td>13</td>
<td>2.77</td>
<td>x</td>
</tr>
<tr>
<td>A4</td>
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<td>14</td>
<td>1.86</td>
<td>x</td>
<td>D4</td>
<td>12</td>
<td>12</td>
<td>1.00</td>
<td>118</td>
<td>F1</td>
<td>20</td>
<td>20</td>
<td>1.00</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>24</td>
<td>18</td>
<td>1.17</td>
<td>x</td>
<td>F2</td>
<td>31</td>
<td>21</td>
<td>1.48</td>
<td>x</td>
<td>F3</td>
<td>27</td>
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<tr>
<td>B2</td>
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<td>E3</td>
<td>36</td>
<td>13</td>
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<td>x</td>
<td>G1</td>
<td>23</td>
<td>20</td>
<td>1.15</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>B3</td>
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<td>14</td>
<td>0.71</td>
<td>x</td>
<td>G2</td>
<td>31</td>
<td>28</td>
<td>1.11</td>
<td>x</td>
<td>G3</td>
<td>35</td>
<td>15</td>
<td>2.33</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>B4</td>
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<td>1.11</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
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<td>x</td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>C3</td>
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<td>x</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>38</td>
<td>28</td>
<td>1.36</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>24</td>
<td>26</td>
<td>0.92</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B5</td>
<td>40</td>
<td>26</td>
<td>1.54</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D3</td>
<td>24</td>
<td>16</td>
<td>1.50</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 18: Video scene composition with indicators in core experiment

For soft warnings it was worked out in chapter 6 to apply thresholds to indicators in the control transition strategy that are concentrated on indicator Q: \( Q_{cut-in} = 1.0 \text{ kph/m}, Q_{cut-out1} = 1.1 \text{ kph/m} \). This leads to a soft warning for those cases that are shaded, e.g. scene A1.

There are exceptions to this rule in those cases that show an underlined trial number, e.g. scenes A2 and C3. For the exceptions the participants have actively to contradict to the warning proposal in the according video in order to comply with the warning model. E.g. C3 is not shaded and no warning is issued, but it requires a soft warning because of the Q value.

The exceptions are intended to counteract a habituation effect of participants that would make them accept the proposal from the video. Participants were made aware in the introduction that a dissent to the warning proposal is possible.

Just for reference the table also contains information about applicability of the enhanced timing model to warn in phase 1 (Warn P1) and the turn flasher usage (Turn-I). By compiling the additional indicator “Turn-I” the timing model decides for all scene if an early warning is possible. The column “warn P1” shows for 53% of cut-ins and 44% of cut-outs that an early warning in phase 1 of the lane change was possible according to the enhanced timing model. This is not used for composition of the core experiment but can later be considered in the evaluation.

Explicitly for the timing, the basic timing model has been selected in chapter 6 for all three types of lane changes in order to conduct the experiment in an efficient way: The soft and hard warning chimes in the video scenes are all issued at the beginning of phase 2 of the lane change. This is the crucial moment when the first wheel of the lane-changing vehicle touches the lane marking. In the assessment sheet the item was addressed by asking if the selected point in time is agreed upon or whether the warning would have been desired at an earlier or later point in time. With this type of asking it was possible to draw a conclusion for research question RQ7.2
The middle section of Table 18 shows the selection of close cut-in videos and their characteristics by indicators. All four selected scenes obtained a hard warning with the according warning chime because of a close cut-in label that was assigned to the NDS data. Just for reference the indicator as well as near field distance (in cm) is listed. With lane change A5 the experiment also offered a manoeuvre with a low quotient (Q= 0,67 kph/m) and invited the participants to dissent with the proposed warning type in order to dispute the objectivity of labelling.

The bullet points below provide a list of independent variables (chosen stimuli) in the video test:

- Lane change label
- speed
- range
- quotient
- near field sensor distance (as add-on for close cut-ins)
- ACC drive experience

The list of dependent variables in the video experiment consists of:

- Percentile agreement to the issuing of a hard warnings
- Percentile agreement to timing of hard warnings
- Percentile agreement to the issuing of a soft warnings due to normal cut-ins
- Percentile agreement to timing of soft warnings due to normal cut-ins
- Percentile agreement to the issuing of a soft warnings due to cut-outs
- Percentile agreement to timing of soft warnings due to cut-outs

Questionnaire

After the video experiment all participants had to fill-in the questionnaire as documented in appendix B. It addressed the research questions RQ2, RQ4 and RQ6, as indicated below. The participants had to answer the questions by means of expressing their views on a Likert scale. The questions served

- to understand whether separately from the chosen indicators the participants select own indicators, proposed e.g. as tightness of a lane change or weather conditions. With the questionnaire the possibility is given to efficiently investigate the influence of further lane change indicators and customer preferences beyond the selected parameters in the first concept of the control transition strategy. (research question RQ7.6)
- to evaluate the appreciation of the presented control transition strategy in the context of automated congestion driving. This measures the subjective satisfaction in general? (research question RQ7.2)
- to ask in which time phase of a lane change the participants prefer a warning: in phase1, at the beginning of phase2 or later in phase3.
- to let participants assess the acceptance of false positive warnings (see research question RQ7.4). Three video scenes (A,B,C) were shown for the assessment. All scenes contained a false positive warning because the lane change manoeuvres were aborted. In scene A and B
the manoeuvre was interrupted during phase 2 while in scene C it is already aborted in phase 1, before a wheel crosses the lane marking.

- to evaluate if exceptions to the proposed strategy are agreed by drivers, by interrupting the warnings and the automated congestion drive e.g. at motorway on-ramps and exits which would reduce the quantity of warnings in a traffic jam. (research question RQ7.6)

7.4 Pilot-Study

The pilot study aims to take corrective actions and to manifest the feasibility of the core experiment before a huge effort is undertaken and the validity of the core experiment is put into question because of testing errors. Six participants participated in the pilot-study without difficulties. A discussion about the set-up of the simulator and the experiment concluded with a positive response.

Results of the video experiment

The results of the pilot-study are presented in Table 19 and discussed below. The results gave first answers into the research questions and provided insides in whether the set-up of the experiment needed to be revised.

<table>
<thead>
<tr>
<th></th>
<th>Overall Agreement to warning type</th>
<th>Agreement to Model-proposed warnings</th>
<th>Agreement to Model-proposed non-warnings</th>
<th>Optimization by threshold variation</th>
<th>Agreement to timing of warning</th>
<th>Improvement by model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close cut-ins</td>
<td>92%</td>
<td>-</td>
<td>-</td>
<td>92%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Normal cut-ins</td>
<td>70%</td>
<td>75%</td>
<td>66%</td>
<td>+ 0%</td>
<td>93%</td>
<td>+ 3%</td>
</tr>
<tr>
<td>Cut-outs</td>
<td>52%</td>
<td>36%</td>
<td>83%</td>
<td>+18%</td>
<td>89%</td>
<td>+ 4%</td>
</tr>
</tbody>
</table>

Table 19: Summary of pilot-study

First of all the pilot study revealed that the agreement for close cut-ins stays is at 92%. All of the 8% of disagreement was connected to video scene A5, which had a low quotient Q = 0.67 m/kph. A potential relationship to Q will be investigated further in the core experiment.

A lower level of agreement is found for soft warnings in conjunction with normal cut-ins (70%). The agreement to model-proposed warnings (75%) and non-warnings (66%) is on a similar level.

The agreement with the proposed control transition strategy during cut-out manoeuvres is even lower with 52%. In addition to this the percentage is unevenly distributed between model-proposed warnings (36%) and non-warnings (83%). During the pilot study participants made a clear statement: The conditions to issue soft warnings due to cut-outs have to be tightened significantly to improve the acceptance of the strategy.

The column “Agreement to timing of warnings” in Table 19 shows a result of about 90% for all type of lane changes. This is a first cue that the proposed basic timing model satisfies driver requirements.
The three-step response scale (correct - too early - too late) of the response to the timing model can be criticised to be not discriminative enough. The five-step Likert scale as presented by (Rost 1996) provides a general method for a more refined spectrum of answers. In order to ensure that the three-step response scale is sufficient for the experiment, all six participants were interviewed if they would have preferred a five-step scale to evaluate the timing. Table 20 represents for scene A1 an alternative rating scale for the timing model (too early - a little too early - correct – a little too late - too late). Four out of six participants answered that this five-step scale offers them unfavourable choice and they clearly preferred the simpler scale that was used during the pilot study. Two participants decided for the five-step scale and argued that this would have given them a refined assessment option of that they would have made use. Based on this additional survey and the majority vote for the three-step response scale it was decided not to change the rating scale for the timing model in the core experiment.

<table>
<thead>
<tr>
<th>Szene</th>
<th>Würden Sie den Warnungstyp hard/softer oder keine für diese Situation akzeptieren?</th>
<th>Falls nicht, welche Warnung würden Sie wählen?</th>
<th>War der Zeitpunkt der Warnung richtig gewählt?</th>
<th>Kommentar / Begründung:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>TYP: Soft ja ☐ nein ☐</td>
<td>Soft ☐ Hard ☐ keine ☐</td>
<td>zu früh ☐ ein wenig zu früh ☐  richtig ☐ ein wenig zu spät ☐ zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>TYP: Soft ja ☐ nein ☐</td>
<td>Soft ☐ Hard ☐ keine ☐</td>
<td>richtig ☐ zu früh ☐ zu spät ☐</td>
<td></td>
</tr>
</tbody>
</table>

Table 20: A1 with alternative 5-step rating scale for timing evaluation

**Optimization attempt by modification of indicator thresholds**

This section investigates whether the agreement results of the pilot study as of Table 19 can be improved by variation of the proposed warning and timing model.

The column “Optimization by threshold variation” in Table 19 shows that the agreement for normal cut-in warnings cannot be increased (+0%) by varying a single indicator threshold. For cut-outs, however, an increased agreement of +18% is possible by this modification. A comparison with Table 18 reveals that a change to $Q_{\text{cut-out}} > 1.5 \text{ kph/m}$ achieves an overall agreement of 70%.

Optimization of agreement to the timing model is measured with the participants’ voting on the three-step response scale: In case that a participant asked for an earlier warning the enhanced timing model could achieve an improvement in some cases, compare Table 18. The column “Improvement by model” in Table 19 shows however that the enhanced timing model offers a potential for improvement of only 3-4%. The decision for using the basic timing model as a reference is supported in this pilot-study because there were also some votes that rated the timing of warning as too early. The according result shall be discussed in the core experiment.
Changes for the design of the core experiment

The pilot-study turned out to proof a successful setup of the experiment with a manageable structure for the data analysis. The following items were proposed to change in the core experiment with regards to the pilot-study:

The agreements to cut-out warnings were under debate. Corresponding to the optimization potential it motivated to eliminate the warning chimes for some cut-out videos, especially those that fall below a quotient $Q_{cut-out}$ of 1.5 kph/m. The decision was made to renew the setup of the core experiment with the new threshold

$$Q_{cut-out} > 1.5 \text{ kph/m}$$

in order to achieve a higher agreement.

The questionnaire format was reviewed with marketing research experts. As a result a Likert scaling was introduced for some questions in contrast to a binary answer (yes/no) in the pilot-study. This helps to refine the answers and obtain a better understanding in the core experiment.

For an improved set-up regarding research questions RQ4 and RQ6 it was recommended by the experts to show accompanying video scenes that present the precise traffic situations. There shall be a chance for every participant to judge concrete scenarios instead of leaving it with a thought experiment. This way the answers become more objective and comparable. For (RQ4) three aborted lane change scenarios -A B C- were shown and the participants rated the warnings on a Likert scale:

A. A car coming from the right side, crossing the lane marking and driving into the lane to a minimal extent, then returning quickly back to the right side.

B. A motorbike from the left side, drives over the lane marking and directly swivels back to overtake the leading vehicle.

C. A car at the right lane, performing a clearly noticeable movement towards the driving lane of the automated vehicle but not driving over the lane marking itself.

To represent a situation with increased lane change densities at on-ramps and exits a video record from a motorway interchange was selected (see research question RQ7.6):

- The video shows eight lane changes within 40 seconds while the participant forecasts how many warnings would be generated on ramps of their personal life’s experiences.

Based on the changes proposed above the experiment set-up was modified. Expected are particularly a higher acceptance score for cut-out manoeuvres and a more unambiguous comprehension of the questionnaire with regards to the research questions.
7.5 Results and discussion of the core experiment

The core experiment was conducted in autumn 2014 according to the set-up described above. All 25 participants went through it without any confusion. Some people let no comments on the sheets, others used the annotation option intensively or showed themselves as friends of lively verbal discussions. All filled-in assessment sheets and questionnaire sheets were utilized as valid input to the experiment evaluation.

The results and the interpretation of the core experiment with the assessment sheets and the questionnaire process are discussed in the following sections.

Results of the video assessment

<table>
<thead>
<tr>
<th>Scene No.</th>
<th>agreement to proposed warning</th>
<th>disagreement hard warning expected</th>
<th>Timing agreed</th>
<th>disagree earlier</th>
<th>disagree later</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>23</td>
<td>2</td>
<td>24</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>A2</td>
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<td>13</td>
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<td>3</td>
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<tr>
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</tr>
<tr>
<td>B2</td>
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<td>16</td>
<td>21</td>
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</tr>
<tr>
<td>C1</td>
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</tr>
<tr>
<td>D3</td>
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<td>9</td>
<td>24</td>
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<td>126</td>
<td>244</td>
<td>19</td>
<td>12</td>
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</table>

<table>
<thead>
<tr>
<th>Cuts</th>
<th>agreement to proposed warning</th>
<th>disagreement hard warning expected</th>
<th>Timing agreed</th>
<th>disagree earlier</th>
<th>disagree later</th>
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</thead>
<tbody>
<tr>
<td>A5</td>
<td>14</td>
<td>11</td>
<td>24</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>B5</td>
<td>20</td>
<td>5</td>
<td>24</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>C5</td>
<td>25</td>
<td></td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D4</td>
<td>25</td>
<td></td>
<td>22</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>84</td>
<td>16</td>
<td>95</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cutouts</th>
<th>agreement to proposed warning</th>
<th>disagreement hard warning expected</th>
<th>Timing agreed</th>
<th>disagree earlier</th>
<th>disagree later</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>22</td>
<td>3</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2</td>
<td>17</td>
<td>8</td>
<td>23</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>F3</td>
<td>21</td>
<td>4</td>
<td>19</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>F1</td>
<td>25</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2</td>
<td>19</td>
<td>6</td>
<td>23</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>E3</td>
<td>12</td>
<td>13</td>
<td>23</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>19</td>
<td>6</td>
<td>24</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>G2</td>
<td>24</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G3</td>
<td>11</td>
<td>14</td>
<td>23</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>170</td>
<td>55</td>
<td>135</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 21: Raw data of participants’ voting

The raw data of the video experiment is presented in Table 21 distinguishing the different lane change types. The numbers show the counts of participants’ votes. The first three columns are
related to agreement of participants with the proposed warnings. The last three columns show raw data with regards to the basic timing of issued warnings.

