Safety Potential of ADAS – Combined Methods for an Effective Evaluation

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ABSTRACT

This paper addresses the research question, how the depending criteria effectiveness, acceptance, controllability and functional safety of advanced driver assistance systems (ADAS) can be evaluated and considered already during the vehicle development process starting at a very early stage.

On the basis of a systematic overview and classification on safety evaluation methods an ADAS development and evaluation process is introduced, in which system, vehicle, driver and the traffic environment are either represented virtually or experimentally.

This evaluation concept, called “circuit of critical driving situations” provides a methodological connection of the mutual dependencies between system effectiveness, acceptance, controllability and functional safety.

The necessary interaction of competences and scientific disciplines is described, in order to implement this approach, namely vehicle technology, psychology and functional safety.

INTRODUCTION

While accident numbers are decreasing in Europe, still over 1 Mio people worldwide are killed in traffic accidents [1]. Half of the deaths are vulnerable road users (pedestrians and cyclists) [2]. Due to the change in mobility behaviour, urbanization, increasing fuel prices and the introduction of electric scooters and pedelecs it is expected that the share of vulnerable road users will increase among the killed individuals [3].

Next to the improvement of passive safety the introduction of advanced driver assistance systems (ADAS) and active safety systems in the market increases road safety. ADAS offer a substantial safety potential, since they are based on one or more sensors perceiving the environment and/or traffic around the vehicle. After interpreting the information, ADAS inform, warn, support or intervene in order to assist the driver in performing the driving task. A positive influence of these systems can be found in accident statistics. An example is the first significant statistical proof of the high safety potential for such a system for electronic stability systems (ESP, DSC) on basis of German accident data [4]. Adaptive cruise control (ACC) and brake assistance also show an accident reduction potential of 20 % within a study of 800 vehicle collisions according to [5].

Since the perception and interpretation of traffic and road parameters is a highly complex task which cannot be fulfilled without faults, ADAS may not always be able to assist the driver in a critical situation and seldom act in situations which do not appear critical to the driver. In very rare cases a system fault may lead to an adverse behaviour of the vehicle, which needs to be controlled by the driver – unless the consequences of this system fault are covered by functional safety.

The acceptance of these systems is growing slowly [6], [7], [8], [9], since manifold systems are hardly integrated in terms of human machine interface (HMI) and function. The initial interaction with these systems when first driving a vehicle may result in an additional burden to the driving task of the driver. Systematic approaches for improvements of the interaction concepts [10], [11] are limited by the car maker’s strategy to market every single system separately.

Further integration and enhancement of today’s systems will also increase the future need for evaluation and validation, which already by today exceeds costs for development of these systems. Therefore a structured evaluation process is required, which facilitates the effective evaluation of ADAS. This causes three major methodological challenges:

- The first challenge refers to the definition of relevant driving situations, which form the basis for a valid system evaluation.
- A second challenge is due to the fact, that during the process different representations of driver, vehicle and traffic situation need to be used, in order to efficiently combine virtual and experimental methods.
- The third challenge is caused by the mutual dependencies between system effectiveness and acceptance on the one hand, and controllability and functional safety on the other hand.

Therefore the objective is to provide an effective ADAS development and evaluation process, combining a limited number of interconnected evaluation methods, which is also in accordance with ISO 26262.

In the following, relevant evaluation methods are presented and discussed and finally combined forming an effective evaluation process.

ADAS CLASSIFICATION

A methodical approach for the classification of ADAS is a formal description of these systems. In accordance to the levels of the driving task the driver can be supported or replaced on the navigation, guidance and stabilization level by different assistant systems. Figure 1 visualizes the three levels of the driving task as input for the control loop driver - vehicle - environment.

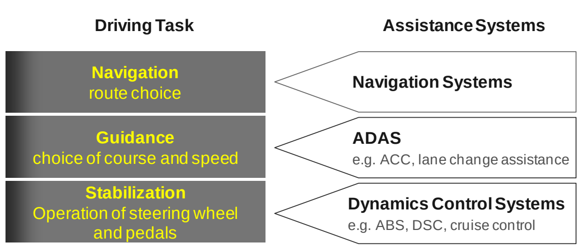

Figure 1. Classification of assistance systems on the basis of the three levels of the driving task.

First prerequisite for competent interaction with ADAS is an active role of the driver in the control loop (Figure 2).

The driver needs to be able to take the final decision independent on the level of support he is receiving by the vehicle's systems. Second prerequisite for competent interaction is that he can perceive all relevant information in time, thus enabling him to anticipate the future development of the traffic situation.

