Human-Centered Development of Advanced Driver Assistance Systems

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Abstract. A methodological approach is presented for the human-centered development of Advanced Driver Assistance Systems (ADAS). A procedure has been developed for the objective evaluation of potential impacts of ADAS usage on traffic safety. The procedure is based on the observation and analysis of the emergence resp. avoidance of driving errors (inadequate speed, insufficient safe distance, etc.) in conjunction with the usage of ADAS. Driving errors are assumed to occur by the coaction of functional ADAS features, the situational context and (psychological) behavioral backgrounds. The applicability of the approach is examplified with a simulated ADAS.

Keywords: Advanced driver assistance systems, traffic safety, driving errors, risk evaluation, driver workload.

1 Introduction

Advanced Driver Assistance Systems (ADAS) are auxiliary (primarily electronical) components in vehicles to support the driver in certain driving situations. They are dedicated to increase driving comfort as well as car safety and more generally road safety. Examples of ADAS are:

- Parking assistant, which detects and measures parking spaces and then steers the car automatically in the parking spot. With the current assistant versions accelerating and braking are still the driver's tasks.
- Adaptive Cruise Control (ACC) which uses either a radar or laser setup to allow the vehicle to automatically slow down when approaching another vehicle and accelerate again to preset speed when traffic allows.
- Lane departure warning (LDW) which warns the driver when the vehicle begins to move out of its lane (unless a turn signal is on in that direction).
- Lane change assistant (LCA) which warns the driver in case of an imminent collision when initiating a lane change manoeuvre. The LCA is typically released when the indicator is activated (contrary to the LDW which is deactivated in that case).

Since ADAS always work with a human driver co-existing, the overall vehicle performance will depend on, not how well the ADAS works by itself, but rather its

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interaction with the human driver. The evaluation of ADAS, therefore, needs to be conducted with human (driver) in the loop.

In particular it is important to design the human-machine interface of ADAS so that the systems provide actual support and do not pose additional stress or distraction on the driver. In this contribution a methodological approach is presented to assess the impact of ADAS design on traffic safety in an objective manner. The applicability of the approach is examplified with a simulated ADAS ("Stop&Go-ACC").

2 Evaluation of the Impact of ADAS on Traffic Safety

2.1 Interrelation Between ADAS, Driving Error and Accident Occurence

Up to now, the relationship between ADAS usage and road safety has been examined only in an incomplete way. A (human-centered) approach to analyse these interrelations consists in regarding changes in the appearance of driving errors in consequence of the application of ADAS. This approach has been applied already from time to time, e.g. by means of trained human observers (mainly driving instructors). What was missing up to now was an objective standardised method which follows the underlying principles, but (ideally) goes without a human observer.

A method which is geared to this objective was developed within the German research program INVENT [1]. The approach starts with a model for accident occurence (see Fig. 1), which was already introduced by Reichart [2]. Whereas Reichart concentrated on the right part of Fig. 1 and worked out a fault tree analysis by means of probability calculations, the INVENT procedure is focusing on the occurrence of the driving error and asks for the ADAS characteristics, the context of the situation and the behavioral background leading to the occurrence or prevention of the error.

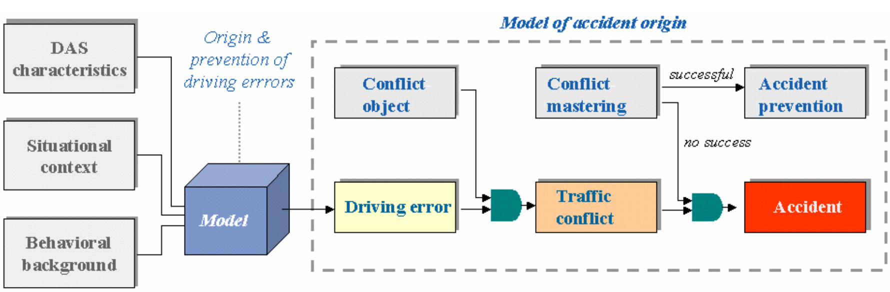

Fig. 1. Generic accident occurence model

It is assumed that the ADAS usage changes the character of the driving task. Depending on the current driving situation, this affects the behavioral background, i.e. the mental or visual workload, the situation awareness and the mental model. These changes result in measurable differences of driver characteristics and the driving behavior.

