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Introduction

Inside ISI-PADAS project, two different phases can be identified. In the first phase, specific experiments were conducted without PADAS, in order to investigate special up to now not explored hypotheses about the stability and predictability of individual driving behaviour and relevant influence factors coming from the situation and the personality of the drivers. This provided an understanding of how different groups of drivers cope with special task characteristics of the current situation. The knowledge and data from the first group of experiments have been used to develop driver models which has been integrated in a Joint Driver-Vehicle-Environment (JDVE) Simulation Platform with models of the vehicle (without assistance system) and the road environment. Experimental results were validated utilising the simulation platform. Moreover, the results of the experiments have been used for the development of PADAS target systems, in order to produce alternative concepts and implementations in form of PADAS prototypes. The Longitudinal Support System (LOSS) prototype has been developed. This PADAS consists of an advanced Adaptive Cruise Control (ACC+) system and an advanced Forward Collision Warning (FCW+) system.

In phase 2, dedicated simulator studies have been performed using PADAS prototypes to investigate the influence of different assistance concepts on driver behaviour in more detail. The LOSS prototype has been tuned and tested: the FCW+ was implemented on the DLR simulator, while the ACC+ was implemented on the URE simulator. On the one hand those experiments were conducted to model and optimise the Warning and Intervention Strategies (WIS) of the PADAS and to evaluate their safety effects. On the other hand, experiments were conducted to evaluate the developed PADAS and to analyse their influence on driver behaviour. Preliminary results proved that PADAS is really effective in driving safety, since capable to reduce the time spent by drivers in very critical and dangerous situation.

Figure 1: ISI-PADAS Project Schema
Development of PADAS Target Systems

In the first edition of this newsletter, we have described in general terms the Development of PADAS Target Systems, which aims at the definition and the implementation of Partially Autonomous Driver Assistance System (PADAS) prototypes, whose main purposes are:

- to investigate the driver-PADAS interaction in phase 2 of Empirical Investigation of Driver Behaviour as a basis for the driver modeling;
- to demonstrate the advantages of the new risk based design methodology developed in ISI-PADAS project.

In the second number of this newsletter, we have provided some more details about the development method and implementation process of the PADAS, by means of the papers presented in the HMAT-2010 conference. Now, the Development of PADAS Target Systems is almost completed and the prototype of a PADAS target application has been developed; in particular, it is named Longitudinal Support System (LOSS). Specifically, this PADAS consists of an advanced Adaptive Cruise Control (ACC+) system and an advanced Forward Collision Warning (FCW+) system, each one composed by some functions, as described in Figure 3:

- Emergency Braking (EB).
- On the other hand, ACC+ is composed of other three main functions:
  - Adaptive Cruise Control (ACC);
  - Assisted Braking (AB);
  - Emergency Braking (EB).

With reference to this scheme, the first functions of ACC+ and FCW+ are different (one is the "traditional" Forward Collision Warning and the other is the "classical" Adaptive Cruise Control), while the other two are the same: Assisted Braking, which assists the driver by applying a braking action, and Emergency Braking, which acts an automatic braking manoeuvre if the drivers do not react to imminent risky situations.

Both PADAS modalities inside LOSS require the definition of specifications considering their respective possible functionalities and taking into account the system definition and the established framework.

Consider now a system that assists the driver by applying corrective controls to the vehicle (giving the driver warning signals and intervening in the braking) so that collisions may be avoided. When a collision is imminent, there is no doubt about what controls to apply: a clear collision warning must be given to the driver, and brakes must be applied as hard as possible to bring the host vehicle to a halt as quickly as possible.

When there is a safe distance between the two vehicles, it is not clear what the optimal controls are. Should no warnings, no braking interventions occur? It could be, for example, that not giving a warning when the vehicle is at a certain "safe distance" leads (eventually) to a situation where a collision is unavoidable whereas a warning leads to an avoidance of the eventual collision. Deciding what corrective controls to exercise in order to avoid an eventual collision is essentially a problem of "credit assignment"; suppose an outcome is a consequence of a sequence of decisions. How do we decide what part each of decisions plays in the outcome? In other words, the credit assignment problem calls for a system for associating decisions to their long-term outcomes.

One of the most important theories for formulating and solving credit assignment in sequential decision-
making problems is the Markov Decision Process (MDP) theory. The MDP model has been a cornerstone of Operations Research and Control Theory for more than five decades. In modelling a problem as an MDP, we contemplate a decision. Due to the high number of states, the problem of solving the MDP can be intractable and therefore the MDP is solved using the Reinforcement Learning paradigm.

