BEHAVIORAL CHANGES AND USER ACCEPTANCE OF ADAPTIVE CRUISE CONTROL (ACC) AND FORWARD COLLISION WARNING (FCW): KEY FINDINGS WITHIN AN EUROPEAN NATURALISTIC FIELD OPERATIONAL TEST

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Paper Number 13-0025

ABSTRACT

In the euroFOT project multiple Advanced Driver Assistance Systems (ADAS) were tested within a large-scale Field Operational Test (FOT) in Europe. Main objective of the project was the impact assessment of different ADAS on safety, traffic efficiency, environment, driver behaviour and user-acceptance in real life situations with normal drivers. The needed data was gathered by means of instrumented vehicles. Altogether, about 1000 vehicles from different manufacturers and with different advanced driver assistance systems took part in the FOT. The Institute of Automotive Engineering (ika) of the RWTH Aachen University analysed the effects of Adaptive Cruise Control (ACC) usage in combination with Forward Collision Warning (FCW) under normal driving conditions of 100 passenger cars. The results of the data analysis show positive effects on traffic safety and fuel consumption. In terms of traffic safety a reduction in number of incidents, harsh braking and critical time-headways were determined. These reductions can be attributed to changed distance behaviour of the drivers.

INTRODUCTION

One of the main challenges of road transport is the reduction of fatalities. The worldwide number of fatalities exceeds more 1.2 million per year (1). To identify possible approaches to improve traffic safety various initiatives were launched in Europe within the last years. One of these approaches is the wide deployment of Advanced Driver Assistance Systems (ADAS).

These systems are designed to support drivers in their daily driving routine by increasing driving comfort, safety and efficiency with regard to traffic flow as well as fuel consumption. In addition to different studies (2) Field Operational Tests (FOT) were conducted within the last few years that aim to investigate short- and long-term effects of ADAS under normal driving conditions. The first large-scale FOT for investigating effects of ADAS was started within the seventh framework program of the European Commission. Objective of the euroFOT project was to assess the impacts of eight different ADAS with regard to driver acceptance, traffic safety and efficiency as well as fuel consumption. All tested functions are in production and are integrated as such in the vehicles. Overall, about 1000 vehicles were used for data collection in the project.

This paper presents the results of the conducted analysis of the collected data of 100 passenger cars equipped with an Adaptive Cruise Control (ACC) and a Forward Collision Warning (FCW) function.

STATE OF THE ART

Field operational tests belong to experiments under realistic settings and are an important method to assess the impact of ADAS because of low controlling factors. This allows investigating the naturalistic driving behaviour under real driving conditions which is highly important for the assessment of ADAS. Based on the collected data the analysis answers predefined research questions to assess the impact. To gather a sufficient amount of data, an experiment duration of several months is necessary.

In the U.S. large-scale FOTs are used as an evaluation method since 1996 (3). In addition to FOTs of Intelligent Speed Adaptation Systems (ISA) (4), Forwards Collision Warning (FCW) (5), Lane Departure Warning (LDW) (6), Adaptive Cruise Control (ACC) (7), and naturalistic driving studies were conducted (8). The following table highlights some of the conducted FOTs in Europe and the U.S.

	Tested Systems	Number of vehicles	Number of participants	Duration [Months]	Mileage [km]
NHTSA ICC FOT (1996 – 1998)	ICC	10	108	13	108,000
VOLVO IVI FOT (2001 – 2004)	ACC, CWS, AdvBS	100	> 1000	> 24	16,300,000
ACAS FOT (2003 2004)	ACC, FCW	14	66	9	158,000
Mack IVI FOT (2004 – 2005)	LDW	22	31	12	1,400,000
IVBSS FOT (2008 – 2010)	FCW, LDW, CSW, LCM	26	108	10	1,394,000
ISA Sweden (1999 – 2002)	ISA	5000	10,000	12	75,000,000
ISA GB (2001 – 2006)	ISA	20	20	5	570,000
The assisted driver (2006 – 2007)	ACC, LDW	20	20	5	n.a.
SeMiFOT (2008 – 2009)	ACC, FCW, LDW, BLIS	14	39	6	171,440
euroFOT (2008 – 2012)	ACC, CSW, FCW, LDW, SRS, BLIS, FEA, IW	971	1038	12	34,868,000
TeleFOT (2008 – 2012)	NAV, SL, SA, SC, GD, TI, eCall, FCW, ACC, LKA, LDW	n.a.	2986	12	n.a.