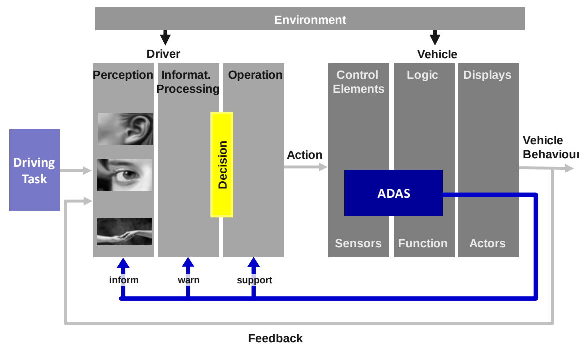

Figure 2. ADAS control loop.

In general the driver can provide an individual and varying amount of cognitive resources depending on physiological preconditions, driving education, experience and current conditions. Depending on the complexity of the driving task the cognitive resources of the driver cover the demand of all levels of the driving task. In critical situations the guidance level and the stabilization level require increasing cognitive and physical resources. With increasing traffic density the driver may first overlook traffic signs relevant for navigation. Increasing variance in traffic speed may lead to safety critical distances. If the driver is not able to react appropriately on the stabilization level, an accident may occur. Therefore the goal of ADAS is to provide the appropriate support, e.g. ease monotonous tasks (traffic jam) or issue warnings/interventions (Figure 3).

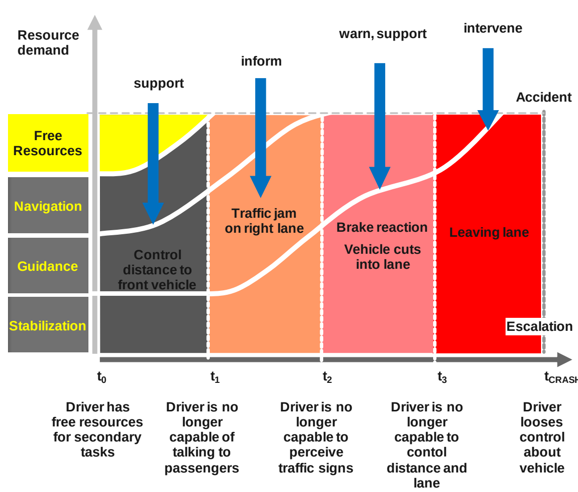

Figure 3. ADAS provide time to act appropriately and de-escalating driving situations.

Especially the analysis of the driving task on the stabilization level reveals that the driver is a controller in the control loop ‘driver-vehicle-traffic’. He compares set and current values and tries to compensate deviations by adapting control variables of the vehicle (Figure 4).

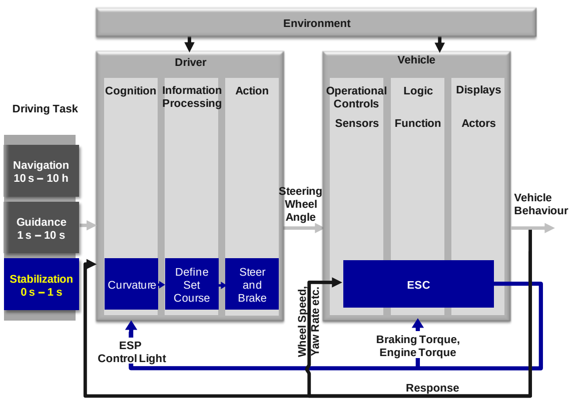

Figure 4. ADAS control loop for safety systems, e.g. ESP.

Also his driving tasks on navigation and guidance level can be seen as control tasks (Figure 5). The system ‘driver-vehicle-traffic’ is thus a closed loop system consisting of driver, vehicle and surrounding environment.

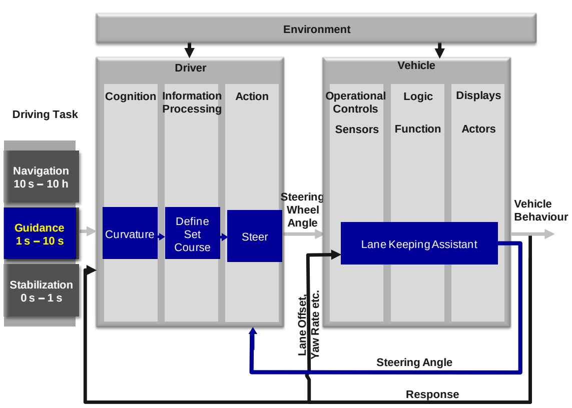

Figure 5. ADAS control loop for comfort systems, e.g. lane keeping assistant.

The three elements of the control loop are the main focus of methods for effective evaluation.