2.2 Evaluation Procedure and Criteria

2.2.1 Specification and Measurement of Driving Errors

Based on the concept of driving errors an evaluation procedure was developed for the objective assessment of the impact of ADAS usage on traffic safety. The basic principle of the evaluation procedure consists in specifying the set of potential (and measurable) driving errors for a given ADAS in the context of the traffic situations, in which the errors could appear. The error specifications are compiled in a generic error data base, structured into the following error categories:

- Speed too high
- Distance too low
- Braking too late/too weak
- Lane keeping/lane change error
- Illegal/risky overtaking
- Illegal/risky crossing or turning
- Omission/error with blinking
- Insufficient monitoring of traffic

The error specifications at first include the measurable indicators together with the technical requirements for the measurement, followed by the proper evaluation criteria and threshold values. When applicable, multiple grades of error severity are introduced. As an example, the specification for the driving error “distance too low with respect to front car” is depicted in Table 1.

Table 1. Example of driving error specification

Driving error:	Distance too low with respect to front car
Corresponding situation:	Car-following (front car with approximately same speed)
Indicator:	Time headway [s]
Technical requirements:	Speed measurement (accuracy +/- 2.5%) Distance measurement (accuracy +/- 2m)
Criteria:	Definition: time headway at time t [s]: $T_h(t) = d(t) / v(t)$ with d(t): distance to front car at time t [m] and v(t): speed of own car at time t [m/s]

Time headway / Duration of error	> 1.7s	1.2s – 1.7s	0.7s – 1.1s	< 0.7s
< 5s	---	---	---	A
5s – 30s	---	---	A	B
> 30s	---	A	B	C

Effect on traffic safety: ---: none A: low B: significant C: serious

In the further course of the evaluation procedure the general list of driving errors is restricted to a subset which includes only the situations relevant to the assessment of the specific ADAS under consideration. Thus, the restricted error list comprises the driving errors the occurrence of which has to be checked in driving simulator and/or field trials.

2.2.2 Specification and Measurement of Behavioral Background Parameters

According to the concept of the evaluation procedure, the measurement of driving errors is complemented by the recording of parameters which provide hints with regard to the behavioral background of the impact of ADAS usage on error occurrence resp. prevention. These indicators include:

- Mental workload to assess the available cognitive resources of the driver; to be measured by steering entropy or RSME (Rating Scale Mental Effort) questionnaire
- Visual workload to asses the amount of visual information the driver has to detect; to be measured by reaction time on peripheral detection task or eyelid closure frequency
- Situational awareness to assess the driver's understanding of the overall traffic situation; to be measured by reaction time on visual cues, e.g. road signs
- Mental model to assess the driver's understanding of the ADAS functionality; to be measured by questionnaires or recorded data of system usage.

2.2.3 Test Plan

The principal test plan for the experimental trials is specified as follows:

- Test cohort of 30 subjects with driving experience of at least 5 years and/or 50.000km, equally distributed from age groups < 31, 31-59, > 59 years.
- Test protocol with driving task under both conditions (with/without ADAS) in random order.
- Independent variables: driving with/without ADAS, driving situation, driver characteristics.
- Dependent variables: driving errors, behavioral background parameters.

The overall evaluation is based on statistical comparison of frequency and duration of the specified error categories.