In Table 22 the agreement to warnings proposed by the control transition strategy is listed. The agreement factors are calculated by the relation of votes that agree with the model to the overall number of votes. The second row presents results separately for ACC drivers and non-ACC drivers in order to refer to research question RQ7.5. This is reflected by showing percentages in three ways: An overall percentage in bold numbers and the distributed percentages for ACC drivers and non-ACC drivers. The general agreement over all warnings is 72%.

<table>
<thead>
<tr>
<th>Warning type</th>
<th>General Agreement to Model-proposed warning type</th>
<th>Agreement to Model-proposed warnings</th>
<th>Agreement to Model-proposed non-warnings</th>
<th>Optimization</th>
<th>Theoretical max. due to voting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close cut-ins</td>
<td>ACC 84%</td>
<td>80%</td>
<td>-</td>
<td>+11%</td>
<td>+ 0%</td>
</tr>
<tr>
<td></td>
<td>non-ACC 89%</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal cut-ins</td>
<td>ACC 66%</td>
<td>65%</td>
<td>70%</td>
<td>+ 3%</td>
<td>+ 5%</td>
</tr>
<tr>
<td></td>
<td>non-ACC 67%</td>
<td></td>
<td>56%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-outs</td>
<td>ACC 76%</td>
<td></td>
<td>65%</td>
<td>+ 0%</td>
<td>+ 2%</td>
</tr>
<tr>
<td></td>
<td>non-ACC 80%</td>
<td></td>
<td>79%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 22: Agreement to warnings

Concerning the issuing of warnings it can be stated that ACC drivers are more critical than non-ACC drivers. This specially applies in direct comparison for close cut-in and cut-out manoeuvres. In order to investigate significance in difference between ACC drivers and non-ACC drivers a chi-square test is conducted. The null hypothesis H₀ states that there are no differences between the two types of participants. Table 23 outlines the results of Chi-Square testing for all three types of lane changes. A significant difference is indicated if the p value lies below 5%. In all three cases H₀ is not rejected and there are no significant differences between ACC drivers and non-ACC drivers to declare.

<table>
<thead>
<tr>
<th>Warning type</th>
<th>Agreed</th>
<th>Not agreed</th>
<th>Chi-square</th>
<th>DF</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACC</td>
<td>Non-ACC</td>
<td>ACC</td>
<td>Non-ACC</td>
<td></td>
</tr>
<tr>
<td>Close cut-ins</td>
<td>45</td>
<td>39</td>
<td>11</td>
<td>5</td>
<td>1,257</td>
</tr>
<tr>
<td>Normal cut-ins</td>
<td>137</td>
<td>111</td>
<td>73</td>
<td>54</td>
<td>0,171</td>
</tr>
<tr>
<td>Cut-outs</td>
<td>91</td>
<td>79</td>
<td>35</td>
<td>20</td>
<td>1,723</td>
</tr>
</tbody>
</table>

Table 23: Significance of differences between ACC drivers and non-ACC drivers

For all three lane change manoeuvre types a detailed review of the proposed warning and timing model is provided below. Furthermore an analysis was performed to identify individual traffic scenes with peculiarities. Figure 38 shows participants’ agreement as a function of Q in scatterplots with linear fit of all types of lane changes. Herewith a hypothesis is formulated that increasing values of Q make the
judgement of participants more unambiguous regarding whether a warning chime is definitely required. This is separately discussed in the following sections.

For assessment of the timing model the percentages of Table 24 apply. Comparison with the results of the pilot study confirms that a consistent behaviour of experimental outcomes occurs.

<table>
<thead>
<tr>
<th></th>
<th>Agreement to applied (basic) timing model</th>
<th>Disagree earlier</th>
<th>Disagree later</th>
<th>Potential changes with enhanced timing model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACC</td>
<td>nonACC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Close cut-ins</td>
<td>95%</td>
<td>95%</td>
<td>5%</td>
<td>-</td>
</tr>
<tr>
<td>Normal cut-ins</td>
<td>89%</td>
<td>91%</td>
<td>7%</td>
<td>+ 1%</td>
</tr>
<tr>
<td>Cut-outs</td>
<td>90%</td>
<td>87%</td>
<td>5%</td>
<td>- 1%</td>
</tr>
</tbody>
</table>

Table 24: Agreement results for timing model

The simulator experiment can now be interpreted in a general manner. This is done separately for the three types of lane changes. An analysis of individual scenes with peculiarities is included. Later on the analysis is combined with the findings of the questionnaire results.

General statements
The basic timing model that was applied in the experiment reaches a high agreement (ca. 90%) for all three types of warnings and does not exhibit significant differences between ACC drivers and non-ACC drivers.

The optimization potential by applying the enhanced timing model is rather low. In fact the application of the detailed timing model deteriorates the level of agreement in case of cut-out
warnings about -1%, see Table 24. This derives from the limited possibilities to apply the enhanced timing model: For the scenes for which participants request an earlier warning only 50% could actually be issued earlier based on the enhanced model (compare Table 18). It is noticeable that he applied optimization method assumes that an earlier warning would lead to an agreement of participants that have asked for it and at the same time that none of the agreeing participants would vote for a later warning in case the warning was issued earlier (in phase1). However, other participants requested warnings to be issued later. In particular for cut-outs this is 5%, accounted in four different scenes. The discrepancy lays in the nature of the experiment setup as participants could not make a free choice at which point in time the warning has to be issued. With this experiment design the enhanced timing model does not offer noticeable improvement over the basic model and for cut-out warnings this even tends to be contra-productive. A conclusion shall be drawn later in conjunction with investigation of error-proneness in research question RQ7.4.

The warning model is considered to primarily select these warnings that are issued in agreement with the participants. It serves to determine when a warning is desired and when not. For the usability of the control transition strategy the following can be concluded: Its effectiveness can be regarded as good for close cut ins (84%) and for cut outs (76%) but can be improved for normal cut-ins (66%). The efficiency level is calculated by considering the balance of soft warnings and non-warnings. Lower percentages are found for cut-ins (56% for non-warnings) and for cut-out (65% for warnings). It means that the efficiency of soft warnings needs to be improved in the further course of this study.

**Close cut-ins:**

**Issuing of warnings:** The agreement is on a similar high level (84%) as in the pilot study. Optimization is not feasible because of a binding relation of close cut-in labels to hard warnings in the preliminary model. When going beyond this preliminary rule it can be stated that 11% improvement is possible if a hard warning for scene A5 is converted into a soft warning. Here the assumption is made that all participants are in accordance with a soft warning – which has to be confirmed with a modification in the model and in a further test. *Figure 38* shows that the agreement rises with higher values of Q which means: the greater Q the clearer is the agreement to the warning. The Pearson correlation of the graph is +0,567 (P = 0,433) and does not prove significance for a linear behaviour.  

**Timing of warnings:** 95% agreement to the simplified timing model is found which is very satisfying.

**Peculiarities:**  
Scene A5 has a remarkably high disagreement factor of 0,78 despite a near-field sensor value of 148cm. This can be connected to the to an eye-catching low value of Q = 0,67. It means that the scene is characterized with a tighter cut-in manoeuver but there is a enough room for the lane changing vehicle to drive into the gap without deceleration. Further it seems feasible with the recognitions of the core experiment to replace the subjective close cut-in labels by objective measurements and indicators. A first recommendation was made in chapter 6 based on *Figure 24* and *Figure 25*. It outlines a significant distinction of close cut-in labels with the indicators of near-field sensor values and values of THW which is the inverse of Q. In a future model design the recommendation shall be considered.
Normal cut-ins:

Issuing of warnings: A percentile agreement of 66% was found with the proposed warning model that uses solely threshold of $Q_{cut-in}$. This result is seen as a moderate success only. By combining the dominant threshold of $Q$ with those of indicators speed (e.g. > 20 kph) or range (e.g. <33 m) offers a limited optimization potential of 3% higher agreement.

Figure 38: The Pearson correlation of the graph is $+0.253 \ (P = 0.364)$. It does not indicate a linear correlation, nonetheless it shows: the higher values of $Q$ are the less ambiguous is the agreement to the warning. This is in-line with the model approach to set an upper threshold of $Q$. The results of the simulator experiment support and validate parts of the model.

Timing of warnings: A good result (89%) was achieved with the basic timing model, see Table 24. It does not offer noticeable optimization by the enhanced timing model. Additionally for normal cut-ins there are demands not only for early warnings but also for delayed warnings, notably 4%. An application of the detailed timing model is once again doubtful because there are no improvements expected.

Peculiarities:
A consensus to the proposed warning model is more difficult to achieve when the participants have to contradict actively to the model: scenes A2 and C3 need an active dissent to comply with the model. This might be the cause for the lower percentage of agreement.

Scene B2 also had a very low agreement of 36%. The scene deals with a rather high Range value (34 m) which can be a possible cause to possibly make it irrelevant for some participants: It provides a comfortable gap to the lane changing vehicle for the manoeuvre. Scene A4 had strong demand to change to hard warning with a high value of $Q = 1.86 \text{ kph/m}$. An underlying near field sensor value confirms the tendency to convert it into the desired type of close cut-in. Another aspect is that the lane changing vehicle was a police car. In the participants’ comments there were hints that it has influenced the subjective ratings of video scene A4.

Likewise in scene D3 several participants demanded a hard warning - with $Q = 1.5 \text{ kph/m}$. Surprisingly for scene B3 as a non-warning scene with $Q = 0.7 \text{ kph/m}$ participants also demanded a hard warning, with no obvious reason. An in-depth investigation unveiled that in both cases – D3 and B3 – the automated congestion assistance system of the prototype vehicle has failed to keep the normal distance after a lane change. In retrospect the validity of the decision to select these two scenes as part of the experiment can be questioned. All these peculiarities have led to an unsatisfactory level of agreement (66%) for normal cut-in warnings. Therefore the results of the questionnaire are specifically considered in order to identify model improvements.

Cut-outs:

Issuing of warnings: A moderate agreement of 76% is achieved. With this adoption of the indicator threshold $Q_{cut-out2} = 1.5 \text{ kph/m}$ (see section 7.4) there is a remarkably improved agreement of +24% with regards to the pilot study. It is worth to mention that only two participants (8%) reject all warnings for cut-out manoeuvres, all other accepted or demanded at least one scene for a soft warning.
**Figure 38**: The Pearson correlation of the graph is -0.485 (P = 0.185), hence a linear correlation is not indicated. The negative correlation value is contra-productive for the validity of the proposed model that uses $Q_{\text{cut-out}}$ as an upper threshold of $Q$ for warnings in cut-out manoeuvres. The result can lead to reject the use of $Q$ further-on for the warning model of cut-out manoeuvres.

**Timing of warnings**: The basic timing model achieves best results with nearly no optimization potential. Again, the enhanced timing model is not recommendable here because more participants want a later warning rather than an earlier warning.

**Peculiarities**: Scenes F3 and G3 have gained low level of agreement to the model. In scene F3 a special type of cut-out is found because the vehicle that leaves the lane drives over a shaded area, i.e. the participants regard this as a driving rule violation of the leading vehicle and might be interested in a warning due to this fact although indicator $Q$ identifies this as a non-warning scene. An explanation why scene G3 does not require a warning cannot be found as in the model a high value for $Q = 2.33$ kph/m fully contradicts to suppressing a warning.

Despite the fact that 92% of participants have selected at least one warning for cut-outs the strategy could drastically be redesigned. A suitable model with indicator thresholds cannot be identified and the overall request for warnings is relatively low. The agreement to non-warnings is higher (79%) than for warnings (65%). Therefore in the redesign of the control transition strategy it is pursued not to consider any warnings for theses manoeuvres at all but to await participants’ agreement in a new experiment.

**Results of the questionnaire process**

In this section the results of the questionnaire process are presented and interpreted along with the findings from the video assessment that show agreement ratings of the control transition strategy. **Figure 39** shows answers to the question about the rationales to accept or disagree to a lane change warning:

Hard warnings are expected if the lane changing vehicle comes in tight distance (88%) to the automated vehicle. Independent from the speed the participants feel uncomfortable with vehicles that perform (tight) close cut-in lane changes. This recognition supports the proposed usage of the near-field distance measurements to identify close cut-ins at an early stage like presented in chapter 5. Further relevant attributes are addressed by participants: The rapidity (quick) of lane changes manoeuvres and the weather conditions (weather) under which lane changes take place could be other motivating factors of agreeing to a hard warning.
High relevancy was found for the indicators *Speed* and *Range* for both hard and soft warnings (76-92%). The choice of indicators based on the NDS data analysis therefore is in accordance with the rationales of participants. It also confirms that indicator Q that represents a combined parameter of speed and range is a valid and strong variable for the control transition strategy. For soft warnings the attribute “tight” also shows ca. 45% of relevance. Unfortunately the near-field sensor measurements for normal cut-ins are not provided in the NDS because sensors measurements are not stable or out of range. The tightness in this case can be captured by a distance measurement of primary sensors (see chapter 5) to the cutting-in vehicles, known as secondary object SO. This indicator is called SO_range and shall be taken into account in the next iteration of the control transition strategy.

*Figure 40* readdresses research question RQ7.3 and shows that the majority of participants (72%) agrees with the basic timing model, i.e. to issue the warning at the beginning of phase2 (InProgress), exactly when the first wheel touches the lane marking. Nonetheless 24% of the participants express their interest in earlier warnings when asked about the preferred timing of the warnings. This slightly conflicts with ratings found in the assessment sheets where the percentages of agreement lay in the area of only 90%. Reason for this discrepancy is found in missing exactness of the questionnaire. The question was not specifically related to soft warnings by the participants: Some participants expressed in comments at the end of the interview process that early warning are only necessary for close-cut-in events which get a hard warning and need an immediate interaction by the driver i.e. in line with expectation a warning for a threat is wanted as early as possible.
The pie charts from Figure 41 onwards represent the results from responses on the Likert scale from \( x = 1 \) (no agreement) to 5 (full agreement). The overall level of agreement is presented by a percentage summary factor \( P \). Due to (Rost 1996) this factor is only applicable if one considers 5 steps of the Likert scale as equidistant. By accepting this simplification the arithmetic mean value is calculated:

\[
P = \frac{1}{n} \sum_{i=1}^{n} 0.25 (x - 1)
\]

With respect to error-proneness (see research question RQ7.4) the results of three scenarios (A-B-C) with false positive warnings are shown in Figure 41. A high level of acceptance to false positive warnings (95 and 79%, resulting in an average of 87%) is found for those scenes with lane changes in progress, i.e. phase2. Much less agreement (47%) is found for a false positive warning that is issued in phase 1, i.e. the lane changing vehicle does not drive over the lane marking. With this finding the target to not allow any false positive warning can be re-evaluated: The control transition strategy needs to be flawless only for these instances of a warning to which the driver cannot clearly associate a lane-change. It deals with warnings that are issued before phase1 of the lane change is finished. In contrast false warnings in a later phase are perceived as a valid driver support by the participants, because they are similarly rated than in Table 22.

