interactive

Accident avoidance by active intervention for Intelligent Vehicles

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Executive Summary

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SEVENTH FRAMEWORK PROGRAMME

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Executive Summary

The general goal of SP3 is to develop information, warning, and intervention strategies (IWI) for the vertical, application-oriented, sub-projects (SP4-6) as well as beyond the project. The IWI strategies refer to how, when and where driver information, warnings, and interventions should be activated.

As a basis for this work, IWI strategies were designed based on the current available State of Art. It is evident however that there are a lot of research questions and design issues that are not yet covered in research. Initial research questions in WP36 were therefore derived from the gaps identified in the literature search done in SP3 as well as on specific research needs identified by the demonstrator owners in SP4-6. A prioritisation of the derived research topics were then made in order to fit the available test facilities with the available resources in the time frame of the project. The aim was also to focus on research questions relevant to several demonstrators.

A range of experiments was carried out in SP3 involving professional drivers of commercial vehicles as well as private car drivers and where generic IWI strategies and prototypes were evaluated in order to provide input for updated IWI strategies, further development in the project as well as insight to Human Factors issues beyond the scope of the project. User-centred experiments were conducted in simulators and test vehicles provided by each of the four partners in SP3. In addition to those experiments, a smaller set of explorations was carried out together with the vertical sub projects.

Based on the specific hypotheses selected for the experiments specific experimental designs were generated. The scenarios were linked to the use cases defined early on in the project which describe very general how the function is intended to work in a specific traffic situation in order to resolve accident scenarios. Independent and dependent measures variables were defined as well as sample selection and statistics. Since the tests carried out in SP3 were in the formative phase of the project and the research questions could vary to a large extent each experiment could have a unique set up.

The following ten experiments described below were carried out by the SP3 partners in WP36.

- Driver Reactions to an Active Steering Intervention to avoid a Rear End Collision (VTEC, Simulator)

    The experiment focused on the assessment of the steering intervention part of the RECA system. The main question investigated was how truck drivers and personal car drivers react when a sudden active steering intervention is presented to the driver. Do truck and personal car drivers react differently, do drivers perform counteractions with regard to braking or steering manoeuvres and does the RECA system manages to avoid more crashes compared with drivers themselves handling critical rear-end situations? The RECA system intervened by triggering a combination of a ramped up torque and vibration. Results shows that the RECA system, when steering is considered, is easy to override when applying pressure to the steering wheel, e.g. due to concentrating on the road scene and the critical event. Still, the RECA system had some effect on the amount of crashes compared to driving without the system. A faster steering response was presented with the RECA system compared to what drivers manage to do themselves in baseline when no system was active. Results indicate that a braking manoeuvre would to a greater extent correspond with the driver's expectations or attempted actions compared to a steering intervention. Most drivers held on to the steering wheel at the time of the intervention which resulted in that many drivers with the system active still crashed with the vehicle in front. In the present study the torque was quite limited and therefore assumptions on how drivers behave with stronger steering torques should

be made based on the additional results from DLR experiment focusing on the same topics.

- Evaluation of Steering Assistance for Side Impact Avoidance and Run off Road Prevention (VTEC, Simulator)

  The experiment focused on the assessment of the vibration and steering intervention part of the RORP (Run Off Road Protection) system and the vibration and steering intervention part of the SIA (Side Impact Avoidance) system. The main question investigated was whether the RORP and SIA systems enhance safety in the relevant scenarios, whether drivers perceive the systems in non-expected critical scenarios when not informed about them beforehand and what drivers' opinions are about the systems and the chosen IWI strategies. SIA and RORP were designed to provide similar warnings and interventions with the main difference being the additional SIA display. Vibrations were presented for both systems in the steering wheel as an asymmetric oscillation, with a period of 85 ms and amplitude changing between -1, 0 and 1 Nm. The outcome of the steering wheel force applied to the steering wheel was a torque ramped from 0 to 4 Nm for the RORP and 0 to 5 Nm for the SIA. Results show that with the RORP system drivers are back in lane quicker than without (Baseline) and no unintended effects of overshoots were found. With the SIA system active the driver and system steer away from the blind spot vehicle faster compared to baseline where SIA is inactivated. Thus, with the SIA system activated drivers steer faster, heftier and with a larger lateral displacement to the left side away from the blind spot vehicle. With the SIA system active a higher percentage of subjects in the treatment group stated that they saw one or both of the two blind spot vehicles on their right compared to the baseline drivers. In order to investigate RORP in future experiments it is advised to include another type of secondary task (force paced) in order to get drivers to get off road. The yaw motion should also be done differently or removed if possible in order to create a more ecologically valid scenario.