ADAS EVALUATION METHODS

In order to evaluate ADAS a variety of methods is already being used today. Due to the progress during the vehicle development process, they use different representations of the driver, the vehicle and the traffic situation.

Classification

As Figure 6 shows, one can distinguish easily between evaluation methods using four levels of abstraction. These basically differ according to the fact, whether the three elements of the control loop ‘driver-vehicle-environment’ are represented by a virtual simulation model or are real. In general validity increases when combining more and more real elements leading to field operational tests (FOT), where normal drivers interact with real (instrumented) vehicles driving in public traffic.

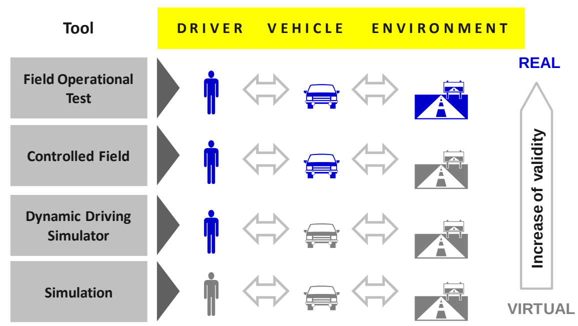

Figure 6. Classification of evaluation method, virtual elements in grey, real elements in blue.

In the controlled field test a real driver is driving a real car, but the traffic situation is ‘simulated’ in terms of a test environment. Using a driving simulator a real driver is sitting in a simulator mock-up, while the vehicle behaviour and the traffic are simulated using high performance simulation tools. If all three elements of the traffic control loop are represented by mathematical models, the result is called a traffic simulation.

Description of Tools

At a very early stage only an abstract system concept exists which is based on a system idea often resulting from analyzing accident statistics. In-depth accident analysis reveals weaknesses in the interaction between the three elements driver, vehicle and environment. This concept is to be designed according to the Code of Practice for the Design and Evaluation of ADAS [12].

The system concept is often depicted in a model (e.g. implemented in MATLAB/Simulink) and can be used in order to simulate the systems effect on traffic flow and traffic efficiency using **traffic simulation software**. This software should be able to depict driver behaviour, environmental conditions and vehicle dynamics in order to yield sufficiently valid results. Especially driver models for different situations (following, lane change, intersections etc.), driving styles (e.g. aggressive, defensive, reaction times, brake forces) and different conditions (traffic density, sight, velocity regulations etc.). A good example is the simulation tool PELOPS (Program for the DEvelopment of LOngitudinal Traffic Processes in System Relevant Environment) [13]. Modelling driver behaviour is a research topic on its own, which has been solved in PELOPS by analyzing many experiments. Another major challenge using a traffic simulation tool is the representation of relevant driving situations, which are infinite in number.

Since traffic simulation can only give results on the effectiveness of a system but not on usability and acceptance, the driver model needs to be replaced by a sufficiently large population of drivers at an early stage in the development process, which can be achieved by using a **driving simulator**. *Figure 7* shows the dynamic driving simulator at ika, which consist of a simulator dome containing the vehicle mock-up, which is being moved by six electromechanical actuators, controlling six degrees of freedom according to the driving situation.

Figure 7. ika dynamic driving simulator.

Driving Simulators have many advantages, but also limitations, which largely depend on the specific simulator concept. Important advantages comprise that a traffic situation is identical for every subject (reliability) and that highly critical situations can be depicted with no danger in a very efficient way. Limitations result especially from the validity of the motion cuing, which is usually not sufficient in order to investigate questions regarding vehicle dynamics. The present ika driving simulator has been optimized in order to evaluate ADAS under normal driving conditions. In order to obtain statistically meaningful results, the number of traffic situations which can be analysed is fairly limited.

Since vehicle dynamics can only be depicted to a limited extent in today's driving simulators, **controlled field tests** are an important methodology in order to obtain more valid results on a system's effectiveness. An overall methodology for the technical assessment is provided in the European research project interactive [14].

On the other hand the prerequisites for this method are rather high: the system's functionality needs to be integrated in a suitable test vehicle, the traffic situations need to be 'simulated' by appropriate means and a test track is needed with sufficient space in order to guarantee for the safety of all persons involved. *Figure 8* shows a slap car on the ika test track, which is used for the evaluation of collision mitigation or autonomous emergency braking systems.

Figure 8. Slap Car on ika test track.

Figure 9 shows the final layout of the Aldenhoven Testing Center (ATC) which is currently being built with the support by ika [15].