![Figure 41: Acceptance of false positive soft warnings](image)

The re-evaluation is supported and commented by (Passchier, van Vugt and Tideman 2015). The author predicts a certain acceptance for false soft warnings in automated vehicles because these do not impact the automated vehicle ride and the driver does not need to take action: “Multiple sensors needs to be combined to improve the redundancy and reliability, and it needs to be guaranteed that the information remains correct also in more extreme scenarios: where some false warnings might be acceptable for a driver warning system, such errors could lead to unacceptable situations if the vehicle will take autonomous action.” Due to the author the tolerance to false positive warnings must not be transferred to the strategy for hard transitions. This study’s result for false positive warnings relate only to soft warnings and must not lead to acceptance of sensor failures, in no circumstances.

The re-evaluation of the timing model leads to a new balancing between the research objectives regarding timing of warnings and error-proneness in the control transition strategy: If false positive soft warnings can be accepted when phase2 of a lane change is reached the proposed basic timing model complies very well with driver agreement. In contrast, by targeting an enhanced timing model to issue warnings as early as possible (namely in phase1) is likely to become disadvantageous through an increased incident of undesired false positive warnings. Conclusively the objective settings for earlier timing of warnings and the avoidance of error-proneness contradict each other.
In the further course of the studies the basic timing model will continuously be applied and seen as valid for the control transition strategy.

![Figure 42: Acceptance of control transition strategy (ACC drivers | non-ACC drivers)](image)

Figure 42 presents further results of the questionnaire process. The left pie-chart treats research question RQ7.6 with the aspect “hands-on-steering-wheel at exit ramps and on-ramps in motorway junctions” This has a percentage summary factor of $P = 64\%$, split into 71% for ACC drivers and 57% for non-ACC drivers. This is interpreted as a modest agreement to a change of the proposed control transition strategy. It is therefore not pursued in the further course of studies.

Research questions RQ7.1 and RQ7.3 are re-addressed with the evaluation of participants’ satisfaction towards the proposed control transition strategy: in the right pie-chart of Figure 42 a summarized satisfaction of 83% is reached while ACC drivers turn out at a more enthusiastic level (91%) to the proposed strategy than non-ACC drivers (73%).

The results of subjective satisfaction match the achievements of the control transition strategy in the video assessment. This has an overall agreement of 72% (including test errors) to the warning model and ca. 91% to the timing model.

### 7.6 Conclusion

Chapter 7 presented the core experiment of this study which was set-up to evaluate the first concept of the control transition strategy as proposed in chapter 6. It was conducted in order to investigate the modelling of the control transition strategy in relation to expectations and the level of agreement of potential drivers. As performance measures the aspects of usability, correct timing and error-proneness of the control transition strategy have been evaluated in the context of the research questions.

In order to evaluate the test set-up the core experiment was pre-tested with a small pilot study involving six participants. The pilot study helped to implement some useful modifications to the core experiment, e.g. the change of a model threshold and the refinement of the questionnaire in order to increase objectivity.

25 participants have been invited to the experiment using a video method with realistic traffic scenes in a basic driving simulator setup. After the video presentations participants went through a survey process.

The research questions of this chapter have been answered to a satisfying grade with the following results:
RQ7.1 investigated the usability of the control transition strategy. Usability was measured by agreement levels of participants to hard and soft warnings. These levels have been evaluated in the simulator experiment in which the participants could agree or disagree to an according warning scheme that was attached to the lane change manoeuvre. Warnings were issued due to the model that used different thresholds of quotient Q as a principal indicator. An overall agreement level of 72% was measured. Effectiveness – which means that the right type of support is given – was high for hard warnings (84%) but for soft warnings it has room for improvement (66%). Efficiency – which means that the right balance of warnings and non-warnings is achieved - can also be enhanced, e.g. non-warnings for cut-ins were agreed to 56%.

RQ7.2 expressed to what level drivers of an automated congestion driving system are satisfied with a warning model that is based on surrounding lane changes. A general subjective satisfaction level for the warning model was investigated in the questionnaire process and resulted at 83%. The proposed control transition strategy revealed to be valued in the simulator environment as an integral part of an automated congestion driving experience. For a higher validity this statement will have to be confirmed in a further step of research. The satisfaction study shall be substantiated with investigations on an acceptance scale due to (Van der Laan, Heino and De Waard 1997) which is utilized in chapter 9.

With RQ7.3 it was investigated to what level drivers comply with the basic timing model. In the driving simulator the participants decided simultaneously whether the warning tone appeared at the right point in time or if they voted for an earlier or later timing. In the core experiment the basic timing model was applied with a good level of agreement for soft warnings (ca. 90%) and even higher for hard warnings (95%). The enhanced timing model sought for a solution that supports a warning as early as possible. In comparison to the basic model this could not contribute to remarkably improved agreement results.

RQ7.4 aimed for error-resistance of the strategy that tries to avoid false positive warnings. A suitable method to investigate the need for error-resistance was installed in the questionnaire process: it was enriched with a sequence of three related videos and resulted in the conclusion that participants are tolerant, at a level of 87%, against false positive warnings, unless warnings are issued in phase1 of the lane change. The experiment results for the timing model turned out to be successful with applying the basic timing model that generates warnings at the precise moment when the first wheel crosses the lane markings. Previous timing objectives could be falsified: It is not a primary goal for participants to issue soft warnings as early as possible and avoid false positive warnings in general. In fact the timing of the basic model suits the needs of participants and the acceptance for false positive warnings grows if they are not issued at an early point in time. The tolerance of drivers towards a false positive warning however only affects normal cut-in manoeuvres which are not related to a safety-relevant driving situation.

With the outcome of RQ7.3 and RQ7.4 it was concluded that the effort to further develop and use an enhanced timing model and the objective of complete error-resistance will not be prioritized in the next step of this study. Confirmation of this decision is pursued in a later experiment. It was also emphasized that weakening the objective of error-resistance does not compromise the reliability and quality in terms of sensor signal integrity. Moreover the basic timing model challenges the sensor system to provide an accurate point in time for the moment of line-crossing.

In research question RQ7.5 the difference of two participant groups was evaluated. The groups are differentiated by the participants’ experiences in advanced driving assistance systems, in special the
practical driving experience with an ACC system.
In all areas of the experiment a previous experience with ACC driving proved to be of no significant
effect on the acceptance, usability and satisfaction of the proposed warning model. Conclusively the
approach to design a strategy that works independent of different driver types is fulfilled with
respect to experience.

RQ7.6 aimed to extend the warning model with further indicators beyond the preliminary model.
The results in RQ1 showed an overall or moderate to adequate perceived usability of the preliminary
warning model. Q was identified in the model as principal indicator that takes vehicle speed and
distance into account and which correlates with the time headway.
In the questionnaire process participants could select indicators additionally to the established
signals.
This selection of indicators led to the recommendations to explore the use of near-field distance and
distance to the cutting-in vehicle as additional indicators to further develop the strategy. For hard
warnings it will be beneficial to make use of the indicators near-field distance and Q which derive
from objective sensor signals. As a desired side effect the warnings will become independent of
labels.
For soft warnings a redesign and refinement was proposed. Normal cut-in manoeuvres have a
significant correlation of agreement with thresholds of indicator Q. This can potentially be
supplemented by a novel indicator that represents the distance to the cutting-in vehicle (SO_range).
Cut-out manoeuvres showed a rather uncontrollable behaviour with indicators. A revised strategy
shall consider neglecting any warning for cut-outs.
A subordinate investigation addressed the acceptance for exceptions in the warning model. In areas
of motorway on-ramps and exit ramps the functionality of the congestion assistance system can be
switched off to avoid excessive warnings in these areas. This adjustment would lead to only a
moderate agreement of 64% and will therefore not be pursued further-on in this study.

In the core experiment the results revealed an overall positive attitude of drivers towards an
automated driving technology with collaborative approach and a control transition strategy that is
based on surrounding lane changes. The assessment of the control transition strategy itself was
overall positive with room for improvement in some areas, e.g. the efficiency of soft warnings.
Refinement of the first concept model will therefore be addressed in the next chapter.
A follow-up driving simulator experiment shall be conducted to assess whether drawbacks in
usability of the control transition strategy can be overcome by a refined model.
8. Model Refinement and Follow-up Experiment

8.1 Introduction

The core experiment has served well to evaluate the first concept of the control transition strategy that was presented as a preliminary model for both, the warning and the timing aspect. The research questions have been answered to the desired extent. However, the results regarding driver agreement and usability can be judged to be still on an unsatisfactory level and offer an opportunity for improvement. Therefore a refined model design and a follow-up experiment are recommended in order to demonstrate progress and advancement in the overall research objective which is to develop a control transition strategy for successful and usable driver support in automated congestion driving.

The results of the planned follow-up experiment are principally aiming to achieve an improved agreement level of participants to a refined strategy. The method to set-up a series of experiments in a simulation environment is well established in automotive research. (van Waterschoot 2013) conducted a suite of experiments for the development of cognitive systems, each with modification that resulted from recognitions of the previous one. In a similar way a new model shall be developed with the learnings from the core experiment in chapter 7.

The timing model development is provisionally paused after the core experiment because it represents a well-balanced compromise of earliness and error-tolerance objectives and resulted in satisfying usability. The focus of refining the model will be on the warning model itself which is that part that determines identification of hard warnings as well as limitations of soft warning. Further-on it is referenced as “refined warning model”.

The research questions RQ for the follow-up experiment can be narrowed down as follows:

RQ8.1: Based on the findings from the core experiment how can the warning model be refined and enhanced in order to increase the agreement levels of participants?
It is intended to change the control transition strategy in a next iteration step with the learnings of the core experiment. New signals like SO_range and Nearfield_range have been identified as relevant indicators in the questionnaire process and shall be integrated into the existing model.
As a second design challenge the model is striving for the goal to objectify rules of the control transition strategy, i.e. close cut-ins manoeuvres shall be detached from the solely dependence on the subjective labels that were assigned in the NDS post-processing work. This prepares the strategy for an application with real-time data.

RQ8.2: How does the refined warning model contribute to an enhanced level of usability in the follow-up experiment?
The usability results for soft warnings shall be brought to a higher level of effectiveness and efficiency. It will also be tested whether there is an improved agreement for cut-out manoeuvres that will not be warned due to the conclusions from chapter 7. In all presented cut-out scenes no soft warning chime will be issued.

RQ8.3: Does the refined model need another iteration step?
The refined warning model is being designed with the known indicator Q of the preliminary model completed with new indicators that shall help for a greater success in agreement and usability. The
question targets on what kind of influence new indicators have in order to learn about necessities to simplify or enhance the model design in a next iterative step.

**RQ8.4: Do participants with differing levels of experience with the control transition strategy vote differently about the usability of the warning system?**

This question focusses again on the generality of the control transition strategy that shall be particularly useful to all kind of drivers. In the core experiment it was possible to establish a participant grouping with differentiated ACC experience. ACC driving experience turned out to be a non-crucial attribute for the strategy. In the follow-up experiment participants shall be devided into three groups that have different experience levels but are all subjected to same test procedure:

- **Group 1A:** former participants with high agreement in the core experiment
- **Group 1B:** former participants with low agreement in the core experiment
- **Group 2:** new participants with fresh eye approach

After addressing all research questions the chapter concludes the new model efforts and the experiment results with a recommendation for a next step in the suite of experiments.

### 8.2 Model enhancements and refinement

With reference to research question RQ8.1 a second design iteration of the control transition strategy is to be introduced. With Figure 43 the representation of the proposed refined warning model is given and the enhancements can be discussed.

![Figure 43: Refined warning model](image)

Objectives of the refined model are firstly to make use of additional indicators in order to achieve a high usability for soft warnings and secondly to base hard warnings on indicators that derive from sensor signals instead of the post-processed labelling. The refined model in Figure 43 works with two new indicators as input signals: SO_range and the near-field distance signal are used. SO_range and near-field represent both the distance to the relevant secondary object that is about to conduct a
Model Refinement and Follow-up Experiment

cut-in manoeuvre as discussed in section 5.7. SO_range is provided by the primary sensor system (radar and camera sensors) and compensates a missing near field signal which is limited in distance coverage and therefore not available for most of the cut-in manoeuvres. During the NDS data analysis there was no option to extract the SO_range signal automatically. For the model refinement it was generated by manual extraction for the video scenes that shall be used in the follow-up experiment.

SO_range can be associated with the attribute “tight” which was indicated as relevant by the participants in the survey of the core experiment. Internally in the model a new indicator $Q_{SO}$ is used that has a similar nature as the principal indicator $Q$. The definition of $Q_{SO}$ is

$$Q_{SO} = \frac{vehicle\_speed(TJA\_vehicle)}{SO\_range}$$

In here both relevant attributes from the questionnaire process are applied, “tight” and “speed”, by using a SO distance signal and the TJA velocity signal.

The Range indicator represents the distance to the leading vehicle (primary object PO) and was also discovered in the core experiment as a useful input to the model.

By using $Q_{SO}$ and Range the new calculation rule for **soft warnings** is established that extends the old one by logical operations:

$$Q > Q_{soft} \text{ OR } (Q_{SO} > Q_{SO,\text{soft}} \text{ AND } \text{Range} < \text{Range}_{th})$$

with $Q_{soft} = 1.0 \text{ kph/m}$ $Q_{SO,\text{soft}} = 2.0 \text{ kph/m}$ $\text{Range}_{th} = 30 \text{ m}$

The first term and threshold is resumed from the previous version of the model. The second term in brackets takes into account that the warning acceptance for a normal cut-in manoeuvre also exists if the cutting-in vehicle performs a tight cut-in manoeuvre ($Q_{SO,\text{soft}} = 2.0 \text{ kph/m}$) in combination with a gap that does not exceed an upper threshold ($\text{Range}_{th} = 30 \text{ m}$). Hence it does not offer a vast room for manoeuvring and it forces the driver of the lane changing vehicle to decelerate. Literally it can be stated that the secondary object has limited space to adopt itself to the traffic flow of the new lane.

The proposed calculation rule for **hard warnings** is also established with logical operations of indicators:

$$\left(\text{Nearfield\_range} < \text{Nearfield}_{th} \text{ OR } Q_{SO} > Q_{SO,\text{hard}}\right) \text{ AND } Q > Q_{hard}$$

with $\text{Nearfield}_{th} = 2.0 \text{ m}$ $Q_{SO,\text{hard}} = 5.0 \text{ kph/m}$ $Q_{hard} = 1.0 \text{ kph/m}$

The indicator Q requests a minimum threshold value $Q_{hard}$ which means that the scenario needs to be at least as relevant as for soft warnings. Otherwise the cutting-in vehicle would even have a lot of space to accelerate into the gap.