3 Application of the Evaluation Approach with Simulated ADAS

In order to verify the evaluation procedure, criteria and threshold values introduced in Chapter 3, a prototypical version of an ADAS was implemented in the Fraunhofer IVI driving simulator. The ADAS prototype selected was a "Stop&Go-ACC", which is a normal Adaptive Cruise Control (ACC) system extended by specific features, which allow to support the driver in case of congestion situations by overtaking the steady stop and driveaway activities.

3.1 Fraunhofer IVI Driving Simulator

The Fraunhofer IVI driving simulator (see Fig. 2) is based on a series-production vehicle in which the driver finds all functions, operating controls and displays as in a real vehicle. A force-feedback steering wheel imparts a realistic driving feel to the driver. Various sensors at the steering wheel, at the pedals and at the transmission selector lever continuously gather data about the vehicle guidance interactions. The simulated vehicle environment is projected to the fore by 3 DLP projectors onto a spherical screen with a sight area of 180x50 degrees. The sight backwards is simulated by transmitting 2 channels of the 3D-model to 2 TFT displays, which are mounted at the positions of the left and of the middle rearview mirrors.

The simulator features specific audio components (sound pc, audio mixer), which allow to generate realistic environmental noise, to utilise the onboard audio systems and to communicate between supervisor and subjects during test trials.

The behavior of the driver can be logged extensively. To record the driver's visual behavior an eyetracking system (FaceLab) is installed, which operates contact-free on the basis of video cameras and optical image analysis.

Fig. 2. Fraunhofer IVI Driving Simulator

3.2 Implementation of a "Stop&Go-ACC" in the Driving Simulator

Adaptive Cruise Control (ACC) systems are now actively being developed and introduced into the consumer market by vehicle manufacturers. The primary functional purpose of these systems is to maintain a safe distance between the ACC-equipped vehicle and its immediately preceding vehicle, when one is present.

In order to provide comfort and convenience to drivers, the ACC vehicles use many of the controls associated with conventional cruise control. In addition, the driver is usually provided with the option to select a desired time gap, which lies between maximum and minimum values determined by the designer of the ACC system. Using this control arrangement, each driver may select a free-driving speed (the "set speed") and a headway gap parameter, which is used by the system in determining the desired range. In this manner, each individual driver can obtain operating conditions that are favorable to that individual's driving preferences.

3.2.1 Functional Specification of the "Stop&Go-ACC"

The specification of the ADAS "Stop&Go-ACC", which was selected to be implemented as a prototype in the driving simulator, was developed and provided by a cooperating sub-project within the INVENT programme [3]. The "Stop&Go-ACC" is in principal a normal ACC (Adaptive Cruise Control) system, dedicated to support the driver in headway control when driving at a higher speed (> 50km/h). The ACC system is extended for the lower speed range (< 50km/h) by a specific functionality, which allows to disburden the driver by overtaking the control in stop&go congestion situations (i.e. to stop and driveaway again and again automatically).

The basic control loop of the ACC system is outlined in Figure 3. It is necessary to control the own velocity ($v_{vehicle}$) as well as the headway to a vehicle in front (dx). As a simplified approach a hierarchical controller is applied with a cascadic structure.

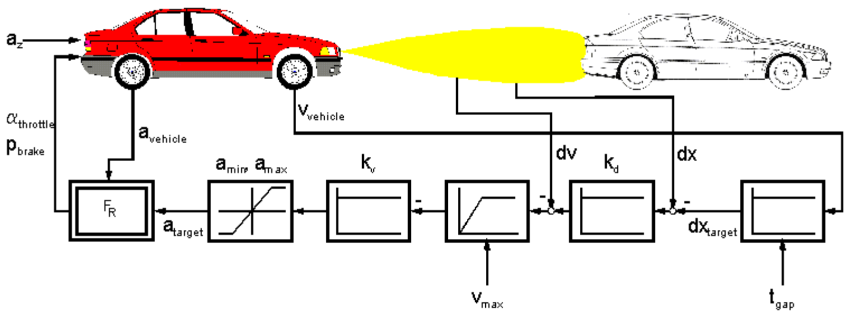

Fig. 3. Basic control loop of the ACC system

The dependent variable of the controller for the simulation is the nominal acceleration (a_z). If a relevant object is located in the own lane within the range of the sensor, the nominal acceleration is calculated as follows:

$$a_z = k_v * (k_d * (dx - dx_{target}) + dv) \quad (1)$$

with $kv = 1 \quad [1/s]$
$kd = 0,2 \; [1/s]$

and dx = distance from ego vehicle to relevant object

$$d_v = v_{object} - v_{vehicle} \quad (2)$$

$$dx_{target} = t_{gap} * v_{vehicle} + d_{min} \quad (3)$$

with $d_{min} = 3 \; [m]$
$t_{gap} = 1,8 \; [s]$

If no relevant object is detected, the nominal acceleration a_z is calculated from the difference between a target speed (v_{target}) adjusted by the driver and the current own velocity ($v_{vehicle}$):

$$a_z = kv * (v_{target} - v_{vehicle}) \quad (4)$$

3.2.2 HMI of the "Stop&Go-ACC"

The HMI of the "Stop&Go-ACC" has been realised in the driving simulator as depicted in Figure 4. To be able to present the specific ACC speedometer and state symbols according to the given specification, an additional TFT display was installed into the cockpit of the simulator vehicle in front of the proper vehicle speedometer.

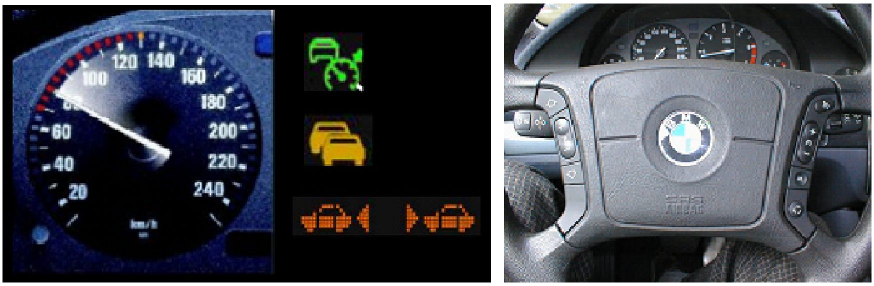

Fig. 4. HMI of the "Stop&Go-ACC"

The relevant features of ADAS HMI implemented are:

- Within the speedometer chaplet the difference between the own velocity and the velocity of a preceeding vehicle (if present) is visualised by means of a segment of lighting up diodes;
- Adjacent to the speedometer at the right there are 3 symbols which indicate (from top to down): ACC activated, preceding vehicle detected, target headway adjusted (1 out of 3 adjustments: 0,8s, 1,0s, 1,3s);
- The enter keys for the "Stop&Go-ACC" are integrated within the multifunction keys of the steering wheel

3.3 Experimental Tests

3.3.1 Test Set-Up

According to the evaluation procedure introduced in chapter 3 experimental tests were set-up to assess the impact of the usage of the "Stop&Go-ACC" on traffic safety. Because this type of ADAS is destined primarily to be applied on highways the selection of traffic situations was restricted to situations on highways like

- free driving,
- following preceding car,
- approaching preceding car,
- lane change / overtaking,
- stop&go driving.

32 subjects participated in the simulator tests.

3.3.2 Exemplary Results

Figure 5 shows for 4 exemplary driving error indicators the time slices within the 3 pre-defined endangering categories (low, considerable, serious endangering).

