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Field Operational Test “The Assisted Driver”

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Abstract— **In order to get a better understanding of how driving with Advanced Driver Assistance (ADA) systems effects traffic flow in terms of safety, throughput and environment in practice a Field Operational Test (FOT), called “The Assisted Driver” was conducted by the Dutch Road Authority Rijkswaterstaat in The Netherlands. The main component of this project was the so-called Full Traffic FOT in which 20 cars, equipped with Adaptive Cruise Control (ACC) and Lane Departure Warning, were driven in mixed traffic for five months. During this period a vast amount of data was collected by installed data-loggers in order to perform an objective impact assessment. The results are quite promising. Driving with ACC and LDW improves traffic safety with approximately 8% and fuel consumption decreases with 3%. Associated emissions can decrease up to 10% and there seems to be no direct negative effect for throughput.**

I. Introduction

For governments it is important to have a clear understanding in the effects, positive and negative, theoretical and practical, of driving with Advanced Driver Assistance (ADA) systems. This insight should be as realistic as possible, therefore, in addition to expert opinions and literature, real life results of Field Operational Tests (FOT) are important to help governments create, adjust or support their policies regarding (the implementation of) ADA systems. From expert workshops and theoretical studies it seems that the use of ADA systems have a large potential [1, 2]. Research has also shown that real life results from FOTs are relatively scarce in comparison to theoretical studies [2]. This has been a motivation for the Dutch government to conduct a new FOT with ADA systems in addition to several other FOTs in recent years such as LDWA, Belonitor and Roadwise. [3, 4, 5]

In 2004 the innovation program of the Dutch Road Authority Rijkswaterstaat “Roads to the Future” decided that it would be time for a pilot project where Dutch car drivers would be given the opportunity to drive with ADA systems. The goal was to find out if these systems, offering longitudinal and lateral support, would actually improve traffic flow in terms of safety, throughput and the environment when tested in real life, with real people on real roads. Also increasing awareness of ADA systems was an objective of the project.

On highways in the Netherlands about approximately 45% of the accidents are head to tail collisions, about 20% are single accidents and about 12% are aside accidents. This was the motivation to choose a combination of a lateral and longitudinal ADA system to be tested. The combination of Adaptive Cruise Control (ACC) and Lane Departure Warning (LDW) was the most realistic. In addition there was even a test with a combination of ACC and Lane Keeping Assist (LKA), in a three-day clinic.

In order realize the whole pilot project, partnerships with several parties were conducted and a planning scheme for the pilot was made. The pilot took the approach that it would be wise to start with communication of the pilot goals and build up the practical pilot step by step. Therefore the planning and realization scheme was as follows:

- Virtual Reality; October 14th, 2004
- Demonstration Day; May 24th, 2005
- VANpool FOT; September 2005- January 2006
- Full Traffic FOT; February 2006- Juni 2006
- Clinic; May 30, 31 and June 1st, 2006
- End presentation of the results; October 23rd 2006

II. Components of “The Assisted Driver”

A. Virtual Reality

As a communication tool a movie was created to show stakeholders what “The Assisted Driver” was all about. The movie can be downloaded from the website of roads to the future: www.wegennaardetoekomst.nl. In addition to this movie a simulator was build as well in order to let people experience driving with ACC, LDW and LKA. The main goal of these two products was to create awareness and to improve communication between stakeholders and potential participants.

B. Demonstration Day

In addition to gathering knowledge about the effects of driving with ADA systems another goal of the project was to increase awareness regarding driver assistance amongst stakeholders such as policymakers. In order to do so a large demonstration day was organized where people could

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actually experience driving with ADA systems, either on a test track or on the public roads. This event took place on the RDW test track in Lelystad, The Netherlands on May 24^{th} 2005.

With more than 200 visitors and over 30 cars equipped with one or more ADA systems the demonstration day was a big success. Reports can be found at various websites, such as IVsource, ERTICO and PReVENT [6, 7, 8].

C. VANpool

The existing carpool initiative "VANpool", in which commuters driving together in a Volkswagen Sharan may use bus lanes and emergency lanes during rush hour to avoid congestion, was asked to be a partner in "The Assisted Driver". Twenty participating cars were equipped with the Advance Warning System (AWS) from Mobileye [9]. This system has two functionalities, Lane Departure Warning (LDW) which warns the driver when he is about to leave his lane unintentionally and Headway Monitoring and Warning (HMW) which gives continuous feedback about the current headway in (tenths of a) second.

Participants were asked to drive for one month without using the system for reference and for four months using the system. Before, during and at the end of the 5 month period the participants were asked to fill out a questionnaire in order to find out their acceptance and behavior of driving with these systems. In addition, two focus groups with participants were organized to get more in depth feedback on their driving experiences.