At the moment this task is almost completed, so the analysis is still in progress. Anyway, preliminary results proved that PADAS is really effective in driving safety, since capable to reduce the time spent by drivers in very critical and dangerous situation (defined as those regions where the Headway (HD) and Time-To-Collision (TTC) indexes are minor that a given threshold: 0.5s for HD and 1s for TTC, respectively).

This so-implemented PADAS has been tuned and tested using the driving simulators. In particular, the FCW+ was implemented on the DLR-simulator, while the ACC+ was implemented on the simulator of project partner URE. Both systems provide the visual, sound and haptic channels; specifically, such a haptic system has been developed by project partners CEA and it is illustrated in Figure 5.

Moreover, as future activities, we are dealing with the integration of PADAS with driver’s Distraction Classifier (from ISI-PADAS Driver Modelling) and with the design guidelines based on Risk Design Methodology (RBD).
In the first phase of the project, specific experiments have been conducted by ISi-PADAS partners in order to collect empirical data, both in real driving condition and in driving simulators, for studying drivers' behaviours without PADAS. Statistical analysis have been performed in order to test research questions and hypotheses and the data has been shared with partners in charge to design, develop and validate models of the driver.

In details, real driving studies were conducted to describe normal driving behaviour with the following results:
- Additional load due to secondary tasks, age of drivers and type of driving manoeuvres can be considered influencing factors for driving performance.
- In steady state manoeuvres like car-following, additional load resulted in compensatory behaviour (like increasing headway).
- In tactical manoeuvres like overtaking, additional load did not lead to behavioural adaptations.

Moreover, given that previous research in Germany showed that unpredictable braking of lead car at intersections can lead to rear-end crashes and that one possible cause is the driver distraction, appropriateness of attention allocation was studied in driving simulators. These studies aimed at analysing driving behaviour in controlled situations where the velocity of the lead car during the approach and at the intersection was either constant or changing and the participants were visually distracted by a secondary task they had to perform. In this situation, the following results were produced:
- Visual attention was shifted more and more to the lead car as unpredictable breaking events occurred at intersections.
- The shift of visual attention occurred especially if the lead car showed normal driving behaviour on straight roads in front of car behaviours.

The second group of experiments was perfomed in the phase 2 of the ISi-PADAS project.

Pivotal for the achievement of this work was the Development of PADAS Target Systems. The developed Partially Autonomous Driving Assistance Systems (PADAS) consisted of a Forward Collision Warning Plus (FCW+) and an Adaptive Cruise Control Plus (ACC+). The FCW+ kept the driver within the control loop since he had to control the longitudinal driving task during car following by himself. The FCW+ intervened only when the situation became critical. In contrast, the ACC+ additionally took over the longitudinal control of the car during car following which was associated with a higher level of automation and less control of the driver.

The investigation of driver behaviour with PADAS were realised in the driving simulators of the different partners. The driving simulator at DLR was a dynamic simulator, whereas the simulators at TUBS and URE and CEA were static simulators. For the analysis of the safety effects of the PADAS and other automation effects PADAS driving studies with 10 to 30 participants in the different driving simulators were conducted. The driving scenarios contained urban or highway routes where the driver had to follow a lead car. One or both of the above described PADAS or, in one study a comparable PADAS, were installed to assist the driver.

Some experiments additionally used a Surrogate Reference Task (SuRT) as a secondary task to examine the visual attention of the driver and measured the gaze behaviour. Furthermore some experiments used questionnaires to measure evaluations of the drivers e.g. regarding their workload, their state or their opinion about the PADAS.

The objectives of this part of the Project were twofold: on the one hand, experiments were conducted to model and optimise the Warning and Intervention Strategies (WIS) of the PADAS and to evaluate their safety effects. On the other hand, experiments were conducted to evaluate the developed PADAS and to analyse their influence on driver behaviour since a number of problems associated with automa-
tion, like impairment of situation awareness or vigilance reduction, are known and reported in the literature.

Regarding the modelling of the PADAS, the performed experiments involved repeated testing of the included policies on the basis of experimental driving data and therefore allowed an iterative training and optimisation of the support systems. At the end of this modelling process, different PADAS resulted, each containing an optimal policy regarding their Warning and Intervention Strategy. The optimisation based on two central variables of the driving behaviour: the Time-To-Collision for the FCW+ and the Headway for the ACC+.