AdvBS: Advanced Braking System, CWS: Collision Warning System, CSW: Curve Speed Warning, GD: Green Driving, FEA: Fuel Efficiency Advisor, IW: Impairment Warning, ICC: Intelligent Cruise Control, ISA: Intelligent Speed Adaptation, LCM: Lane Change Merge, LKA: Lane Keeping Assist, NAV: Navigation System, SA: Speed Alert, SC: Speed Camera, SL: Speed Limiter, SRS: Speed Regulation System, TI: Traffic Information

Figure 1. Overview of FOTs in Europe and the U.S.

METHODOLOGY

In the following, the data management process as well as the analysis approach for the ACC and FCW used in euroFOT is presented. To that end, first the data management process is presented. Afterwards the defined experimental design of both systems and the data analysis approach of the collected data is described.

Data management

The participants of the FOT are non-professional drivers that were recruited by different car dealerships in Germany. They were contacted by the dealerships after buying a vehicle of the specific manufacturer equipped with ACC and FCW. This vehicle is used afterwards for the FOT. To collect all relevant data (CAN data and GPS data) data loggers (Data Acquisition System (DAS)) were installed in all 100 customer vehicles. The data loggers are able to record, temporarily store and transmit the data afterwards to a centralized server system. Overall, about 100 CAN signals were recorded. In addition to dynamic measures (velocity, acceleration, yaw rate, steering angle, wheel speed etc.) status information of different systems were considered (e.g. state of turn indicator, wiper, ADAS). To avoid modifications of the customers' vehicles and influences to the driving behavior no additional data sources like video systems were used. Figure 2 presents an overview of the process stages for data management.

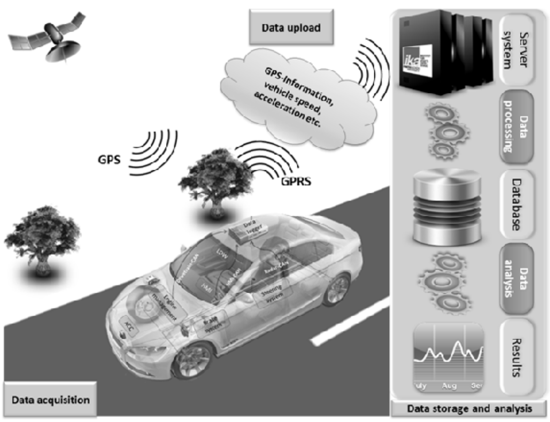

Figure 2. Data acquisition and processing

The data measured on the connected CAN-channels will be stored in a first stage on a FLASH storage device installed on the DAS. The DAS offers the possibility to communicate with the device during operational time of the field test using an integrated GPRS module. This allows wireless uploading of recorded information to a centralized server system, while the DAS is collecting data simultaneously. Therefore the data is compressed and encrypted. By means of a GPRS connection the DAS status and operation on board of the vehicle can also be checked and monitored during the entire operation time.

The upload procedures are designed and implemented to work fully autonomously. Autonomous operation means that no user interaction – neither on the driver side nor on the operator side – is required. Hence the drivers are totally kept out of the data retrieval loop. No training of the drivers participating in the field test is needed and the loss of data due to maloperation is excluded. Besides the event recognition and data retrieval steps the entire process chain for data management has been automated (11). Figure 3 presents the structure of the software architecture that has been developed at ika for this purpose.