- Driver Reactions in Situations where the Collision is inevitable and the System intervenes via Steering (DLR, simulator)

  This study aimed at investigating how drivers behave in a critical driving situation in urban environment where the collision is inevitable and an assistance system tries to optimize the position of collision by applying a torque on the steering wheel. In a simulator experiment with a mixed within-between design 40 participants experienced a collision situation. The simulated system intervention was a torque on the steering wheel which was triggered at time to collision (TTC) of 0.7s. The direction of the steering intervention was varied. There was no braking performed by the system. The torque of the automatic steering intervention was constantly 7Nm until the collision. The clustering of the driver responses seemed to reveal a certain reaction pattern: During an unexpected confrontation with the system intervention, the majority of the drivers reacted by holding the steering wheel without braking. The study demonstrated that if a system intervenes in a critical cross-traffic situation with a steering response, drivers react by reflexively holding the steering wheel or counter-steering. The experiment showed that drivers are not able to consciously perform an adequate response. The study implies that the driver's tendency to hold the steering wheel must be overcome. This could be achieved for example by pre-warnings or temporal driver decoupling. These points will be investigated in the following studies.

- Testing Different Designs for an Evasive Steering Manoeuvre (DLR, Simulator)

  In this study a strong automatic steering intervention was tested in a critical situation and in an unjustified activation situation. In a simulator experiment the intervention of the automation was triggered at a Time To Collision (TTC) of 1.4 sec to a vehicle in front. A torque of 9.9 Nm was applied to the steering wheel. In addition to the steering intervention, two different pre-warning strategies were implemented to signal the upcoming intervention. It was hypothesized that the pre-warning might minimize the driver's tendency to counteract the steering intervention. An acoustic warning tone (beep) and haptic warning (double-tic on steering wheel) were compared with an intervention without pre-warning and a control group without intervention. The results of the study with 40 participants showed that the steering intervention reduced the number of total crashes by 30 to 50%. Other than expected, there was no significant reduction in the crash rate for the variants with pre-warnings compared to the pure intervention. Nevertheless, it seems that drivers were often not aware of the steering intervention itself and tended to counteract the steering intervention leading to a reduced effectiveness of the intervention with respect to collision avoidance. The results also showed that higher torques applied to the steering wheel were not adequate to improve the collision avoidance effectiveness per se as drivers had problems controlling the unjustified steering manoeuvre in this study.

- Interaction Strategies for Automatic Evasive Manoeuvres with the FASCar II Test Vehicle (DLR, Test Vehicle)

  Previous studies showed that the efficiency of an automatic steering intervention can be negatively influenced by the driver involvement in this manoeuvre. To avoid this, this study examined if temporarily decoupling the driver from steering led to a more effectively collision avoidance and still enables controllability in an unjustified activation of the manoeuvre. In a between-subject design 45 participants drove an experimental vehicle equipped with the assistance in a collision-avoidance and a controllability situation. The character of the assistance system was varied systematically and the condition driver coupled and driver decoupled were compared with a control group. The condition driver decoupled leads to a significantly improved collision avoidance. 93% of all crashes could be avoided when the driver was decoupled from steering. The main reason for the efficiency of the decoupled condition was that counter steering of the participants was ignored. However, if the avoidance manoeuvre started unjustified, the decoupling of the drivers with the parameterization chosen in this experiment led to bad controllability performance. Although the driver decoupling strategy seems not to be perfect, we conclude that it still might bear some potential for improving collision avoidance while being controllable at the same time. This point needs further investigation.

- Interaction strategies for automatic evasive manoeuvres using steer-by-wire (DLR, Simulator)

  A further study in the DLR driving simulator with 57 participants tested the controllability of an automatic steering intervention which decoupled the driver from steering for a short period of time. Different interaction designs were tested to improve the effectiveness as well as the controllability of the steering intervention. The results of the test drives confirm that automatic and decoupled steering manoeuvre for collision avoidance are very effective helping to avoid between 80-86 percent of all crashes. In false alarm situations, people were able to abort the automatic steering intervention as soon as they realize that the manoeuvre was unjustified. However, no participant achieved the criteria of “fully controlled false alarm” which was defined as staying in the own lane. Further improvements are needed to find the right balance between effectiveness of the steering intervention and the controllability in false alarm situations.

- Distinguishable Warnings in an Integrated Continuous Support Concept (CRF, Simulator)

  How Continuous Support can be designed was investigated in this study. The focus was on how to give distinguishable warnings for different meanings (e.g. lateral and longitudinal) in an integrated concept. Communication channels and channel combinations have been central in this study and the effect of different warning modalities on the driver's perception and reactions has been investigated. During the test each driver tested different feedbacks combinations (visual, haptic and acoustic) in different use cases. Results analysis indicate that conditions; which include a visual component; are generally perceived as more beneficial in terms of user experience, perceived effectiveness and quality of information. In particular for Rear-end Collision and Dangerous Curve use cases visual and haptic (pedal) feedbacks are those recommended. In contrast to that recommended feedbacks for the Blind Spot use case are visual, haptic on steering wheel and acoustic.