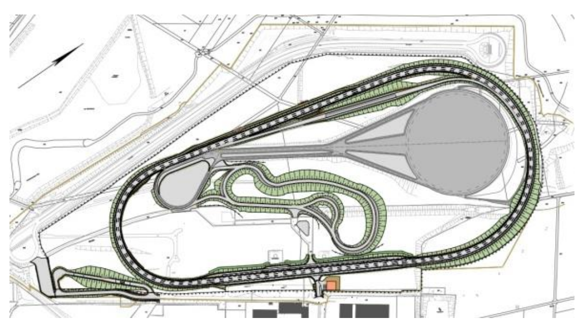

Figure 9. ATC test track layout, to be finished by October 2013.

The Aldenhoven Testing Center comprises relevant infrastructural elements for ADAS and dynamic vehicle testing in the controlled filed. These consist of a vehicle dynamics area (200 m diameter), a high speed oval for velocities up to 110 km/h, a handling course and further elements such as braking tracks or climbing hills. A unique feature is the Galileo infrastructure which simulates the signals of Galileo satellites enabling research and development of Galileo-based applications. Due to the available road elements different driving situations can be simulated and research results of critical situations for Galileo enhanced safety systems can be obtained.

Finally every ADAS functionality needs to be evaluated on public roads, because the variance of critical traffic situations is in real life is infinite. Only a small portion of situations can be depicted and evaluated in the driving simulator and the controlled field test. So called f**ield operational tests (FOT)** or n**aturalistic driving studies (NDS)** aim to investigate short- and long-term effects of ADAS under normal driving conditions. Carrying out tests on public roads requires road legal vehicles which are highly instrumented in order to gather all relevant data – but the subject driving the vehicle should hardly recognize the measurement equipment. *Figure 10* shows a typical test vehicle, which ika uses for implementing and testing ADAS applications.

Figure 10. ika ADAS test vehicle.

Since critical situations are fortunately quite rare events, it is usually not sufficient to perform a FOT with one vehicle, but with 10 to 100 vehicles.

In order to gather and process the data of e.g. 100 vehicles an appropriate data communication and handling structure needs to be set up. The process of collecting FOT/NDS data requires full automation in terms of data acquisition, management, processing and data analysis, in order to guarantee fast and complete evaluation of the data. Figure 11 provides the fully implemented process of ika, which was developed and applied within the framework of the European research project euroFOT. In euroFOT a total of almost 2 Mio. km data (493 GB raw data) were collected and analysed with focus on ACC and FCW [16].

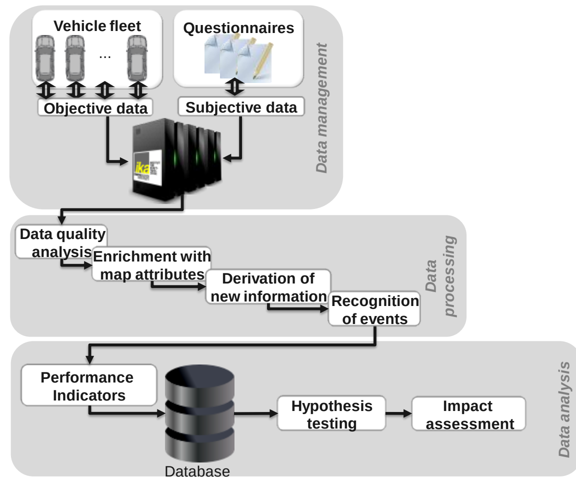

Figure 11. ika's FOT data management process.

While critical situations have been depicted in all other methods on an analytical basis, the FOT is the only setting which continuously generates new critical driving situation. In order to make use of these valuable data the 'circuit of critical situations' is proposed and described in this paper for the very first time.

Circuit of critical situations

The general idea is first to make use of the valuable data obtained when performing tests on public roads and secondly to make sure that critical situations are used in a consistent and effective manner. *Figure 12* depicts the principle idea of collecting hundreds of critical situations during field operational tests and naturalistic driving studies and feeding them into the traffic simulation data base.

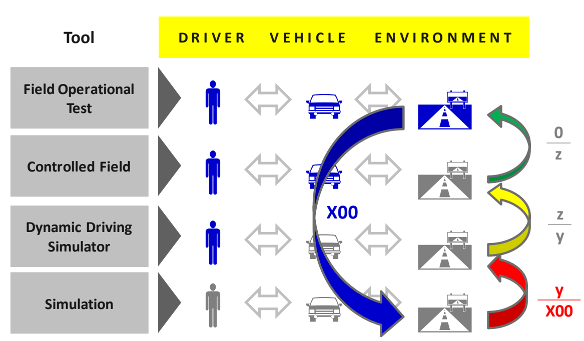

Figure 12. ika Circuit of critical situations.