With the first term the near field measurement establishes Nearfield_range as a relevant indicator for hard warnings. However, it is known from the naturalistic driving study NDS that the near-field sensors do not reliably provide values in conjunction with close cut-in labels and therefore it cannot
stand alone. It has to be complemented with a high threshold for $Q_{GO}$. The rule combines the narrowness of the close cut-in manoeuvre with regards to the primary and the secondary object.

Along with the advancement to characterize close cut-ins with thresholds of indicators there is another major advantage: close cut-in manoeuvres and according hard warnings are resolved and uncoupled from label indicators. Hereby they can principally be generated in real time during driving and are no longer depending on subjective assessment in post-processing work.

The proposed threshold values of $Q_{GO\_sof}$ and $Range_{th}$ as well as $Nearfield_{th}$ and $Q_{GO\_hard}$ derive from the agreement results in the core experiment. They are selected in order to optimize the agreement levels. This shall be evaluated in the oncoming follow-up experiment whether another iteration of the model or its thresholds is required.

The warning model is now based on objective indicators deriving from sensor signals. In contrast, this cannot be stated for the timing model. The proposed basic timing model still requires the recognition of that point in time of the lane change when the first wheel touches the line marking. This has to be reminded for the conclusion of this chapter.

### 8.3 Setup of the Follow-Up Experiment

#### Procedure

It was decided to copy the experiment setup from chapter 7 to the follow up experiment because the research questions of this chapter are focussed on refined modelling work and the improvement of usability results, which can best be assessed in similar context. Accordingly the representation in Figure 36 is identical for the setup of the follow-up experiment including the introduction to the control transition strategy, the lay-out of the assessment sheet and the counter-balance principle. The experiment procedure as shown in Figure 37 also applies - except the pilot study in the beginning and the questionnaire process in the end of the test. These have been omitted because it was not expected to gain new insights by repeating them. Regarding usability the research question RQ8.2 focuses on efficiency and effectiveness in order to bring these to an improved level on satisfaction which was investigated by the questionnaire. The question does not focus on satisfaction which was investigated by the questionnaire.

The replication of the setup is furthermore a mean to underpin the internal validity of the experiment (Krauth 2000).

#### Stimulus material

In Table 25 the list of video scenes is composed for the experiment in order to put the refined model under test. Many valid video scenes of lane change manoeuvres are reused from the core experiment while it was important to eliminate misleading scenes (see section 7.5) because they were contra-productive for the development of the control transition strategy. E.g. scene A5 is reused but according to the refined model is converted from a hard control transition into a soft
control transition. In order to increase internal validity of the test also new scenes have been added. The basic timing model is again applied for the issuing of warning chimes. Because it is not under test in the follow-up experiment participants no longer had to fill in the assessment sheets regarding the timing model.

<table>
<thead>
<tr>
<th>Type</th>
<th>Scene</th>
<th>Speed (kph)</th>
<th>Range (m)</th>
<th>Quotient (kph/m)</th>
<th>nearField (cm)</th>
<th>SO_range (m)</th>
<th>Qsc (s/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUT-IN</td>
<td>A1</td>
<td>31</td>
<td>23</td>
<td>1.35</td>
<td>997</td>
<td>18.3</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>25</td>
<td>36</td>
<td>0.69</td>
<td>76</td>
<td>7.6</td>
<td>3.29</td>
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<tr>
<td></td>
<td>A3</td>
<td>37</td>
<td>26</td>
<td>1.42</td>
<td>977</td>
<td>7.4</td>
<td>6.00</td>
</tr>
<tr>
<td></td>
<td>A4</td>
<td>26</td>
<td>14</td>
<td>1.56</td>
<td>520</td>
<td>9.9</td>
<td>2.63</td>
</tr>
<tr>
<td></td>
<td>A5</td>
<td>18</td>
<td>27</td>
<td>0.67</td>
<td>146</td>
<td>5.6</td>
<td>3.21</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>41</td>
<td>34</td>
<td>1.21</td>
<td>500</td>
<td>16</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>B4</td>
<td>31</td>
<td>28</td>
<td>1.11</td>
<td>10.1</td>
<td>3.07</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C1</td>
<td>27</td>
<td>21</td>
<td>1.29</td>
<td>11.1</td>
<td>2.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>31</td>
<td>37</td>
<td>0.84</td>
<td>16.5</td>
<td>1.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>30</td>
<td>21</td>
<td>1.43</td>
<td>11.7</td>
<td>2.56</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C4</td>
<td>36</td>
<td>28</td>
<td>1.36</td>
<td>18</td>
<td>2.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D1</td>
<td>24</td>
<td>26</td>
<td>0.92</td>
<td>17.7</td>
<td>1.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D2</td>
<td>40</td>
<td>26</td>
<td>1.54</td>
<td>21</td>
<td>1.90</td>
<td></td>
</tr>
<tr>
<td>CUT-OUT</td>
<td>A6</td>
<td>32</td>
<td>25</td>
<td>1.30</td>
<td>163</td>
<td>2</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>B6</td>
<td>20</td>
<td>12</td>
<td>1.67</td>
<td>186</td>
<td>2</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>C5</td>
<td>35</td>
<td>20</td>
<td>1.75</td>
<td>820</td>
<td>6</td>
<td>5.83</td>
</tr>
<tr>
<td></td>
<td>D4</td>
<td>12</td>
<td>12</td>
<td>1.00</td>
<td>118</td>
<td>4.4</td>
<td>2.73</td>
</tr>
<tr>
<td></td>
<td>E3</td>
<td>36</td>
<td>13</td>
<td>2.77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F3</td>
<td>27</td>
<td>19</td>
<td>1.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>35</td>
<td>15</td>
<td>2.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H1</td>
<td>13</td>
<td>8</td>
<td>1.62</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 25: Scene composition for the follow-up experiment with new indicators

Participants

The objective of participant selection is to form different groups that may potentially have a different attitude towards the control transition strategy. The core experiment provided a distinction of participants that had different ACC drive experiences but the results did not turn out significant differences. The acquisition of participants for the follow-up experiment requests in to research question RQ8.4 a new gouping which includes the reactivation of former participants for group 1A and 1B.

Figure 44 shows the characteristics of group 1A and 1B regarding their agreement to the proposed control transition strategy resulting from the previous experiment. The agreement factor of a participants is built as the ratio of model compliant votes and complete votes. The two curves show agreement factors of all lane changes and separately the agreement factor of normal cut-ins which have a special attention in the research quesitons of this chapter. Participants outside the standard deviation (±1 σ) are selected for the test, Group 1A (N_{1A} = 5) is formed by participants that showed already an inclination towards the strategy and an agreement factor higher than 0,79. Whereas group 1B (N_{1B} = 5) consists of participants that were more critical towards the preliminary model in chapter 7 and showed an agreement factor lower than 0,57.
Figure 44: Agreement factors of former participants

Another group - labeled group 2 - is formed \((N_{2} = 10)\) to represent participants with an “unbiased condition” in this experiment, i.e. they do not have earlier experiences with the subject of automated congestion driving, a related experiment and the proposed control transition strategy. The total number of participants \((N_{\text{total}} = 20)\) is formed in order to have a count of representants similar to the previous experiment. Together with groups 1A and 1B the three groups are to be analyzed regarding their agreement with the refined model.

8.4 Results and Discussion

The follow-up experiment was conducted in spring 2015 and it was setup in a similar way as the first experiment. Table 26 introduces the primary results of the experiment by listing the percentile agreements to the warnings issued during different lane change manoeuvres in order to provide answers to research question RQ8.2. Similar to Table 22 of the core experiment columns 2 and 3 show the agreements to issued warnings and to non-warnings as proposed by the control transition strategy.

<table>
<thead>
<tr>
<th></th>
<th>Agreement to Model-proposed warnings</th>
<th>Agreement to Model-proposed non-warnings</th>
<th>Overall: Agreement to Model-proposed warning type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close cut-ins</td>
<td>89%</td>
<td>-</td>
<td>89%</td>
</tr>
<tr>
<td>Normal cut-ins</td>
<td>76%</td>
<td>80%</td>
<td>77%</td>
</tr>
<tr>
<td>Cut-outs</td>
<td>-</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Overall</td>
<td>79%</td>
<td>83%</td>
<td>82%</td>
</tr>
</tbody>
</table>

Table 26: Agreement results of warning model

A first evaluation of these results reveals an improvement in all categories of strategy. Striking is the overall improvement of +10% to 82%. This new score corresponds to the effectiveness of the control transition strategy stating that the right type of support in the shape of hard, soft and non-warnings was provided.
Agreement to close cut-in warnings grows with +5% from 84% to 89% which is a progressive result of the refined model. The new non-warning concept for cut-out manoeuvres results in a substantial increase from 76% to 95%. The percentile increase of +11% for normal cut-ins from 66% in the core experiment to 77% illustrates another major achievement of the refined model. The third column in Table 26 shows that non-warnings find an equally high agreement level than warnings. The new efficiency score of the refined control transition strategy can be rated in the area of 79-83% (see last row of Table 26).

It was attempted to optimize the results by variation of indicator thresholds in the refined warning model (e.g. by setting $Q_{SO_{soft}} = 2.5 \text{ kph/m}$). It did not lead to higher agreement percentages. The defined model thresholds are at an optimal value in this experiment. Therefore they can be carried over to a next iteration step of experiments.

Conclusively it can be stated for research question RQ8.2 that the usability scores for the strategy have been increased for the two aspects, effectiveness and efficiency.

Regarding research question RQ8.3 it shall be investigated whether the construct of the refined warning model needs another iteration step e.g. by simplifying the connections in the model which includes combined Boolean operations. For that purpose a more detailed presentation of single video scenes and their relationship with the newly introduced indicators $Q_{SO}$ and Nearfield_range is given in the scatterplot diagrams of Figure 45. The dots represent normal cut-in manoeuvres; the squares are close-cut-ins. The plots provide a tests if a linear relationship with the results of agreement exists. For $Q_{SO}$ the Pearson correlation is at +0.217 ($P = 0.386$), for Nearfield_range the correlation factor is negative -0.453 ($P = 0.188$). With the linear fittings the expected correlation is slightly suggested but no significance can be proven by Pearson analysis. The new indicators do not demonstrate a direct influence on their own. The logical linking with the old indicators Q and Range is indispensable. For RQ8.3 it can be stated that the new indicators cannot be applied separately.

The analysis for research question RQ8.4 is provided in Table 27. It serves to learn about differences in the agreement results of the three groups as introduced in section 8.3. Chi-Square testing is shown for all types of lane changes. Overall the table points out that there are no significant differences revealed (i.e. $p > 0.05$) for the three different groups, likewise the result for ACC and non-ACC drivers in the core experiment. (MINITAB 2007) indicated that the chi-square test result is fully valid for normal cut-in manoeuvres. For close cut-ins and cut-outs the application of chi-square test may not be valid due to expected counts of less than 5.
As an outcome for research question RQ8.4 it can be stated that for normal cut-in manoeuvres and related soft warnings a difference of all groups was not found. Consequently the control transition strategy proved to be resistant against this kind of driver and participant variation.

<table>
<thead>
<tr>
<th></th>
<th>Warning type agreed</th>
<th>Warning type not agreed</th>
<th>Chi-square</th>
<th>DF</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>group1A</td>
<td>group1B</td>
<td>group 2</td>
<td>group1A</td>
<td>group1B</td>
</tr>
<tr>
<td>Close cut-ins</td>
<td>19</td>
<td>17</td>
<td>35</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Normal cut-ins</td>
<td>53</td>
<td>54</td>
<td>108</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Cut-outs</td>
<td>18</td>
<td>20</td>
<td>38</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 27: Significance of group differences (groups 1A|1B|2)

Finally is has to be stated that reproducibility of results in the both experiments, the core and the follow-up experiment, has one major drawback that is learned from video scene A1: This scene got a soft warning in the core experiment because the threshold for indicator Q was reached. In the follow-up experiment the same scene was presented by chance as a non-warning proposal (underlined scene) due to experiment setup rules. The agreement to the model went drastically down from 92% to 35% - just by the conversion into a non-warning proposal. For the participants in the second experiment it meant they had to actively dissent in order to comply with the model, what the majority of participants did not do.

It is already known from the core experiment that underlined scenes achieve lower agreement ratings. The fact that participants are less likely to dissent than to comply with a proposition can be connected to power of suggestion. TV media (Eberle 2002) report about this phenomenon: “...suggestive power of television is based on the impression of authenticity of the audio-visual presentation by the combination of moving images and sound.” Eberle’s statement criticises indirectly the validity of the chosen test setup for the purpose of developing the control transition strategy.

In order to avoid suggestive effects of video methods and to enhance further validity of the experiments in this thesis a consecutive experiment has to be considered that differs in its setup from a driving simulator test using the video method.

8.5 Conclusion

The first concept of the control transition strategy was evaluated in chapter 7 and left opportunities to improve the scores for driver agreement and usability of the concept. Now chapter 8 described the next iteration step for the concept by presenting a refined warning model and the follow-up experiment as the second participant-based test in a driving simulator.

The precise answers to the defined research questions of this chapter are as follows:

RQ8.1 aimed on the design of a refined warning model. In the refined model the issuing of warnings for cut-out manoeuvres has been excluded. The first concept was built on basic modelling: Q was used as main indicator for soft warnings and close cut-in labels exclusively for hard warnings. The
refinement of the warning model was based on the findings in the core experiment leading to enhancements of the strategy with new indicators for the cut-in manoeuvres: In parallel to the known indicator $Q$ the Range indicator was added as well as an indicator $Q_{SO}$ that represents the time headway to the cutting-in vehicle. For close cut-in manoeuvres the indicator Nearfield_range was introduced. The issue of warnings was determined on indicators thresholds and logical operations. The progress of the refined warning model furthermore consisted of mainly using sensor values in lieu of subjective lane change labels. With the current state of technology this is unfortunately not yet feasible for the timing model which remains dependant on label indicators.

In RQ8.2 it was investigated whether the refined control transition strategy indeed led to a higher level of usability perceived by the drivers. The follow-up experiment was setup with groups of participants that reviewed video scenes similar to the set-up of the core experiment. A remarkable improvement in the agreement of participants warning issued by the refined control transition strategy was achieved. Compared to the previous experiment the overall agreement increased to 82%. Usability of the strategy revealed an improved scoring, with +10% in effectiveness and efficiency scores up to 83% (for non-warnings).

With RQ8.3 it was addressed whether the new model construction and thresholds have been adequately defined or if a further model iteration is required. $Q_{SO}$ and Nearfield-range were tested for a direct influence on the agreement of participants to the warning model. The presumed tendency was found in a correlation test, however, there was no significance of a direct linear dependency. None of the indicators is thereby decisive on its own. The achieved agreement to the refined model is based on logical operations on combined indicators and their thresholds. The warning model development can be concluded at this stage and further research emphasis may be given to an assessment in context of a different testing method.