- Simultaneous Longitudinal and Lateral Warning Events and Early Warnings (CRF, Simulator)

  The best feedback configurations on simultaneous longitudinal and lateral warnings and early warnings were investigated. The focus of this study was particularly on best feedback configuration on different implemented use cases and on the best timing when the haptic feedback should be given in a Rear End Collision (warning phase only or pre-warning and warning phase). Results suggest a general preference to drive with warnings than without. Looking at both, objective and subjective data emerge that users have a general preference for visual haptic instead of visual acoustic stimuli regarding the warning conditions. With haptic warnings subjects decelerate faster in case of an obstacle or a dangerous curve and maintain a more regular driving style. Moreover visual-haptic stimuli were better rated than visual-acoustic on the user experience scale and on the frontal warning system interfaces scales. Questionnaire analysis also emerge that subjects prefer to drive without visual-acoustic warning feedback. Regarding pre warning conditions, no strong evidences emerged from the user experience or driving performance or system interfaces questionnaires. The objective measures report a higher time to collision and more regular driving style (through steering STD and lateral deviation measures) for the visual-haptic condition. On the contrary, users' subjective evaluation ranks the visual pre-warning over the visual-haptic combination.

- Different Types of Haptic Pedal Signals for Different Longitudinal Warning Scenarios + Follow-up Study (ATG, Simulator)

  The effect of haptic pedal feedback on driver reactions in warning situations was investigated. A detailed parameterization of three different haptic signals was executed. Two experiments took place in a static simulator with altogether N=53 subjects. It could be shown that a haptic warning without additional acoustic or visual warning is not sufficient in a Curve Speed Warning scenario. By adding visual and acoustic stimuli to the haptic feedback, the overall brake reaction time decreased significantly. The type of haptic signal, Vibration, Counterforce or Double-Tick, did not influence drivers braking performance. Surprisingly, a considerable percentage of drivers (29%) completely failed to apply the brakes when confronted with the CSW in a first exposure. Additional visual and acoustic cues had no positive influence on the non-braking rate. Thus the CSW seems not to be self-explanatory and the situational awareness needs further enhancement. Regarding the acceptance of haptic signals Vibration was perceived as most annoying and least acceptable, Counterforce and Double-Tick reached both a broader acceptance. When looking at applying haptic signals to different warning scenarios the majority of the sample generally preferred to differentiate haptic signals especially using least annoying signal (Double-Tick) for Speed Limit Warning. By applying a false warning event it could be shown that the used haptic pedal forces did not seriously affect driver's controllability in the specific situation.

- Validation of a Visual Concept for Continuous Support Functions: Comprehensibility & Mode Confusion (ATG, Simulator).

In this study a newly developed Human-Vehicle-Interaction concept for Continuous Support (CS) functions was tested. The implementation of dedicated steering wheel controls combined with visual, acoustic, and haptic feedback strategies for highly-automated driving in a static driving simulator was executed. The concept comprised three different automation levels (modes) as well as a variety of integrated warning functions and strategies for longitudinal and lateral hazards. 24 subjects experienced the entire system concept in various scenarios. The strategy to integrate assistance functions into modes was liked by the vast majority of the sample. Furthermore the assistance modes were easy to understand and operate. Being exposed to the mode switch concept for the first time all subjects were able to operate the system also without any instructions after some time. Already with the second mode change operation the time-on-task figures decreased significantly. Also the visual concept was highly acceptable: The indication of safety zone segments around the vehicle in the display - representing the safety-shield metaphor - was well understood. Especially the spatial indication of the hazard by showing the related obstacle and the activated shield segment was assessed very positively. Need for optimization could be revealed in the integration of functions and definition of automation modes making system functions adaptable to individual driver wishes.

Four additional experiments were carried out in the responsibility of the vertical subprojects in collaboration with SP3 partners and are described in the deliverable as well:

- Comparison between Conventional Warnings and Additional Brake Pulse
  (VCC, VTEC, Test Vehicle)

  In this study with 22 test subjects it was investigated how drivers react on forward collision warning when it includes warning and sound compared to warning, sound and brake pulse. The additional brake pulse had the effect of initiating more brake pedal applications under the condition of false positive warnings. Steering behaviour was not negatively affected.

- Driver Behaviour & Perceived Safety in Collision Avoidance Situations
  (FFA, Test Vehicle)

  This investigation focussed on the threat assessment for the decision making related to the initiation of system interventions. For this reason an experiment was conducted with 26 subjects. Results showed that last moment driver reactions were much earlier than the physical limits for both steering as well as braking.