This data based is continuously updated by data from different sources such as projects, which provide data collection. The critical situations are clustered into different categories depending on the areas of effective applications.

When a new system concept is defined, these comprehensive set of critical situations can be used in traffic simulation in order to identify those situations which appear to play an important role for the innovative system. Those *y* critical situations which have been identified, are depicted in the driving simulator using the same simulation format. The tests in the driving simulator allow a much more in-depth analysis of the situations and of the interaction between driver and vehicle in these situations. On this basis the system concept can be optimized and implemented in an appropriate ADAS test vehicle. Since critical situations are even more difficult to 'simulate' on a test track, the number should be reduced significantly to a value *z* before conducting tests in the controlled field, which typically amounts low numbers. Again the results are used in order to finalize the system design. Ideally, no critical situation remains, which is of special interest for the tests on public roads.

ADAS EVALUATION PROCESS

The circuit of critical situations already forms a connecting element between the various methods – but it is only a logical link. From a process point of view it is decisive that driving simulator tests are being carried out at a very early stage of the development process, far before the system has been decided for market introduction. One important reason is the potential to derive quantitative input for the system specification in terms of controllability and functional safety. Any system fault, which cannot be controlled by the driver, needs to be addressed by functional safety, e.g. by redundancies in signal processing or actuators.

The same is true for controlled field tests: they can also provide valuable input for system specification. It should therefore be performed quite early in the development process, compare Figure 13. Expert tests provide a detailed insight in the system design and first indications on robustness and reliability of the development.

The final validation and approval is conducted in FOTs.

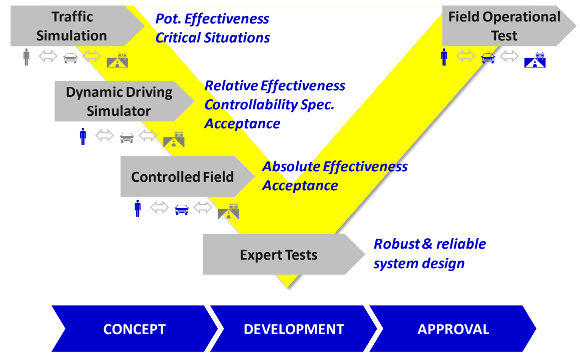

Figure 13. ADAS development process.

The definition of reliable and distinct evaluation criteria for the development process is most challenging in order to determine "safe" and "unsafe" functions and provide a reliable sign off. Especially the lack of boundary values on the driver behaviour level in terms of controllability, effectiveness and acceptance is one of the major research areas. A first approach to solve this need is to establish a driver behaviour related data base of characteristic values resulting from available research and evaluation work in this respective field. This approach will be elaborated by ika in the German research project UR:BAN [17].

Evaluation of functional safety needs to be already integrated in the concept and development phases. Guidelines for verification and validation in the evaluation process are provided by ISO 26262 [18]. Test cases need to be derived ranging from fault injection tests to user tests under real-life conditions depending on the ASIL of the ADAS function. Based on the fundaments of the ADAS development process including methods and evaluation criteria a first set of requirements for the functional safety tests are derived. The given linkage between acceptance, controllability, effectiveness and functional safety can therefore be depicted in total.

While the overall ADAS evaluation process as well as the 'circuit of critical situations' can be described in a generic way, the specific criteria and the experimental design of the interconnected methods also depend on the individual advanced driver assistance system under investigation.

Therefore the application of this process requires an interdisciplinary cooperation between automotive engineers and experimental psychologists in order to implement this approach. Only the interaction between vehicle technology, psychology and functional safety allows an overall consideration of all necessary aspects of the evaluation process.

CONCLUSION

This paper introduces an integrated and effective approach for ADAS evaluation, which is based on extensive research within numerous national and European research projects as well as on ika's long experience in ADAS development and evaluation in cooperation with industry, leading to many patents and publications of the authors.

The concept of the "circuit of critical situations" is introduced and discussed. Based on critical situations identified in FOT or NDS critical driving situations are fed into traffic simulations, driving simulator studies and controlled field testing. Using the same format in all evaluation methods provides the possibility to optimise the ADAS function suggestively.

The circuit of critical situations requires availability and in-depth knowledge of different evaluation tools and methods as well as the necessary data base on driving situations in order to cover all aspects of the developed ADAS. The linkage between controllability, effectiveness acceptance and functional safety is considered in the methodological approach.

In the next step the first implementation of the concept will be provided and circuit of critical situations will be applied to the development of an ADAS function.

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