RQ8.4 investigated the effect of different participant characteristics on their agreement with the refined strategy. The participants were grouped into three cluster teams, consisting of unexperienced, critical and sympathising participants. No significantly different levels of agreement to the refined strategy were found. Like before in chapter 7, this is a building block to substantiate that the strategy is universally usable for different kinds of drivers.

The refined warning model and the results of the follow-up experiment revealed chances and challenges to the research. The progress by remarkably increasing the agreement and usability levels of participants in the follow-up experiment remains a major achievement of the refined model.

Using video scenes within the current experiments has two drawbacks in authenticity: Firstly that the level of realism is lower because results are influenced by the power of suggestion inherent to the video method. Secondly only distinct and isolated scenes are lined up that do not represent the coherent traffic flow as a real driving experience. Both drawbacks lead to lower validity of the results, due to which they might not be fully representative to real life behaviour. It is highly desirable to conduct a further experiment under realistic driving conditions to test the model and the control transition strategy along with stronger external validity. Conducting a field test that offers real traffic jam driving with the use of an active congestion assistance system will help to overcome the artificial effects of video watching.

The process of establishing a field test in the sequence of experiments is well known in automotive research: (van der Voort 2001) made use of simulator experiments to initially evaluate a new fuel-efficiency support tool. They were followed up by a field test validation. (Risto 2014) studied the
effect and acceptance of commuting drivers towards advice messages – initially in a university driving simulator and subsequently in a functional prototype and real motorway traffic. An equal approach shall be pursued in this study. The next iteration step of developing the control transition strategy will be to work with the current model status (which is the refined warning model of Figure 43 and the basic timing model of Figure 33) and concentrate remaining research questions on evaluating this model in a more realistic driving context.

As a closing remark to this chapter it shall be uttered that the refined warning model did not resolve a generic issue: A complete disengagement of the control transition strategy from manual labels was targeted, however, this was not feasible because in the follow-up experiment the basic timing model was still used which is not supported with sensor signals. The line crossing event of a lane change was still captured by labels. This fact has to be reminded when the proposed control transition strategy is translated into requirements for automated congestion driving technology. In practice the system's digital image processing unit will need to identify line crossing events with a reproducible accuracy for any type of vehicles on wheels. (Urhahne, Steiger and van der Voort 2014) declared the necessity of providing appropriate sensors signals in real-time that guarantee an equal or even higher quality than human labels or equivalent human perception.

In this view the proposed model cannot fully satisfy the approach to comply with sensor systems that were used in the prototype vehicles of this study. The issue of correct timing for the control transition strategy is closely linked to advanced image processing capabilities. This subject is recommended for ongoing research in automated driving.
9. Field Test

9.1 Introduction

Previous experiments explored main aspects of the control transition strategy. They started with a first concept of a warning model that was tested in a simulator study of the core experiment. It turned out that usability of the strategy has highest priority for further research while remaining aspects like early timing and error-tolerance stay in the background. The follow-up experiment was based on a refined model with additional indicators that resulted in an improved usability and driver agreement. These first two experiments were conducted in a basic driving simulator. Although having the advantage of a safe and controlled testing environment, driving simulator experiments are exposed to a reduced external validity due to a lower level of realism. Furthermore the simulator experiments only addressed short, individual and specific traffic scenarios, not allowing monitoring participant behaviour over a longer time frame consisting of sequential naturalistic traffic scenes. Hence, previous participants in this study had to abstract the testing situation in a driving simulator instead of driving a real car on a real motorway.

The third experiment puts the usability research of the proposed control transition strategy into a broader and realistic context regarding the technology of collaborative automated congestion driving. In comparison to the previous tests the final experiment is executed in the form of a small-scale field test and allows to test under a higher level of realism as well as over a time-coherent sequence of traffic scenes. Again the definition of usability according to ISO 9241-11 shall be addressed in this investigation to cover its crucial aspects of effectiveness, efficiency and satisfaction.

The usability of the strategy will be assessed while driving in full context of the technology: The participants of the field test will drive a vehicle equipped with a prototyped congestion assistance system on their own – in the driver’s seat and behind a steering wheel. The principal focus of the test drives is to determine the usability of a warning model based on surrounding lane changes. However – the participants are also exposed to the experience that another reason for warnings and control transition like time-outs and end of congestion driving can appear in parallel. The participants have the opportunity to experience and evaluate the control transition strategy in a realistic setting of automated congestion driving.

The remaining research questions for the field study can be narrowed down as follows:

RQ9.1: Is the nature of field test data comparable to NDS data?

The model design is based on data material from the naturalistic driving study NDS (chapter 5). This was conducted at an earlier time (2012) and at different locations in Europe. The consistency of congestion driving data shall be compared by statistic means in order to confirm that data for model development with NDS data and model evaluation in the field study is equivalent to a high degree. In addition a similarity of data can confirm that the conditions for applying the model are primarily not dependant on time and location. This would also proof that the usability of the strategy is maintained in general manner.
RQ9.2: Do the added model indicators have a positive influence on the agreement of drivers with the refined warning model?
This question focusses on soft warnings: While the principal indicator \( Q \) stood alone in the preliminary model it did not perform well. Additional indicators \( Q_{SO} \) and Range have been identified for the refined model (see section 8.2) and according threshold values were introduced with a second logical term. Now the introduction of this term shall be retested under realistic driving conditions in the field test to answer the question: how does the second term perform for the agreement to the control transition strategy? The method will be to investigate the influence of the second term and its threshold values in scatterplots.

RQ9.3: What level of agreement to the control transition strategy do drivers reach under the circumstances of a field test...?

- for cut-outs,
- for close cut-ins,
- for normal cut-ins,
- and for the timing of the proposed warnings?

The research question can principally be answered by evaluating the drivers’ spontaneous responses to warnings that are issued in the field test. The levels of agreement can be calculated from these responses. It contributes to the research of model effectiveness and efficiency for the different warning types: hard and soft warnings as well as non-warnings. They shall be compared with the results of the driving simulator experiments. Consistency and progress of results with regards to the core and follow-up experiment are expected.

Additionally a questionnaire will be presented to the participants after each test drive in the field test. The individual perception of the control transition strategy by the participants will be investigated with queries RQ9.4 to RQ9.8:

- **RQ9.4:** How effective do participants rate the strategy based on lane changes?
  As part of the usability study the effectiveness of the warning model shall be subjectively judged by the participants on a five-step Likert scale.

- **RQ9.5:** To what extent do participants accept the proposed strategy?
  One part of the usability study is the expressed acceptance which in itself is divided into two main attributes: usefulness and satisfaction. As an established method to investigate system acceptance this question shall be addressed by the Van der Laan scale (Van der Laan, Heino and De Waard 1997).

- **RQ9.6:** Is the proposed strategy acceptable in combination with parallel warnings that appear in a timely period (3 min)?
  The parallel time-out warning concept is introduced in the procedure section of this paragraph and stands in for other possible warning reasons (like loss of lane markings etc.) that can be scope of a congestion assistance system. This thesis concentrates on the proposed control transition strategy based on lane changes. The research question reveals from a usability perspective whether warnings can be combined in a harmonized manner within a larger framework and substantiates the generality of the model work.

- **RQ9.7:** Do drivers understand that they have to react differently to soft and hard warnings?
  The warning model relates to transitions in control: Hard warnings are meant to instantly
return to manual driving while soft warnings create awareness that the responsibility remains always with the driver and a take-over can be needed at any time. Soft warnings are not assumed to provoke a physical reaction of the driver by hands or feet. This research question will investigate to what extent the participants understand this concept and are able to differentiate the action needed on both warning types as intended by the control transition strategy.

- RQ9.8: Do the drivers appreciate the proposed control transition strategy based on lane changes as relevant part of an automated congestion system?

These queries in the questionnaire process target on a general judgement about the experience to drive first time an automated vehicle with the given limitations and the applied strategy. It places the research on usability and acceptance of a warning model into perspective of a holistic customer’s view.

In the interest to accustom the control transition strategy to a universal type of driver the participants were divided into two groups. Herewith an additional research question is formulated:

RQ9.9: Do "fresh-eye" drivers assess the usability of the strategy differently from experienced drivers?

The question focusses on the comparison of two different groups in the field test. A hypothesis is made that there are no significant differences between groups of drivers that have been familiarized with the subject of automated driving and those that were unexperienced ("fresh-eye").

This chapter reports about the setup and the execution of the field test and presents its results in order to address above listed research questions. In the conclusions it summarizes the progress that was achieved in the field test as a final experiment within this research in comparison to the previous experiments.

9.2 Method

This subsection serves to present the basic setup of the field test by describing four major methodical aspects: the selection of participants, vehicle equipment, test procedure, data collection and post-processing for test evaluation.

Participants

In correspondence with RQ9.9 the participants have been selected to form two equal-sized groups, a group of ‘fresh-eye’-participants and a group of persons that were familiar with the subject of automated congestion driving and the control transition strategy because they attended in one of the former simulator experiments.

Accordingly ten persons (N=10) have been recruited for this field experiment distributed over three testing days. The age varied from 38 to 51 years. Two female drivers were present. The participation was on a voluntary basis without monetary or other rewards. All participants showed an interest in the subject of automated congestion driving and they were motivated to drive a prototype vehicle. While the participants in the core experiment were grouped into ACC and no-ACC experience the participants in the field test were selected independently from their affinity towards ACC because no
significant differences between these groups were found.

Vehicle Equipment

The field test was conducted with a vehicle that offered congestion driving functionality (TJA) on a prototype level. It was identical to one of the equipped vehicles that was used in the naturalistic drive study NDS as presented in chapter 5. The tests were conducted in autumn 2015 at the motorway ring around Cologne. At that time the prototype vehicle was prepared to drive on public roads with automated longitudinal and lateral control under supervision of a safety engineer (supervisor) on the passenger seat. While external validity of test results is generally rising the observer effect caused by a supervisor cannot be neglected. (Saunders, Lewis and Thornhill 2009) described this as a natural effect because the participant is conscious of being observed. His recommendation “minimal interaction” of the observer was followed in principle and actually no interaction was performed with the ten drivers: The vehicle was fitted with a duplicated pedal system at the passenger side in order to allow the supervisor an intervention on the automated drive in case of critical situations. This facility was never used during the tests but it provided a comfortable and safe feeling for the participant and the supervisor.

The TJA system in the field test was calibrated to be active at a speed in traffic congestions up to 60 kph because previous testing revealed a stable behaviour. Fortunately this enabled a collection of more traffic scenes that were relevant for the research questions. For comparison: In the NDS analysis and according simulator experiments the functionality was supported up to 50 kph.

The vehicle had the identical set of sensors as used in the NDS: a digital imaging unit behind the windscreen and a radar sensor in the front bumper as the input for longitudinal and lateral vehicle control. It was calibrated in the same way as during the NDS; for safety reasons the distance to the leading vehicle was kept in a conservative manner. Additionally ultrasonic sensors and a Lidar sensor were used to perform a near field measurement, see Figure 23.

Another predefined part of the congestion assistance system was tuned to issue a time-out warning after 3 minutes of automated driving. It requested the participants to put the hands back on the steering wheel for a brief moment. The automated drive was continued thereafter.

The application of the warning model for lane changes is described in the next section. For timing and technical reasons it was not implemented as a working prototype system.

Procedure

The organizational and logistic constraints of the field test are described by the fact that the vehicle was available for five working days with two day of preparation and three days of testing. A typical congestion drive could be guaranteed in the morning and afternoon rush hours. A drive around noon potentially resulted in less congestion and consequently less lane changes per drive. The nature of field tests does not allow anticipating what kind of traffic situations and how many surrounding lane changes the individual test drivers would experience. The tests were not controllable or reproducible for each participant and it was not ensured that all kind of manoeuvres and relevant traffic scenes would happen in every test run. On the other hand external validity rises because there is less artificiality in the test setup and the generality is increased because each event is unique. All participant had to reserve minimum 1,5 hours of test time. In average the participant had ca. 30 minutes and 8-10 kilometres of relevant test driving in motorway congestion, the rest was spend as travel and interview time.
Prior to the test drive the participants are verbally introduced to the subject of automated congestion driving and the activation and functionality of TJA was explained. The participants have been familiarized with the control transition strategy based on lane changes and its task to differentiate between hard and soft warnings and non-warnings. Therefore the warning chimes for soft and hard warnings were presented over the vehicles audio system before the test drive.

The drivers had to consciously start and maintain the congestion assistance functionality, and they observed the visual HMI elements to understand when the automated driving was active or inactive. As soon as the automated test drives in traffic jam started the participant and the supervisor on the passenger seat watched the surrounding traffic in common.

The warning model was implemented in manual format. At every instance, when a related lane change occurred, the supervisor generated the soft warning chime via the vehicle audio system at the point in time when the line crossing of a lane changing vehicle was identified. This surrogate to realize the warning model in the prototype vehicle with human interaction was inspired by the “Wizard of Oz” method, see e.g. (Kelley 1984). In contrast the Wizard of Oz technique normally works with hidden human support.

Directly after the warning chime the participants were prompted to decide whether the issuing of a warning was considered applicable as well as if the type of warning was correct. In ca. 15% of the cases the participants were undecided to answer with a clear “yes” or “no”. A preferred decision (e.g. rather yes than no) could be elicited for all lane changes from the participants in order to process the model with unambiguous test results.

There were some instances when participants requested a hard warning instead because a cutting-in vehicle was perceived as a close cut-in event. In these cases the supervisor asked for a confirmation of their demand by generating a delayed hard warning chime and by confirming their willingness to intervene and take over the automatic vehicle drive themselves unless already done in a spontaneous reaction. The requests for hard and soft warnings as well as non-warnings were documented in writing as well as they were recorded on a voice recorder.

In parallel to warning chimes in response to the proposed control transition strategy there were also the afore mentioned audible warnings in case that the automated congestion drive was exceeding a time limit of 3 minutes. Every test driver had experienced such an event and had to react accordingly by shortly taking over the steering control followed by the continuation of the automated drive. The occurrence of time-out warnings could therefore be assessed by all participants.

After the drive event, when the vehicle was parked, the drivers participated in the questionnaire process in order to provide further input to the related research questions of this chapter. The eight questions are documented in the Appendix B. The main purpose of the questions is directed to subjective usability rating of the control transition strategy. It includes the assessment of acceptance based on the Van der Laan scale (Van der Laan, Heino and De Waard 1997); this scale measure system acceptance differentiated to usefulness and satisfaction. The final questions have been asked to put the automated driving experience in perspective to the proposed control transition strategy.

Data collection and post-processing

The field test with 10 participants originated 96 lane change manoeuvres: 58 normal cut-ins, 8 supposed close-cut-ins, and 30 cut-outs. The refined model puts a main focus of attention to the category of cut-in lane changes since cut-out manoeuvres are deemed before as non-critical for the warning model which finally has to be confirmed with the results of the field test.
After the drives the records of lane change manoeuvres and the questionnaires were evaluated by manual post-processing.