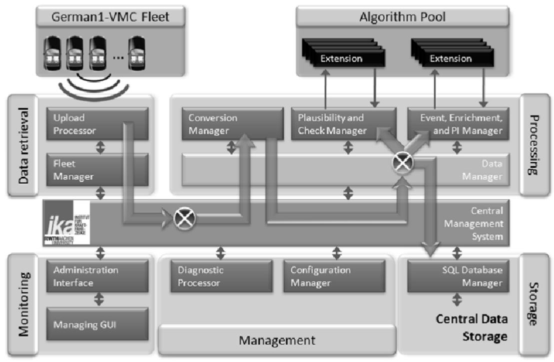

Figure 3. Software architecture of data management process

The architecture for data management on the server side consists of several different software components. The coordination of the interaction between the software components is performed by the Central Management System (CMS). After data has been successfully uploaded on the server, the CMS is responsible for passing the data to the Data Manager, which subsequently manages the data processing. Data is passed between these software elements each time one process step is accomplished. The processed data is stored on an SQL based server at the end, in order to make the data available for the analysis. For configuration management and diagnostic purposes as well as operator access, additional software components (e.g. diagnostic processor etc.) complete the infrastructure for the automation of the whole process chain.

Experimental design

For the impact assessment it is necessary to assess also trips without the influence of the system as a reference (baseline) besides trips with activated system (treatment). The comparison of the collected data in both phases (baseline/treatment) forms the

basis for the assessment of the systems' impact. Based on these research questions hypotheses to be tested (e.g. ACC decreases the number of incidents) have been defined. By means of the hypotheses the required signals and data sources for data collection have been identified.
The experimental duration of the FOT for the vehicle fleet of 100 passenger cars was twelve months of which the first three months served as a baseline. During this baseline period the ADAS were deactivated, while all necessary data was collected from the vehicle's CAN-Bus. By means of the baseline the naturalistic driving behavior of the participants was analyzed. In the following treatment period the systems were activated and the drivers were free to use the systems as desired. Neither further instructions were given to the drivers nor were they accompanied by a supervisor. Drivers used the vehicles in their daily routine (e.g. way to work). The experimental design for the 100 passenger cars is shown in Figure 4.

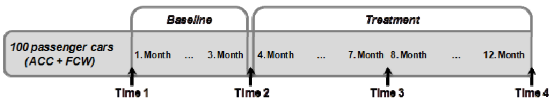

Figure 4. Experimental design for the vehicle fleet of 100 passenger cars

In addition to the selection of relevant driving events (e.g. incidents, lane change maneuvers) different indicators are necessary for the impact analysis. Especially for the hypothesis testing the so called performance indicators (e.g. number of harsh braking events, average speed) are required for the statistical analysis. Moreover, so called situational variables such as weather conditions or road type are relevant for the hypothesis testing in order to ensure that the comparison of baseline and treatment is done under similar circumstances to avoid influences from external effects. By combining the relevant events with the situational variables scenarios for the comparison of baseline and treatment were determined. An example for detection of relevant scenarios is presented in Figure 5.

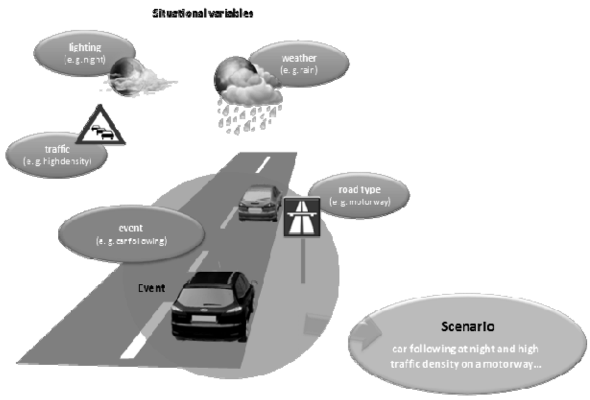

Figure 5. Procedural steps to cluster data for analysis purposes

The combination of the car following event (relevant event for ACC) with different situational variables provides the scenario of a car following event under the relevant weather, traffic, lighting and road type conditions, e.g. car following on a motorway, in day light and high traffic density.