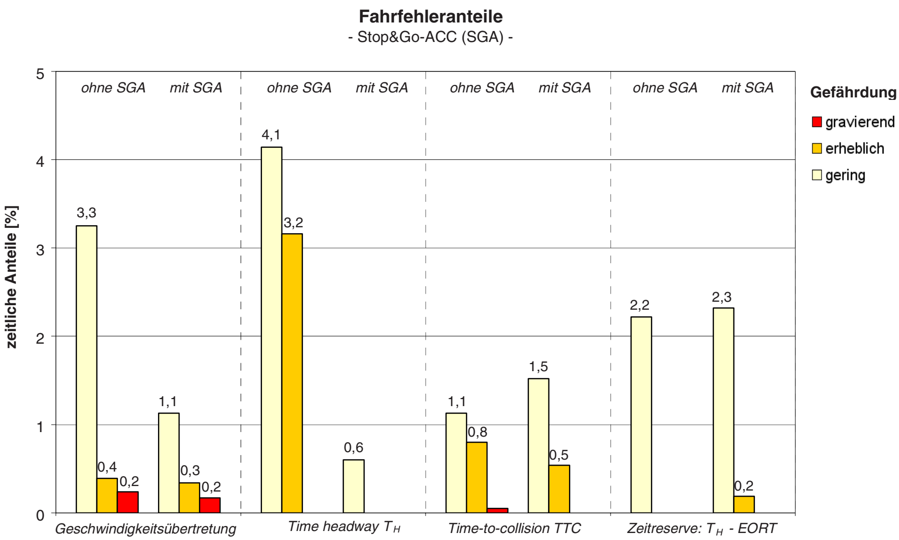

Fig. 5. Selected results (driving errors)

To improve the facility of inspection the category "no endangering" was omitted in each case.

The following remarkable statements can be derived from the analysis of the results:

- The share of the driving error "speed too high" in conjunction with "low endangering" is 3 times higher when driving without the "Stop&Go-ACC" than with the system.
- The time shares of the driving error "time headway too low" in conjunction with low or considerable endangering are clearly higher when driving with the "Stop&Go-ACC" than without it.
- With regard to the driving error indicator "Time-to-collision" (TTC), which is of relevance particularly when approaching with higher differential velocities to a preceding vehicle, there could not be detected remarkable variations when driving with the "Stop&Go-ACC" vs. without it.
- As a dependent parameter with regard to the visual distraction the "time reserve" t_{Res} was calculated as the difference between the time headway t_H and the measured "Eyes-off-the-road-time" (EORT). With regard to the glance behavior the results show now remarkable variations when driving with the "Stop&Go-ACC" vs. driving without the system.Discussion and conclusions

4 Discussion and Conclusions

The evaluation method presented in this contribution describes an objective and standardised procedure in the assessment of ADAS impacts on traffic safety. In a consecutive study [4] this approach was taken up and validated by means of tests in real traffic. The evaluation procedure was refined in particular to that effect that the data recorded in the trials are aggregated statistically in several stages, among other things with factor analysis, to seven dimensionally independent scales of driving safety.

The questions remaining with regard to the applicability of the evaluation procedure include:

- Is the comparison of driving with and without ADAS adequate to assess its overall safety applications?
- Can the selection of relevant situations be done for each ADAS in a specific way without loosing generality?
- Which variation is needed or tolerable for the realization of the experiments concerning the number of subjects, group effects, etc.?
- What is the best way to measure the behavioral background values?
- How can long-term effects be covered within the evaluation procedure?

The focus on the occurrence and prevention of driving errors offers the large advantage to overcome the societal luck and statistical issue that accidents are relatively rare events. On the other hand, the proposed evaluation method deals with the emergence of driving errors only. But, the conflict mastering strategy after the occurrence of a driving error may be affected by the ADAS usage as well. In this context, probability calculations as given by Reichart [2] can be of additional value. Again, the behavioral background of mental models as well as situation awareness play an important role in the conflict mastering strategy.

Accident data analysis are additional important means to detect deficiencies of all drivers or of specific groups [5], to make predictions of the safety benefits [6], or to analyze the safety impact by retrospective comparison of accident data with and without ADAS [7]. These techniques can be adopted supplementary to the evaluation procedure presented in this contribution, which already by itself achieves the goal to be an objective method applicable to all kind of ADAS at an early stage of development.

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