The post-processing work of the test drives consisted in investigating the video material of all relevant lane change events. Indicator data was extracted for the crucial moment of the lane change when a line crossing occurred. The refined warning model from the follow-up experiment was completely carried over to the field test with all indicators and threshold calibration. It was investigated if due to the model a warning had to be issued and secondly whether the participants’ votes were in accordance to the model output. The results were processed in a logic table for further representation in diagrams.

For hard warning requests the post-processing work consisted of a detailed observation of the complete lane change and the near field measurement. This also led to purification of events as described at the end of this section.

In order to paraphrase the interim performance and the drawbacks of the used prototype system two scenes from the field test are shown in Figure 46. Bold rectangles notify the identification of a primary object PO, thin rectangles a secondary object SO. Exemplarily the photo snapshots raise an understanding that in some instances it was not possible to capture indicator data as accurately as requested by the model. The rectangles represent vehicle objects identified by their rear end. Here one perceives missing detection of lane changing vehicles during line crossing. Hence the secondary object indicators $SO\_range$ and $Q_{SO}$ were not provided accurately in some instances. The right snapshot in Figure 46 represents a close cut-in manoeuvre with available near-field measurement but no rear end detection during line crossing.

Primary developments of image processing in the automotive industry are concentrating on full vehicle rear end detection, see (Ming and Jo 2011) and (Sun, Bebis and Miller 2006). It is based on the fact that rear end collisions are a prioritized subject for vehicle safety. In related publications the target vehicles are always handled as primary objects (PO) while in this thesis the requirement for parallel object detection of both, PO and SO, is substantial. Publications about lane change detection with secondary objects SO are rare in current literature. (Lee, et al. 2014) report a method to recognize lane changes by using image frames played in reverse. This deals with a post-processing method and cannot be applied for real time calculations. (Baek, Kim and Boo 2014) present a method with image processing to avoid misreading of the target image in a blind spot detection system. There is some progress in vehicle detection on neighbouring lanes, however the investigations of prioritizing multiple objects still remains a field for intensive research.

As before mentioned - in sporadic cases the rear end detection of secondary objects SO was not available in this field test because vehicles’ rear ends were partially out of view or covered by a succeeding car (compare Figure 46). The post-processing had to treat these cases individually: missing distances of the secondary objects SO were measured with time latencies (e.g. 1 second later the rear end was identified and indicator measurements were provided).
Figure 46: Driving scenes from the field test

*Figure 46* also serves to illustrate the execution of the simplified timing model: the image processing in the prototype vehicle was not enabled to identify single devices of a vehicle’s side view. Hence, the relation of the wheels to the line markings could not be calculated in order to fulfil the trigger requirements of the timing model. This is the reason why the timing of warnings was issued by observation and manual triggering of the supervising co-driver.

Post-processing of some cut-in manoeuvres with a hard warning request needed special attention: *Table 28* represents raw data of eight supposed close cut-in events. Participants selected a hard warning for those lane changes that pose a threat to their opinion.

<table>
<thead>
<tr>
<th>desired warning</th>
<th>near field Q [kph/m] &lt; 2m</th>
<th>Q SO [kph/m]</th>
<th>condition for warning reached</th>
<th>Participant vote is Model compliant</th>
</tr>
</thead>
<tbody>
<tr>
<td>hard</td>
<td>1.4</td>
<td>y</td>
<td>1</td>
<td>y</td>
</tr>
<tr>
<td>hard</td>
<td>0.8</td>
<td>y</td>
<td>1</td>
<td>y</td>
</tr>
<tr>
<td>hard</td>
<td>1.0</td>
<td>y</td>
<td>1</td>
<td>y</td>
</tr>
<tr>
<td>hard</td>
<td>0.9</td>
<td>n</td>
<td>2.3</td>
<td>n</td>
</tr>
<tr>
<td>hard</td>
<td>0.7</td>
<td>n</td>
<td>1.6</td>
<td>invalid</td>
</tr>
<tr>
<td>hard</td>
<td>1.0</td>
<td>n</td>
<td>1.4</td>
<td>invalid</td>
</tr>
<tr>
<td>hard</td>
<td>2.4</td>
<td>y</td>
<td>1</td>
<td>y</td>
</tr>
<tr>
<td>hard</td>
<td>3.9</td>
<td>y</td>
<td>1</td>
<td>y</td>
</tr>
</tbody>
</table>

*Table 28: Raw data for hard warnings*

The main criterion for the perception of close cut-ins lies in the near field measurement. In three cases there was no near-field detection. The refined model for hard warnings involves alternatively a second term that takes indicator $Q_{so}$ into account, but this term was not applicable because the threshold value of 5 kph/m was not reached. A detailed analysis of two incompatible votes unveiled that these events had to be invalidated (see *Table 28*). The rational for this is connected with another drawback of object detection in the prototype vehicle: after the lane change the secondary object turned into a primary object. This in itself did not indicate a threat; but the PO was identified late after the line crossing, the TJA system decelerated late and kept an unusual short distance to the leading vehicle. This was perceived as a threat to the test drivers; they interrupted the automated drive themselves with the request for a hard warning although the preceding lane change did not fulfil the conditions for a close cut-in at the time of line crossing. Hence the request for a hard warning was not initiated by the perception of a close cut-in manoeuvre, but by a lately detected primary object.
9.3 Test results and discussion

Figure 47 displays the distribution of indicator Q of normal lane changes with regards to research question RQ9.1. This is compared with the bigger amount of data from the NDS (see also Figure 30). In normality tests both test series showed normalized behaviour (N=58, Mean= 1.06, P=0.020) and (N=391 Mean = 1.04, P=0.049). In a one-way ANOVA the hypothesis is to prove that both series of Q are different. This is rejected (F = 0.18; P = 0.669) meaning that the distribution of Q in the field test is comparable to the naturalistic driving study although the data was recorded with a time difference of three years and in a city apart from all locations in which NDS data were collected. Both test series of normal lane changes have a common characteristic with regards to the distribution of Q. This raises confidence that the design of the control transition strategy in chapters 6 and 8 which is built on NDS data recorded in 2012 is reproducible with average traffic jam driving.

![Figure 47: Distribution of Q in NDS and field test (normal cut-ins)](image)

In the refined model Q still plays a major role for soft warnings due to normal cut-ins. The core experiment has shown that a lot of warnings can be issued correctly just because a threshold value of Q is reached. The refinement of the model came with a second term containing the new indicators Q_{SO} and Range with thresholds

\[ \text{Range} < 30\text{m} \quad \text{AND} \quad Q_{SO} > 2\text{kph/m} \]

In this context Figure 48 takes a look on research question RQ9.2 to investigate the influence of the second term regarding model usability. The figure represents in two scatterplots the Q_{SO} and Range on the agreement of participants (left) and on the warning model (right). Both upper left quadrants are filled constantly with accepted warnings as well as model generated warnings. This means a consistency of 100% for the introduction of the second model term. In the remaining three quadrants there are also warning conditions which derive from the first model term with principal indicator Q.
The analysis of the second term of the warning model for soft transitions is important for the field test. The term has been introduced and calibrated by results of the simulator experiments and could not be verified by means of the NDS data because the SO_Range signal was not available (compare section 8.2).

The conclusion about $Q_{SO}$ and Range is that their introduction had a positive influence for the usability of the warning model because they proof full compatibility (100%) with driver acceptance within the given indicator thresholds. In the context of the model with its first and second term an overall agreement to model-proposed soft warnings is at 84.4% (see Table 29), a value that increased stepwise in each experiment, in comparison to the follow-up experiment it gained +7%.

<table>
<thead>
<tr>
<th></th>
<th>Agreement to Model-proposed warnings</th>
<th>Agreement to Model-proposed non-warnings</th>
<th>Overall Agreement to Model-proposed warning type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close cut-ins</td>
<td>83.3%</td>
<td>-</td>
<td>83.3%</td>
</tr>
<tr>
<td>Normal cut-ins</td>
<td>89.1%</td>
<td>66.6%</td>
<td>84.4%</td>
</tr>
<tr>
<td>Cut-outs</td>
<td>-</td>
<td>96.6%</td>
<td>96.6%</td>
</tr>
<tr>
<td>Overall</td>
<td>88.4%</td>
<td>88.1%</td>
<td>88.3%</td>
</tr>
</tbody>
</table>

*Table 29: Field test agreement results*

*Table 29* presents an overview of measured agreement to the refined warning model in the field test. This is related to research question RQ9.3 in order to assess two aspects of usability: effectiveness and efficiency. The strategy is effective if it provides the right type of support in form of hard warnings, soft warnings and non-warnings. It is efficient if it provides the right balance of warning support.

First of all it can be stated that the strategy not to warn for cut-out manoeuvres is fully confirmed in the field test (96.6%). Only one event out of thirty had been selected for a soft warning. The overall usability of this part of the model is on a very high level.

Secondly the investigation of hard warnings that are related to close cut-ins is based on 8 instances of which two have been invalidated. Five out of six manoeuvres (83.3%) comply with model propositions. One does not because it gives a soft warning in lieu of a desired hard warning. The root cause for this individual mismatch could not be distilled.

No hard warning was issued by the model when not requested by the driver which means a surplus
for model effectiveness by avoiding the wrong type of warning. It also emphasizes reliability of the near field measurements.

Thirdly – more detailed findings can be presented regarding model usability for soft warnings caused by normal cut-ins:

Effectiveness relates to issuing the right type of warning, i.e. in form of desired soft warnings and non-warnings: In the field test the drivers request a soft warning for 77,6% of normal cut-ins (45 of 58). A comparison to the simulator experiments can be made by applying the percentile willingness to be warned (Request_to_warn) for n normal lane changes:

$$\text{Warning\_Effect} = \frac{1}{n} \sum_{i=1}^{n} \text{Request\_to\_warn}\ (i)$$

In the simulator experiments the value of warning_effect lies lower at 62,7% and 60,8 %. One can concludes that in real life situations the drivers apparently are more receptive to normal lane changes and request more effective warnings than in a simulator environment. Alike differences in results of real life driving and simulator test are also found with (Santos, et al. 2005) and (van der Voort 2001).

Due to Table 29 the effectiveness of the model is rated at a high level: the drivers agree with 89,1% (41 of 46) soft warnings that are issued by the model. However in 12 instances of lane changes the model does not issue a soft warning. In eight of those instances (66,6%) the drivers agreed. The quantity of non-warnings has an impact on model efficiency. It seems that drivers desire more warnings instead of non-warnings. In order to improve the efficiency of non-warnings a recalibration of indicator threshold is feasible. An adoption of the Range threshold from 30m to 40m increases the agreement by two more scenes. These are marked by circles in Figure 48. For the evaluation in Table 29 it means that the efficiency of non-warnings grows to 80% (8 of 10) while increasing the effectiveness of soft warnings slightly to 89,6% (43 of 48).

The results of the questionnaire process are also connected to the usability study. The answers from the participants are per definition subjective and relate to effectiveness as well as usefulness and satisfaction.

The timing model efforts have been abandoned since the core experiment was conducted and a preference was given to the basic timing model. The usability for this timing strategy according to research question RQ9.3 was re-tested by the query:

Do you expect soft warnings a) prior to line crossing, b) at line crossing or c) after line crossing? The outcome is a distribution of a) 0% b) 80 % and c) 20% and substantiates that an enhanced timing model is not necessarily required in automated congestion driving; especially early warnings for normal cut-ins (before line crossing) are not requested at all. Equally this result stresses that the recognition of line crossing in the image processing sensors is a substantial demand for the proposed control transition strategy.

With regards to research question RQ9.4 the perceived effectiveness is represented in Figure 50. Equivalent to chapter 7 the answers are noted on a five-point Likert scale with a summary percentage factor P. Pie-chart 1) shows the outcome with a summary factor $P = 80\%$ which is comparable to 88,4% effectiveness in real driving (see Table 29).
Research question RQ9.5 is aimed at the expressed system acceptance due to (Van der Laan, Heino and De Waard 1997). The acceptance score is divided into two attributes: usefulness and satisfaction are evaluated on a scale interval [-2 .. +2], compare (van Driel, Hoedemaeker and van Arem 2007). Usefulness is assessed with five items (useful-useless, good-bad, effective-superfluous, assisting-worthless and raising alertness-sleep inducing) while satisfaction is related to four items (pleasant-unpleasant, nice-annoying, likeable-irritating and desirable-undesirable). Figure 49 represents the scores of both attributes with a clear focus on the positive side of ratings.

![Usefulness and Satisfaction Scores](image)

**Figure 49: Participant ratings on acceptance scale due to van der Laan**

The summary factors are calculated due to (De Waard 1997) and they confirm the overall appraisal with

\[
\text{USEFULLNESS} = +1,12 \quad \text{and} \quad \text{SATISFACTION} = +1,08 .
\]

There are no obvious contradictions. The widest range of ratings is found with the item “alertness” from -1 to +2 and a subscale factor of +0,70.

The result of expressed acceptance can be put into perspective to the before calculated usability. If the van der Laan scale was moved to a range of 0 – 100 % the values are equivalent to ca. 82,4% and 81,6%. This resides in a similar range as effectiveness. Evaluation of both parts of the field test – driving and questionnaire – can be seen as harmonized.

Research question RQ9.6 also depicts the subject of harmonization and generalization of the proposed strategy. The drivers were asked whether they accept another warning model that worked in parallel. It was triggered after a time-out of 3 minutes of driver’s inactivity and urged the driver to take over control for a short moment. The answers are illustrated on a five-point Likert scale in Figure 50 in pie-chart 2 and lead to a summary score P = 85% which is in the same range as the overall usability rating of the strategy with 88,3% (see Table 29). It can be interpreted that combinations of warnings are well accepted by the participants. The prospect on combined warnings in a future embodiment of collaborative congestion driving is positive. However, the according warning models need to be carefully designed and differentiated for each single warning reason. The driver shall be conscious about the expected reactions. The following section reports about challenges in this subject.
Research question RQ9.7 points at the driver’s perception of the control transition strategy and the understanding that soft and hard warnings have a different meaning for the transition of vehicle control. The question is formulated in a slightly suggestive form in order to challenge a clear contradiction from the participants: Would you react to soft warnings also with a take-over? The result is presented in Figure 50 (pie-chart 3), it is summarized with 28% which is surprisingly high and does support the assumption that the participants clearly differentiate the warning types with an unambiguous result. There are few participants who think about driver’s action with soft warnings.

An attempt to interpret this result is the following: In interviews of the questionnaire process it turned out that some people mix-up the take-over scenario: for the 3 minutes time-out warning it involves a short touch of the steering wheel and the continuation of the automated drive thereafter. This is a sign of life, known as “dead man’s switch” in publications e.g. (Newman 2010). In contrast a hard control transition as intended by the strategy includes an interruption and manual interaction of the driver (e.g. on the steering wheel or on the brake pedal) because the automation system shuts down and thereafter the systems needs to be resumed by a button press. All participants have experienced time-out warnings but only half of the participants have seen a close cut-in when they requested a hard warning. Some drivers were probably not able to fully differentiate between these scenarios for the above reason which puts the result for research question RQ9.7 in perspective.