Furthermore subjective data is collected by means of four time-based (Time 1 to Time 4) questionnaires to analyze the effect on user acceptance. The first two questionnaires (Time 1 and Time 2, see Figure 4) were spread during the baseline phase. The remaining questionnaires (Time 3 and 4) were distributed at half-time and at the end of the treatment phase.

Data analysis

The required signals were recorded with defined sampling rate. By means of the installed data loggers the collected data were transmitted wirelessly to the centralized server system at the ika (see Figure 6). After the successful transmission of the data to the server (within the data management) the data processing is conducted. Firstly, the data quality analysis includes the assessment of missing data parts and plausibility checks of the recorded signals. In a second step, the gathered data was enriched with map attributes (e.g. road type, speed limits) from a digital map based on the recorded GPS information. Afterwards, additional information (e.g. time-headway, time-to-collision (TTC), average speed) was calculated from the collected data. Finally, situational variables and relevant driving events were identified by means of an automated recognition process (12).
The data analysis starts with the calculation of the performance indicators that are necessary for the hypothesis testing. Afterwards, the processed data was stored on a database, which served as a basis for the data analysis. The results of the hypothesis testing were used as input for the impact assessment, see Figure 6.

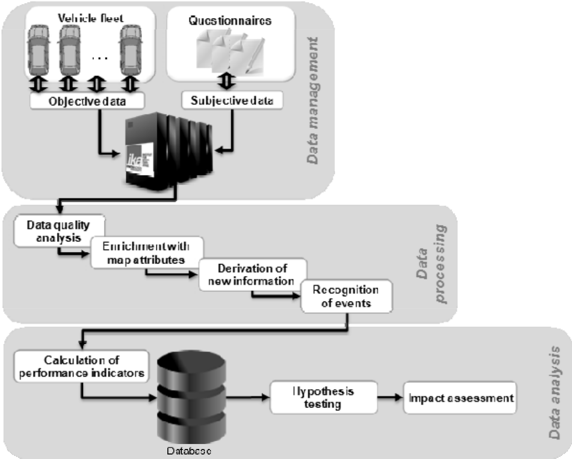

Figure 6. Processing steps between data collection and impact assessment

The processing of the raw data led to an increase in the data amount due to the enrichment and derivation process. Overall, about 1 TB of data is available for the impact assessment, see Figure 7.

	Mileage [km]	Number of drivers	Number of trips	Data amount
Raw data	1,954,329	98	144,280	493 GB*
Data processing	1,954,329	98	144,280	990 GB
Impact assessment				
Baseline	233,071	84	6048	100 GB
Treatment	747,296	84	18,268	293 GB

* compressed

Figure 7. Overview of data amount

RESULTS OF THE IMPACT ASSESSMENT

The magnitude and the experimental set-up of the conducted FOT allow detailed insights into various aspects of the daily use of ACC and FCW by normal customers. In the following some of the main outcomes of the conducted statistical analysis are presented. Thereby, the analysis focuses on changes in traffic safety, driver behavior and environment while driving on motorways. For the safety impact assessment various indicators are used to determine the impact of ACC and FCW. An assessment by means of accidents occurred within the FOT is not a feasible approach. Only a few accidents (< 4) occurred within the data collection phase, which are not sufficient to provide any statistical valid conclusions.

Safety

The combination of ACC and FCW show a positive impact on driving safety. While there was no decrease in average speed (an indicator previously linked to increase in safety (13)), the average time-headway (THW) shows an increase of about 16% (see Figure 8) and leads therefore to larger/greater safety margins. Due to the predefined settings of the ACC time-headway the number of (intended or unintended) close approaching maneuvers is highly reduced and prevents therefore critical driving situations. The analysis of critical time-headways (< 0.5 s) reveals a reduction of 73% on motorways. As a consequence of the safer distance behavior the frequency of harsh braking maneuvers is lower when driving with active ACC. Two out of three harsh braking events (67%) can be avoided by the use of ACC. Like for the harsh braking events the number of incidents is lower when using ACC and FCW. The incidents based on vehicle kinematics show more than 80% reduction. Details on the incident definition can be found in (14).