A further ACC+ was developed which additionally considered the distraction of the driver. An experiment analysed the safety effects of the developed FCW+ and showed that the FCW+, due to its shorter reaction time, was able to increase the traffic safety without resulting in some unwanted side effects, like making the driver more vulnerable for distractions or taking the driver out-of-the-loop.

Experiments with regard to the ACC+ demonstrated that developing the WIS based on an approach that directly derives the WIS from drivers’ behaviour by a combination of a Markov Decision Process (MDP) and Reinforcement Learning can outperform a traditionally designed ACC+. Furthermore, the experiments showed that PADAS might have negative side effects by reducing drivers’ situation awareness especially when it is used in a context not explicitly designed for, but that such systems may reduce subjectively perceived driver workload and increase drivers’ self-estimated comfort.

A specific experiment on the HMI-design and its effects on driver behaviour of such PADAS indicated that using a combination of acoustic and haptic signals might be useful to ensure that the driver understands the system’s warning and reacts promptly.

The results obtained in the experiments are being used to further develop the driver models of ISI-PADAS. As the experiments did not only investigate the drivers’ interaction with the PADAS in situations where it was designed for and should show its positive effects if designed well (such as safety effects in car following situations), but also in situations where it might show unintended negative side effects (such as reduction of situation awareness in system limit situations), the results enable the modellers to integrate a wide variety of system effects in the ISI-PADAS driver models.

Being able to model such effects will greatly improve the estimation of risk associated with a PADAS design and will allow to integrate countermeasures from the very beginning of the process.
The development and testing of PADAS is always very time consuming, especially when it is going to be tested under various conditions and with many subjects. As it is comparatively easy to speed up software and hardware systems, the most retarding factor in the loop of PADAS testing is the driver – of course only capable of driving in real time.

Thus a possible way of reducing the time effort needed for PADAS testing lies in the use of driver models instead of real drivers. Once all aspects needed for PADAS testing are automated, the time effort can be reduced dramatically.

Inside the ISi-PADAS project, the goal of the JDVE Simulation Platform is to enable the possibility of testing in real time as well as in accelerated time.

Main expected benefits from this general approach concern:

- A better identification of the end-users’ needs during the earlier stages of PADAS design (i.e., user-centred design method based on a virtual tool and on driver models able to simulate or to diagnose human error risk).
- The possibility to virtually test the PADAS effects on road safety for a large share of driving scenarios (including critical cases).
- The possibility to reduce the time of future PADAS development.

Developing such a platform has been a real challenge and requires to progressively synchronise and to gradually integrate the different contributions of all the ISi-PADAS partners while the project is in progress. In order to simplify this process, pre-existing platforms, methods and tools have been used in accordance with the specific needs of the ISi-PADAS consortium.

One of the pre-existing tools utilised inside the project has been the SIVIC platform developed by INRETS-LIVIC for driving assistance design. Synthetically, it is a Vehicle-Environment (VE) Platform which integrates virtual models of vehicles, sensors, and of road environments. In ISi-PADAS, this tool has been enhanced in order to design and implement a cognitive simulation.
model of the driver called COSMODRIVE. From a theoretical point of view, COSMODRIVE model aims at simulating drivers mental activities at different levels, including more particularly (i) the perception of the road environment, (ii) the elaboration of a mental representation of the driving situation; (iii) the decision-making and, lastly, (iv) the behavioural performance.

At the end of the first phase of the project, the JDVE Simulation Platform was able to jointly support simulations of driver models interacting with vehicles, while immersed in a virtual environment. During the second phase, the following activities have been performed:

• Some experiments have been performed by using the JDVE.
• The PADAS has been connected to the JDVE.
• The driver models have been integrated. In particular, the CASCAS driver model by OFFIS has been attached to the Joint Driver Vehicle Environment Simulation Platform (JDVE). This enables the JDVE to completely simulate the driver, vehicle, and environment in the same simulation platform that was used during some of the Empirical Investigation of Driver Behaviour experiments. This is an ideal precondition for comparison of the results.
• The first thousand test drives have been performed using the CASCAS driver model, results will be available in the near future.
• The JDVE and the Risk Based Design (RBD) Tool has been connected. The RBD Tool is a software developed inside the project which allows the user to evaluate hazards associated to human errors and inadequate driver behaviour. The basic idea of the RBD methodology is to be able to create predictions of critical-prone situations for drivers.

From this general design, it is clear that the JDVE performs a central role in the project by putting together the work from all partners, as shown in Figure 13.
Visit www.isi-padas.eu

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