![Figure 50: Questionnaire results (5 point Likert scale)](image)

For research question RQ9.8 the pie-chart 4) of Figure 50 applies. This query was about the appreciation of automated congestion driving with the presented control transition strategy that is based on lane change warnings and the demand to come back with either attention or even with a hand-over to manual driving. A summary factor $P = 80\%$ is in-line with previous ratings about usability. It confirms that driving automation can make a next step that goes beyond the known driver assistance and support systems. The result does not determine a full affirmation of the presented strategy in the prototype but it shows a special appraisal of what the drivers have learned about automated driving and whether this fits into their future view of driving experience.

The warning system in automated driving plays an important role to pave the way for future driving technologies. This is confirmed by statements of (VDA 2015): “A high degree of automation is possible in assistance functions... It supports the driver in his or her driving tasks by informing, warning and – if designed to do so – actively intervening to regulate driving events”.

Research question RQ9.9 deals with a comparison: How does participation in previous simulator studies affect the perceived usability of the warning system in the field test? Familiarized participants have been in touch with the topic of automated congestion driving in previous experiments while new (“fresh-eye”) participants are confronted with this subject first time.
Due to Table 30 the hypothesis of a difference between the groups is rejected for normal cut-ins ($p = 0.968$). (MINITAB 2007) restricts that chi-square testing has limited validation because one cell is less than 5. Noticeable is an unbalance of familiarized and “fresh-eye” samples – 19 versus 39 normal cut-ins. This is explained by the unfortunate distribution of driving scenes. The majority of familiarized participants had driven in traffic jams during noon time when congestions had different characteristics in terms of time and speed and therefore less lane changes occurred. For research question RQ9.9 the conclusion stands to reason that in the field test familiarized participants evaluate the effectiveness of the strategy on an equal level than fresh-eye participants.

<table>
<thead>
<tr>
<th></th>
<th>Warning type agreed</th>
<th>Warning type not agreed</th>
<th>Chi-square</th>
<th>DF</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal cut-ins</td>
<td>fam. 16</td>
<td>fresh 33</td>
<td>3</td>
<td>6</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>fam. 6</td>
<td>fresh 0</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Close cut-ins</td>
<td>fam. 1</td>
<td>fresh 4</td>
<td>0</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 30: Comparison of participant groups (familiarized vs. “fresh-eye”)

For cut out manoeuvres only one sample out of thirty revealed a disagreement and a comparison of the groups is not feasible with statistical means. Also for close cut-ins a statistical statement (e.g. by a chi-square test) is hardly to achieve because of the limited sample numbers.

A further comparison of usability within the groups is made by the questionnaire process with reference to research questions RQ9.4 and RQ9.5: Effectivity is rated 75% versus 85% and the acceptance due to (De Waard 1997) is split into usefulness (0.80 vs. 1.44) and satisfaction (0.80 vs. 1.35). The lower voting scores of familiarized participants can be explained by the fact that they were exposed to a less lively driving experience than “fresh eye” drivers.

In summary the comparison of usability in both groups does not exhibit remarkable differences. The model is resistant towards this type of participants’ diversity in the field test.
9.4 Conclusion

The field test was conducted for participants as a combination of a driving experience on motorways and a questionnaire process to conclude the experimental investigations of the control transition strategy. It puts the results of driving simulator experiments in perspective by providing a higher level of realism. Further aspects of real automated congestion driving were included like complemented time-out warnings and driving in full context of coherent traffic jams. The principal research topic of the field test remained the usability of the warning model and the control transition strategy that is based on surrounding lane changes. The definition of usability includes the aspects of effectiveness, efficiency and satisfaction.

The research questions of this chapter have been answered accordingly:

RQ9.1 addressed the consistence of NDS and field test data. Remembering that the model and the control transition strategy were built on data of the naturalistic driving study a comparison to field test data was conducted. The records were cognate to the records of the NDS: in the distribution of normal lane changes, measured by indicator Q, no significant difference was found. This was seen as verification that circumstances of the field test were similar to those of the design process of the strategy and raised confidence to come closer to the claim of universality.

The field test also facilitated the investigation of RQ9.2 and RQ9.3. The participants had to respond to the proposed warnings in a spontaneous reaction during the drive experience whether they agreed or not. The agreement results were projected to the usability of the warning model.

RQ9.2 sought the answer whether introduction of indicators QSO and Range had a positive influence on usability in the field test. They have been developed for the refined model algorithm because of subjective participant ratings of in the core experiment. The second term of the algorithm is based on a smaller subset of NDS data and needed a re-evaluation with data from real driving tests. In a scatterplot representation QSO and Range were found to contribute in a beneficial manner. In logical conjunction with principal indicator Q they manifest a high usability 84% of the strategy for cut-in manoeuvres in the field test. This is a clear upgrade by 7% compared to the simulator experiments.

RQ9.3 investigated the degree of agreement to the warnings. In the field test the achievements of the proposed control transition strategy did not differ significantly from the follow-up simulator study: The overall agreement grew slightly from 82% to a value of 85%. However – the willingness of drivers to receive soft warnings increased from ca. 61% to 77% in the field test. It means that under real road driving conditions the participants were more susceptible for awareness alerts than in simulator experiments. The strategy not to warn for any cut-out manoeuvres was nearly fully confirmed by the participants (96%).

A major portion of the model is dedicated to normal cut-ins with related soft warnings. Effectiveness is about the right type of warning and lay at 84%. Efficiency is related to the right balance of soft warnings and non-warnings. In the field test a rising number of desired soft warnings was found; that is why the agreement to non-warnings lays lower at 67%.

Overall the control transition strategy complies in terms of usability of different warning types (hard warnings, soft warnings and non-warnings) at high percentage levels of 80-90%.

The basic timing model developed and manifested in chapter 6 was also confirmed in the questionnaire process: 80% of participants wanted the warnings exactly at the point in time when a
lane changing vehicle crosses the line marking first time with a wheel. The other 20% preferred a later timing of the warning. No participant requested the warnings to be issued earlier.

In the questionnaire process subjective ratings of participants were evaluated: **RQ9.4** and **RQ9.5** dealt with a usability judgement about the control transition strategy by effectiveness and expressed acceptance. Participants rated effectiveness on a five-point Likert scale at 80% which supports the assumption that the ratio of hard warnings, soft warnings and non-warnings is well perceived. The expressed acceptance of the warning system was measured on the van der Laan scale: Usefulness and satisfaction turned out at a comparable level (82%) as the ratings from the driving experience. This indicates a good balance and harmonization of usability results in the questionnaire process and the test drives.

In **RQ9.6** the acceptance was investigated if another warning concept, namely a time-out notification, can run in parallel to lane change warnings. The nature of the field test brought the drivers closer to a more comprehensive view on automated congestion systems. The participants perceived both warning elements as highly compatible (85%). This is a first sign that the proposed model is suitable for embedding into a larger framework of driving automation supported by fair usability of the strategy.

**RQ9.7** investigated whether participants recognize the difference of the warning types in terms of driver’s reactions. Soft warnings were perceived that drivers should not take any action. They are seen as an awareness notification in a traffic situation with no risks. In contrast the majority of participants understood hard warnings as a need for an immediate control transition, back to manual operation of the driver. The questionnaire unveiled a small ambiguity about different reactions that had to be taken: participants mixed up the demand for hard warnings based on lane changes and the time-out notifications as discussed in RQ9.6. Research to align separate warning types and driver’s reactions is ongoing in order to avoid confusion and misinterpretation in this matter (van den Beukel, van der Voort and Eger 2015).

With **RQ9.8** the participants were interviewed about their appreciation of an automated congestion driving system that maintains the proposed strategy based on surrounding lane changes. A rating value of 80% for the strategy gives a clear hint that acceptance is on the right track.

Research question **RQ9.9** looked out for a comparison of two different participant groups that were invited to the field test: one group that was familiar with the subject from earlier experiments and another group that was completely new to the subject. Despite a different experience level with regards to an automated congestion driving system the groups revealed no major differences in the judgement of usability. This is seen as another step towards the approach that the warning system shall be usable for a universal type of driver.

Conclusively the field test has proven that the control transition strategy and the according warning model is usable and works well under real driving circumstances. The test served as a valuable complement to the simulator studies that were based on video material. In the iterative research process of refining the model and changing to a real driving environment the usability results were on a continuous upgrade.

As a limitation of the field trial it has to be taken into account that, due to the infrastructural limits of the research work, it was conducted and assessed on a small-scale volume of participants (N= 10). It is recommended to substantiate and confirm the findings of this chapter with a repetitive trial in either a large-scale experimental study.
The field test implied chances but also challenges to the research:
A fully automated calculation of the control transition strategy was not managed because algorithms on real-time imaging data still have technological limitations and issues in a prototype vehicle. This was the reason why the test has been rolled-out with some manual interaction and the need of post-processing work for evaluation. Furthermore it was taken into account that the on-board sensor systems were on a prototype level. The basic timing model was executed manually and not in an automated real-time version because an exact and automated measurement of the point in time when the wheel crosses line markings was not supported by the prototype system. Furthermore the detection of relevant secondary objects that were involved in a lane change event was not fully resilient. Progress in image processor performance in the matter of complete and accurate secondary object detection is highly recommended in the context of research for automated congestion driving. This would allow flawless calculation and automated computing of the proposed control transition strategy with a timing model. Consequently it would support collaborative automated congestion driving in the desired manner and therefore it is recommended for future investigations.

With the finalization of the field test in this chapter the series of data collection, modelling and experiments is closed in order to review the contributions toward the global research questions in this work.
10. Conclusions & Recommendations

In the introduction it was illustrated that, in particular in media, driving automation is ultimately envisioned to offer driverless operated vehicles for individual transportation tasks. This will be a major societal change for road users and presents a technological challenge that, however, will be preceded by a step-wise introduction of driving automation features. This implies that human drivers and automated driving systems will at least in the coming decade continue to coexist in vehicles and they will need to cooperate during the automated drive. Therefore the focus of driving automation will be on intelligent collaboration between the driver and the vehicle in which the driver will have to be guided that his role in the driving task is going to change.

The presented thesis “Who is driving my car?” has a strong relation to this fundamental and relevant topic in the automotive industry. It deals with the development of a control transition strategy for an automated congestion system that is based on surrounding lane changes, which presents an innovative subject in the field of partially and highly automated driving. These automation levels are built on collaboration between the driver and the automated system.

Due to the collaborative approach, the driver remains responsible to supervise the automated motion of the vehicle and just because of this responsibility he has to be prepared to change over to manual driving at any time.

While driving in automated mode on motorways with full longitudinal and lateral control the strategy proposes transitions in control in the shape of soft and hard warnings that support the driver in this collaboration task. In case of soft warnings the driver is informed about surrounding traffic situations that are relevant but non-critical and he regains awareness about his driving responsibility. In contrast hard warnings identify traffic scenarios that are perceived as a threat to the driver and so he wants to and has to instantaneously take over the driving activity until the situation is cleared and he can continue the automated drive. In this way the strategy detects lane changes and supports the driver with a clear guidance if and how to react to these maneuvers.

The control transition strategy was designed with a clear focus on the drivers that are supposed to make use of it. The approach of user-centered design required analysis of usability, correct timing and error-resistance of warnings. Usability was studied with regards to efficiency, effectiveness and satisfaction. For correct timing the hypothesis was made that warnings are desired as early as possible. For error-tolerance the assumption was that no false positive warnings are accepted by the drivers.

The chosen research approach consisted in a sequence of data collection and analysis, preliminary modelling, a simulator experiment with natural driving videos, re-modelling, a follow-up experiment and confirmation of results in a field test.

Starting with an in depth analysis of 30 hours of traffic jam records that have been collected in a naturalistic driving study (NDS) it could be deducted that lane change maneuvers are a solid basis for the control transition strategy, consisting of cut-in and cut-out scenarios. The occurrences of these events dominate the potential causes of possible warnings (ca. 94%). The used prototype vehicles were equipped with sensor systems that were not enabled to grasp lane changes to the required extent, e.g. they could not resolve maneuvers in three relevant phases of the lane change. To overcome this deficit additional label signals were added in manual post-processing.
work by human interaction. The labels have been investigated for conformance and coherence in order to make further use of them in the subsequent research. Special attention was given to the close cut-in labels that determine whether a traffic scenario is interpreted as a threat to the driver and whether it needs a hard warning. With the confirmation to apply the label signals a list of indicators - like e.g. the vehicle speed and distance (range) to the leading vehicle - was compiled. By this methodology it was possible to recommend indicators for modelling the control transition strategy based on surrounding lane changes.

For a first concept of the strategy the label signals were applied in conjunction with signals from the sensor systems to build a preliminary warning and timing model. As one important indicator for the warning model the signal Q was introduced that represents the inverse of the time headway. In a generic form the model proposes soft warnings for cut-in and cut-out maneuvers that exceed certain thresholds of Q, Speed and Range signals while it targets to limit soft warnings to those instances that are relevant to the driver. Hard warnings have initially been linked to “close cut-in” signals from the labelling process. Regarding correct timing a basic timing model was presented that sets the warning time to exactly that point in time when a lane-changing vehicle hits the lane marking, at the border of phase1 and phase2 of the maneuver. Alternatively an enhanced timing model was presented in order to enable earlier warnings in phase1 with the application of additional indicators like the turn flasher signal.

The modelling was concluded with proposing a first concept of the control transition strategy for use in a participant based experiment. A pilot study and a core experiment were setup using a simulator that was fed with selected video data from the naturalistic driving study. In the video experiment the usability of the control transition strategy and the timing-correctness of warnings were investigated. An additional questionnaire process was developed in order to study error-proneness and it served as well to let participants identify undiscovered indicators.

The experiment revealed that a satisfying “correct timing” rating (90%) was achieved with the basic timing model. The objective of the enhanced timing model was to warn as early as possible to avoid false positive warnings. Both timing models however could not achieve the objective of complete avoidance of false positive warnings. Participants indicated no need for a complete error-free strategy. However, errors that were created in the early phase of a lane change were not accepted. As a consequence it was decided to proceed with the basic timing model and to concentrate the further development of the control transition strategy on usability objectives rather than timing and error-tolerance. Usability results evolved on a moderate level with room for improvement. Especially soft warnings for cut-out maneuvers seemed not to provide the intended support and were considered for exclusion from the strategy. The questionnaire unveiled the additional indicator SO_range for cut-in maneuvers that stands for the distance to the cutting-in vehicle. It was taken into account for the next iteration step of the warning model.

Prior to the follow-up experiment the new refined warning model was compiled. It was a progress to uncouple the hard warnings from close cut-in labels that were indeed created in the manual post-processing of NDS data. Two new indicators were distilled from the analysis: \( Q_{SO} \) that represents the inverse of time headway to the cutting-in vehicle and Near_field_range that measures shorter distance around the front edges of the vehicle. The refined warning model outputs hard and soft warnings based on logical operators with thresholds of these indicators. The follow-up experiment was equivalently setup in the driving simulator with NDS video data and served for evaluation of the new model design. The usability results of the follow-up experiment turned out on an improved and
satisfactory level for efficiency and effectiveness of the refined model. Especially the re-design not to warn for cut-out maneuvers contributed to better results.