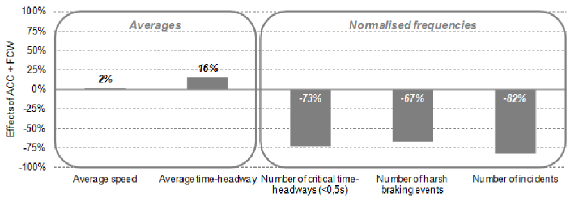

Figure 8. Overview of safety indicators for driving with active ACC and FCW on motorways

Explanations for the increase in average time-headway and the reduction of critical time-headways, harsh braking events and incidents can be found in the selectable ACC settings that can never be lower than the legally prescribed value which is not always considered by drivers in their normal driving behavior. Resulting from the increase in average time-headway the reaction time to avoid (unintended) close approaching events is higher. If the driving situation exceeds the braking capacities of the ACC because of a highly decelerating vehicle in front, the presented warnings (by the ACC and FCW) give the driver appropriate time to react on the driving situation. It could be shown in the analysis that this effect can be mainly attributed to the ACC by comparing situations where only one of the functions was active.

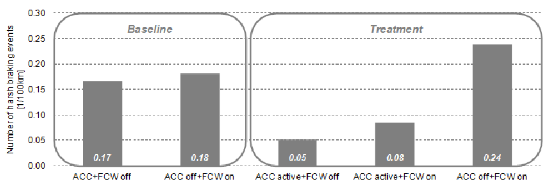

Figure 9. Number of harsh braking events within different experimental phases

In phases of active ACC (independent on the FCW status) a significant decrease of harsh braking events was observed, see Figure 9. In case of deactivated ACC and activated FCW no such effect could be shown. To specify the contribution of each individual function the change in issued FCW warnings was investigated. To that end, it can be seen in Figure 10 that the highest reduction during the treatment period was found in phases when the

ACC was active. The number of warnings was significantly decreased by about 80%.

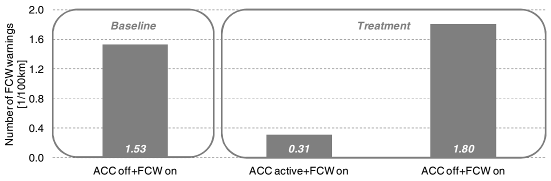

Figure 10. Number of FCW warnings in different experimental phases

Driver behavior

ACC related changes in the driving behavior can be deduced from the same performance indicators that are associated with safety. Those are mainly based on objective data and indicate especially a safe distance behavior which leads to safety benefits. Additionally, the questionnaire data indicates that the expectations of drivers to the ACC are not affected, i.e. the scores on satisfaction and usefulness that drivers gave before gaining access to the systems match those given during and after the trial.
In Figure 11 it can be seen that the acceptance rating on the Van der Laan scale (scaling from -2 to +2) shows low variation.