- Analysing the Driver Behaviour in Critical Situations to Improve Collision Mitigation Systems by a Driver Model (DLR, VW, Test Vehicle)

  In order to adapt the starting point of a Collision Mitigation System to driver's reaction time and behaviour a driver model was implemented. It was investigated, how large the additional time offset is for 18 distracted drivers on the breaking reaction time. Results confirm the approach for the driver model in SP6 to distinguish between distracted and non-distracted drivers.

- Influence on the Driver Reaction Time while Performing a Secondary Task (DLR, Simulator)

  The aim of this study with 20 subjects was to estimate the potential of driver modelling for the improvement of collision mitigation systems. Specifically, the question was whether a model that detects driving behaviour can be used to implement an autonomous braking system that can be triggered before the collision is physically unavoidable. Results showed that it is possible to generate a driver model from data that is able to predict the driver's behaviour with high accuracy.

Based on those experimental results, the different IWI strategies were updated and input was given to the demonstrator owners in the vertical subprojects. The most important impacts on the SP3 functional requirements are summed up in the following.

System initiated evasive steering manoeuvres seem to result in situations where (i) the majority of drivers show a reflexive reaction by holding the steering wheel, or counteract the intervention to some extent; and (ii) even strong steering wheel forces are not clearly perceived by all drivers. An experiment shows that this is also the case for a false alarm scenario, i.e. drivers counteract the steering intervention. Also the use of pre-warnings could not completely solve these unwanted driver reactions. Only temporarily decoupling the driver from steering is leading to a more effectively collision avoidance and still enables controllability in an unjustified activation of the manoeuvre.

As long as the driver is not decoupled from steering and no superimposed steering is used, no level of torque has been found in the studies which guarantees 100% successful collision avoidance, and still allows easy overriding and controllability of false alarms. There is evidence that the counter-torque often applied by the driver is not necessarily the result of a conscious overriding decision. The driver's intention (if it exists) is hard to detect, and valid data for an arbitration strategy based on drivers' intentions seem to be difficult to obtain.

Compared to the evasive steering intervention in rear-end collision scenarios the system initiated steering avoidance manoeuvres in critical lateral (side impact and run-off road) situations were effective and well accepted by the drivers. It is recommended to ramp up the steering wheel force when possible (depending on curb width, other lane characteristics and how fast the situation evolves). It is also recommended to use a combination of steering wheel force and vibrations or sound in order to create a well transparent system intervention with no risk of confusing the steering intervention for irregularities from road, flat tire or such.

Results on preferred communication channels to use for lateral threats also correspond to available guidelines. Threats related to blind spots information should also be presented visually which is already the case today in many production vehicles.

It has been shown that when auditory information can be replaced with haptic information in certain use cases this can result in higher level of acceptance. In a multi-danger scenario with lateral and frontal danger at the same time, it should be avoided to use an acoustic warning feedback both for frontal and lateral warnings.

Haptic feedback in the gas pedal alone in critical scenarios (rear-end collision, excessive curve speed, and speed limit violation) is not enough to prompt the driver to start acting accordingly and underlines the need for multimodal warning. For longitudinal threads it is recommended to use a visual feedback associated with haptic pedal feedback or brake pulse, while for a lateral danger a visual feedback should be associated with haptic steering wheel feedback.

Several functions should be able to use the same IWI strategies. E.g. SIA and RORP functionality can share the same torque and vibration in the steering wheel.

The period in which the automation has control over the vehicle needs to be prolonged in order for it to stabilize the vehicle. Drivers were not able to take over control after sharp steering manoeuvres (e.g. in rear-end situations). It has to be ensured that the driver takes over control as requested by some kind of interlocked transition (explicit mechanism that checks if transition was successful)

It might be useful offering different warning options or warning levels, especially when it comes to haptic feedback strategies, to the driver, which he/she can adapt according to his/her preferences. In that way, amongst those drivers one might reach higher acceptance levels to install warning systems. For systems offering different kind of automation modes the user acceptance is also highly depending on the possibilities to customize the single modes to user specific needs and preferences.

Summing up, the experiments conducted in SP3 provide important insight of the driver-vehicle interaction for different use cases and applications addressed in the interactIVe project. In a structured approach research questions were selected that are tightly coupled with the interactIVe use cases, the functions, requirements and the IWI strategies. These research questions were answered by experiments in different test environments, ranging from basic and dynamic simulators to test vehicles. During the course of the studies much knowledge was gained for the continuous driver support e.g. on the IWI strategies and on the use of active devices as well as on emergency interventions e.g. on collision avoidance by steering or lane departure avoidance. As summarized above, several studies showed the successful implementation of the IWI strategies.

However, the results of the studies also show that there is still further research needed on specific topics. Future studies should help to further improve the effective human-machine interaction for continuous support, in emergency situations as well as during the transitions between these two. Because of the variety of the study objectives and addressed use cases separate study-specific conclusions and outlooks are stated in the final chapter of the document.