In order to continue the progress of the control transition strategy and to enhance the external validity of the test series the third experiment was setup as a small-scale field test that involves participants as real drivers in an automated congestion driving system. They could assess the newly adjusted warning model that was implemented as a support tool in a prototype vehicle.

The results of the experiment showed again an improved efficiency and effectiveness for the strategy. This was also achieved because of the fact that in real traffic driving a higher degree of soft warnings is accepted and desired than in a laboratory test environment. The design of a control transition strategy that is based on surrounding lane changes was well received and it satisfied the participants on a high level (80%).

At the same time it was confirmed that the proposed strategy can be well combined with another support system that was installed on-board of the prototype vehicle. It issued time-out warnings which appeared in a period of 3 minutes and requested a brief manual confirmation to continue the automated drive. An acceptance level of 85% was found for the combination of both. This demonstrates the ability of the strategy to integrate into a wider range of related functions for automated congestion driving.

In three experiments of this study the participants have been divided into different groups to analyze individual group dependencies that could affect usability results. Either previous involvement with the subject of automated congestion driving or experiences with driver assistance systems like ACC were distinctive attributes of participants. However, in none of the tests a significant difference in usability was found amongst the groups. Conclusively the strategy fulfils an initial approach of robustness against this variation of driver types.

While preferring the basic timing model nonetheless this places a high demand to on-board image processing and object detection systems. By a precise recognition of lane change maneuvers these systems have to identify the exact point in time when the lane changing vehicle crosses the line marking. A further requirement for the supporting sensor technology was found in the need to reliably recognize secondary objects at the same point in time of line crossing independent from the visible shape of the vehicle. The detection of relevant objects under all circumstances was not provided by the available prototype systems. It has to be added to the list of requirements for implementing the proposed control transition strategy. Image processing and object recognition performance are key enablers to realize this strategy.

In summary this study paves the way to introduce cooperative driver support for automated driving systems on motorways, consisting in a two-fold control transition strategy with soft and hard warnings. The applied user-centred design process led to participants’ evaluations with high usability and acceptance results. With the presented thesis progress is made to move forward with partially and highly automated driving systems. The proposed control transition strategy supports the changing role of the driver in the vehicle in order to commute the driver from a full active involvement into a supervising and intervening position.

Applicability of the presented strategy beyond the driving speed of congestion traffic can be suggested and will need further research.
Recommendations

Although this study was able to identify a control transition strategy that was well received by drivers during evaluative studies and has proven to satisfy the participants on a high level, there still remain some research challenges to be addressed.

A future research task will be to evaluate the composition of a complete driver support in automated congestion driving. A special attention shall be given to visual, audible and haptic embodiments of driver support by warnings beyond the pure acoustic modality that was used in this study. Initial concepts have been developed, e.g. (van den Beukel and van der Voort 2013), which have to come to a comparable level of user-centered design evaluation.

Technology advancement is also required for realization of thorough object recognition systems. Particularly sensor systems, image processing and reliable object detection by sensor fusion as presented by (Stein, et al. 2013) are recommended for ongoing research. As requested in this study a combination of high-performance image processing technology and near-field detection sensors will be key to success. The expectations in this area are realistically high because earlier progress of sensor technologies turned out to satisfy the challenging requirements of the future. Sensor systems for automotive applications are often leaned on prior developments from the aerospace and defense industries. Initially, they are seen as unaffordable; however, the design changes in a way to make them available in the auto industry.

The question in the beginning “Who is driving my car?” that builds the title of this thesis remains with the simple answer which is: “YOU!”. The development objectives for highly and fully automated vehicles are going to convert the answer into “Not you - but your vehicle’s brain!” The claims for this conversion grow enormously and challenge the performance requirements for new automotive micro-controllers and sensor systems. Not only on-board sensor technology is required (as realized in this study) but a list of off-board technologies has to be added: Vehicle communication with road and city infrastructure (V2X) will be part of it in order to avoid heavy traffic congestions and to guide individual vehicles in conjunction with regional traffic flow. Vehicle-to-vehicle (V2V) communication will ensure that the proposed driving trajectories of adjacent vehicles are matched with that of the automated ego vehicle.

The mid-term target of driving automation is presented in the fourth level of Table 1. The vision of fully automated driving encompasses a further change of the drivers’ role because he is allowed to permanently execute a secondary task. Even with this change the achievements of this work are valuable. As long as a driver is on board he will always be considered as a fallback solution and a control transition strategy will come into play.

A full release from the supervising role of a responsible driver will come with the initially mentioned driverless taxis. When this type of automation is fully realized where only passengers exist with no human drivers a control transition strategy will become expendable. The introduction scenarios for this technology are still uncertain. The future of automated driving depends very much on the ability to bring in supporting technologies to market at the right point in time. As an additional challenge the development also depends on further evolution of social and legal acceptance.

In the light of such uncertainties it is likely that the control transition strategy will remain applicable for the coming ten years. These fields will present exciting subjects for future research as the automated driving roadmap and the technological progress adapt to meet each other.


Citymobil EU project. [citymobil-project.eu](http://citymobil-project.eu). 2011.


DAPRA. “DARPA Urban Challenge” archived website. 2007.


HAVEit EU project. *haveit-eu.org.* 2011.


SARTRE EU project. satre-project.eu. 2012.


Appendix A: Assessment sheet and questionnaire (core experiment)

The following pages represent the questionnaire (in original German language) that is used for the main part of the experiment. After the pilot experiment was conducted there were only marginal modifications made to this form. The questions 3-7 have been extended with the choice of tick boxes in a way that from a binary answer “yes or no” the selection was offered on a Likert scale in 5 steps.

<table>
<thead>
<tr>
<th>1. Alter</th>
<th>Geschlecht</th>
<th>ACC Fahrer</th>
<th>KM-Laufleistung/Jahr</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ 20-30</td>
<td>□ männlich</td>
<td>□ ja</td>
<td>□ &lt; 10.000</td>
</tr>
<tr>
<td>□ 31-40</td>
<td>□ &gt; 60</td>
<td>□ nein</td>
<td>□ 10-20.000</td>
</tr>
<tr>
<td>□ 41-50</td>
<td></td>
<td></td>
<td>□ 21-30.000</td>
</tr>
</tbody>
</table>

2. Was waren ihre Kriterien für die Auswahl der Warnungen?

Für die Warnung selber:

Harder warning: Weaker warning:

- □ eng eingeschert
- □ schnell eingeschert
- □ Geschwindigkeit
- □ Größe der Lücke
- □ Bremslichter sichtbar
- □ Wetterverhältnisse
- □ ________________

Für den Zeitpunkt der Warnung:

- □ Fahrzeug beginnt sich zur Linie zu bewegen
- □ Fahrzeug überfährt Linie
- □ Fahrzeug hat Spur verlassen
- □ ________________ (eigene Wahl)

3. Waren die akustischen Warnungen gut geeignet um Ihnen die Situation zu verdeutlichen?

Harder warning: Weaker warning:

- □ sehr gut
- □ eher ja
- □ weiß nicht
- □ eher nein
- □ nein
4. Können Sie sich auch eine Vibration (haptische Warnung) im Sitz vorstellen?

Harte Warnungen: Weiße Warnungen:
☐ ja ☐ ja
☐ eher ja ☐ eher ja
☐ weiß nicht ☐ weiß nicht
☐ eher nein ☐ eher nein
☐ auf keinen Fall ☐ auf keinen Fall

5. Würden Sie auch Warnungen akzeptieren, wenn der Spurwechsel vor Ihnen nur angedeutet aber nicht durchgeführt wird (3 Situationen im Video)?

Fall A ☐ ☐ ☐ ☐ ☐ ☐
Ja eher ja weiß nicht eher nein auf keinen Fall

Fall B ☐ ☐ ☐ ☐ ☐ ☐
Ja eher ja weiß nicht eher nein auf keinen Fall

Fall C ☐ ☐ ☐ ☐ ☐ ☐
Ja eher ja weiß nicht eher nein auf keinen Fall

6. Auf Auf- und Abfahrten von Autobahnen existiert eine höhere Spurwechselfdichte. Wäre es für Sie aus Gründen der Sicherheit akzeptabel, den Stauben assistenten dahingehend einzuschränken, dass auf solchen Abschnitten grundsätzlich im Hands-On-Betrieb gefahren wird (Beispielvideo)?

☐ ☐ ☐ ☐ ☐ ☐
Ja eher ja weiß nicht eher nein auf keinen Fall

7. Glauben Sie, dass diese Art vom kooperativen Fahren, bei dem der Fahrer aus Gründen der Sicherheit immer wieder seine Aufmerksamkeit auf die Verkehrssituationen richten muss, Ihren eigenen Ansprüchen an ein automatisiertes Fahren entgegenkommen würde?

☐ ☐ ☐ ☐ ☐ ☐
Ja eher ja weiß nicht eher nein auf keinen Fall

8. Würde ein solches kooperatives Fahrtsystem beim Neuwagenkauf für Sie in Betracht kommen?

☐ ☐ ☐ ☐ ☐ ☐
Ja eher ja weiß nicht eher nein auf keinen Fall
<table>
<thead>
<tr>
<th>Szene</th>
<th>Würden Sie den Warnungstyp hard/soft oder keine für diese Situation akzeptieren?</th>
<th>Falls nicht, welche Warnung würden Sie wählen?</th>
<th>War der Zeitpunkt der Warnung richtig gewählt?</th>
<th>Kommentar / Begründung</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>TYP: Soft  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>TYP: Soft  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>TYP: Soft  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>A4</td>
<td>TYP: Soft  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>A5</td>
<td>TYP: Hard  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>TYP: Soft  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>TYP: Soft  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>TYP: keine  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>B4</td>
<td>TYP: Soft  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
<tr>
<td>B5</td>
<td>TYP: Hard  ja ☐ nein ☐</td>
<td>Soft ☐</td>
<td>richtig ☐</td>
<td>zu früh ☐</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard ☐</td>
<td>zu spät ☐</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B: Questionnaire (field test)

<table>
<thead>
<tr>
<th>Frage</th>
<th>Antwortmöglichkeiten</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wie effektiv empfinden Sie das vorgestellte Warnsystem?</td>
<td>☐ sehr effektiv ☐ effektiv ☐ weiß nicht ☐ weniger effektiv ☐ völlig ineffektiv</td>
</tr>
<tr>
<td>2. Akzeptieren Sie die parallele Warnung, die ca. alle 2/3 Minuten ausgesprochen wird?</td>
<td>☐ ja ☐ eher ja ☐ weiß nicht ☐ eher nein ☐ auf keinen Fall</td>
</tr>
<tr>
<td>3. Würden Sie auf die soft Warning auch mit einer Übernahme reagieren wollen?</td>
<td>☐ ja, definitiv ☐ eher ja ☐ weiß nicht ☐ eher nein ☐ auf keinen Fall</td>
</tr>
<tr>
<td>5. Welchen Zeitpunkt für die Warning bevorzugen Sie?</td>
<td>☐ vor dem Überqueren ☐ Fahrzeug überfährt Linie ☐ Fahrzeug hat Spur verlassen</td>
</tr>
<tr>
<td>6. Glauben Sie, dass diese Art vom kooperativen Fahren, bei dem der Fahrer aus Gründen der Sicherheit immer wieder seine Aufmerksamkeit auf die Verkehrssituationen richten muss, ihren eigenen Ansprüchen an ein automatisiertes Fahren entgegenkommen würde?</td>
<td>☐ ja ☐ eher ja ☐ weiß nicht ☐ eher nein ☐ auf keinen Fall</td>
</tr>
<tr>
<td>7. Würde ein solches kooperatives Fahrsystem beim Neuwagenkauf für Sie in Betracht kommen?</td>
<td>☐ ja ☐ eher ja ☐ weiß nicht ☐ eher nein ☐ auf keinen Fall</td>
</tr>
<tr>
<td>8. Akzeptanzbeurteilung lt. Van der Laan Skala</td>
<td></td>
</tr>
<tr>
<td>Bitte beurteilen Sie jetzt das System. Lesen Sie hierfür aufmerksam jedes Wortpaar und machen Sie jeweils ein Kreuz pro Zelle.</td>
<td></td>
</tr>
<tr>
<td>1 Nutzlich</td>
<td>☐ ☐ ☐ ☐ ☐ ☐ Nutzlos</td>
</tr>
<tr>
<td>2 Angenehm</td>
<td>☐ ☐ ☐ ☐ ☐ ☐ Unangenehm</td>
</tr>
<tr>
<td>3 Schlecht</td>
<td>☐ ☐ ☐ ☐ ☐ ☐ Gut</td>
</tr>
<tr>
<td>4 Nett</td>
<td>☐ ☐ ☐ ☐ ☐ ☐ Nervig</td>
</tr>
<tr>
<td>5 Effizient</td>
<td>☐ ☐ ☐ ☐ ☐ ☐ Unnötig</td>
</tr>
<tr>
<td>6 Ärgerlich</td>
<td>☐ ☐ ☐ ☐ ☐ ☐ Erfreulich</td>
</tr>
<tr>
<td>7 Hilfreich</td>
<td>☐ ☐ ☐ ☐ ☐ ☐ Wertlos</td>
</tr>
<tr>
<td>8 Nicht wünschenswert</td>
<td>☐ ☐ ☐ ☐ ☐ ☐ Wünschenswert</td>
</tr>
<tr>
<td>9 Aktivierend</td>
<td>☐ ☐ ☐ ☐ ☐ ☐ Einschlafend</td>
</tr>
</tbody>
</table>
The role of the driver is changing now that vehicles with driving automation technologies appear on the road. The driver has to collaborate with the driving automation and remains responsible for transitions in control, in particular for changing back to manual control. In the context of automated congestion driving this research develops and analyses driver support in the form of a control transition strategy that issues soft and hard warnings based on lane changes by surrounding traffic. The strategy models the generation of a specific type of warning as well as the timing of issuing. The research comprises the analysis of a naturalistic driving study that built the initial input for the development of the control transition strategy. As part of an iterative development process, the control transition strategy was subjected to a series of participant based evaluations. The two driving simulator experiments as well as a small scale field test revealed that the control transition strategy provides valuable driver support for automated congestion driving technology.

About the author:
Joseph A. Urhahne works as a research and development engineer with Ford Motor Company in Cologne, Germany. He studied electrical engineering at the RWTH Aachen University and finalized his diploma thesis at the École Nationale Supérieure d’Arts et Métiers ENSAM in Paris. After working 25 years in the field of automotive engineering and research he resumed his academic career, which resulted in this PhD thesis in cooperation with the University of Twente, The Netherlands.

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