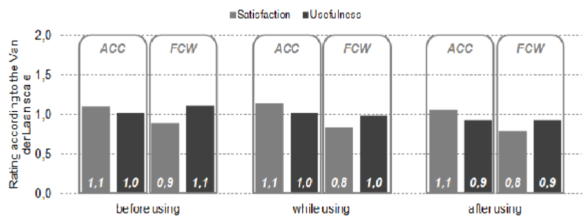

Figure 11. Acceptance rating for ACC and FCW

The acceptance is based on the average of the questionnaire items related to satisfaction and usefulness. In terms of usage, drivers mainly use ACC on motorways. Here, the proportion of kilometers driven with active ACC reaches almost 50%. The increase in the usage frequency can be confirmed by evaluating the travel time and distance with and without active ACC. Comparing the first months to the last months of the FOT there is a significant increase of ACC usage in terms of travel time with active ACC (31%) and frequency of ACC activations (53%). The drivers seem to get used to the positive perception of the ACC and use the system longer and more often over time even though they do not indicate a change in their usage behavior within the questionnaires. This increased use of ACC is in line with the perceived increase of safety and comfort which is self-reported by the drivers. In contrast, self-reported ratings on trust do not change over time and thus do not reflect the positive perception related to safety and comfort.
The majority of the drivers (close to 70%) perceive the FCW as safety increasing and most helpful on motorways in normal traffic conditions. The ratings on satisfaction and usefulness remain high throughout the study, but are in general slightly lower than those of ACC. The slight decrease in the ratings can be interpreted by high expectations of the drivers at the project start. In addition, drivers are not uniformly positive to the investigated FCW's audio-visual interface. Some reported that they perceive the timing of the warnings as to early and therefore annoying. This can be attributed to varying individual comfort zones in terms of following distances and reinforces the need for investigating new and creative ways of offering individual adaptations possibilities. Acceptance is a key parameter for the effectiveness of ADAS since unsatisfied drivers tend to switch of the system and therefore no benefit can be achieved.

Fuel consumption

Based on a lower variation in speed when driving with active ACC, it is hypothesized that there are also positive effects on environment in terms of fuel consumption and CO_2 emission. The analysis of the fuel consumption shows a significant reduction of 2.77% while driving on motorways. This system related change in fuel consumption and the measured average fuel consumption of 7.3 l/100km is combined with the usage rate of 49.4% that is reached during the FOT on motorways and projected to the EU-27 level (see Figure 12).

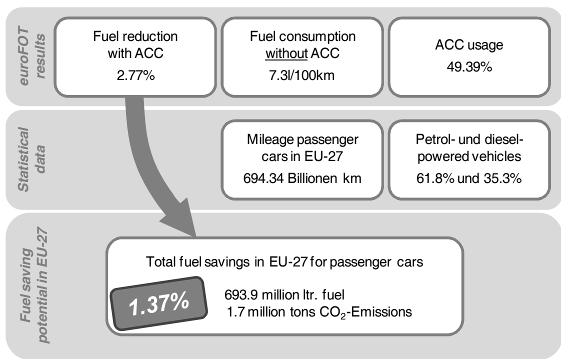

Figure 12. Fuel saving potential of ACC for driving on motorways

For the European passenger car fleet which consists of approximately 62% petrol and 35% diesel powered vehicles the overall fuel saving potential of 1.37% accounts for almost 700 million liters of fuel every year and 1.7 million tons of CO_2 based on the average fuel consumption that is evaluated with the objective data. The statistical data on the total mileage of passenger cars and the fleet composition can be found in (15) and (16). The final results of the impact assessment including statistical information can be found in ().

CONCLUSIONS AND RECOMMENDATIONS

During the euroFOT project data of about 1000 vehicles was collected. With the help of the gathered data the impact of eight different ADAS was evaluated. The analysis of the effects of ACC and FCW usage showed positive effects on traffic safety, driver behavior and driver acceptance as well as fuel consumption.

The relevant factor for the reduction in harsh braking events, incidents etc. can be attributed to changed distance behavior. The analysis shows that the average time-headway was increased at about 16%. In addition to the usage rate of 50% the analysis of acceptance rating revealed a positive perception of the ACC and FCW. Furthermore, a reduction in fuel consumption of 2.8% was observed which results in less CO_2 emissions.

Based on the gathered insights with regards to how drivers use the systems valuable input for the various stakeholders (suppliers, vehicle manufacturers, and research institutes) for improving system design and promoting product development is provided. Moreover the positive results are a powerful tool to raise public awareness about the potential of ADAS. These will provide further impulses for consideration of ADAS in the customer's purchase decision. By means of increased penetration rates a major contribution for improving traffic safety can be achieved.

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