D. Full Traffic

The main part of the project was the so-called Full Traffic FOT. The objective of the Full Traffic FOT was to perform an objective analysis of the effect of driving with Adaptive Cruise Control (ACC) and LDW (in mixed traffic on Dutch roads) on individual driving behavior and ultimately the impact on traffic flow in terms of safety, throughput and environment, as well as evaluate driver behavior and acceptance.

In order to do so twenty Volkswagen Passats (automatic) with ACC were equipped with LDW, again the aftermarket system from Mobileye, and data loggers to collect data such as headway, velocity, acceleration, position within the lane, etc. In cooperation with Pon's automobielhandel (Dutch importer of Volkswagen) and Autopon Lease (their lease company) nineteen participants were selected to drive these cars during a five month period (February 1^{st} – June 30^{th} 2006), again the first month without using the systems for reference and the next four months using the systems. During the whole period data has been gathered with the data loggers. This data has been used for an objective analysis of the impact of driving with ADA systems on traffic flow. In addition to this the participants were asked to fill out questionnaires at the beginning, middle and end of the period in order to find out their acceptance of the systems and whether their (perceived) driving behavior changes. Again two focus groups were organized to gather more in depth information.

The twentieth car has been used for demonstration purposes and to increase awareness amongst different stakeholders in the Netherlands.

E. Clinic

In the Full Traffic FOT the participants used two different types of driver assistance, an active system (ACC) and a passive system (LDW). Where LDW only gives a warning ACC actually supports the driver by taking over part of the driving task. We wanted to find out if the participants perceive Lane Keeping Assist (LKA) as an added value to LDW or that they think that driving with two active supporting systems (ACC and LKA) is "too much".

Toyota Motors Europe made a Lexus GS (left-hand drive) and a Toyota Majesta (right-hand drive) available for three days. Both cars were equipped with ACC and LKA (which is now available on the Lexus LS 460 in Europe). The participants of the Full Traffic FOT were invited to make a test drive in order to experience driving with the combination of ACC and LKA and compare it with driving with ACC and LDW, which they had done for approximately three months at that time. After the test-drive, of at least one hour, they were interviewed.

III. The Systems

A brief description of the functionalities of the ADA systems that have been used in "The Assisted Driver" is given below.

A. Lane Departure Warning

The LDW from Mobileye has three components: a camera with a processing unit, a display mounted on the dashboard and two speakers. The camera detects the lane markings and the processing unit calculates whether the car is about to leave the lane or not. Only when a driver is about to leave the lane unintentionally a warning is given, this is based on whether the driver uses the indicators or not. The warning is given by a sound (which resembles a car driving over a rumble strip) on the side of the car that is about to cross or crosses the lane marking. This is accompanied by a flashing display.

B. Lane Keeping Assist

LKA uses basically the same components as LDW and there is feedback on the steering wheel in order to guide the car towards the center of the lane. Continuously the system monitors whether the driver is in the middle of the lane or not, if not a (relatively small) torque is provided to the steering wheel resulting in the car moving back to the middle of the lane. Essentially LKA makes it a bit more difficult to steer away from the middle of the lane and makes it a bit easier to steer towards the middle of the lane. This results in better lane keeping but the driver is still able to overrule by applying torque suddenly (evasive maneuver for instance) or switching off the system.

C. Headway Monitoring and Warning

A second function of AWS is giving continuously feedback about the following distance or headway in (tenths of a) second. HMW uses the same camera and processing unit to calculate the headway when following a car. If the headway is safe (1.2 s or larger in this FOT) the display is green. When the driver is closing in on the preceding vehicle and the headway drops below 1.2 s the display will change to orange accompanied by a beep. If the driver closes in on the vehicle even further and is tailgating (headway is 0.7 s or less) the display will change to red accompanied by a beeping sound, which remains as long as the driver is tailgating. When the driver increases his headway the display will go back to orange and ultimately green when a safe following distance has been achieved.

D. Adaptive Cruise Control

With ACC you cannot only select your desired driving speed but also the preferred following distance. For the Volkswagen Passat the headways can be set at 1.0 s, 1.4 s, 1.8 s, etc. ACC uses radar to detect vehicles in front of the car and to calculate the current headway. If the headway is larger than the selected headway it functions as a normal cruise control, accelerating to or remaining at the desired speed. When a slower vehicle is approached the car will decelerate until the desired following distance is reached. When the preceding vehicle accelerates or leaves the lane, the car will accelerate until the desired speed again. When the driver accelerates while ACC is switched on (for an overtaking maneuver for instance) the ACC is temporarily deactivated but resumes when the driver releases the accelerator. When the driver brakes, ACC switches off for safety reasons.

IV. Full Traffic – driving Behavior

The analysis of the driving behavior and acceptance, based on three questionnaires and two focus groups has led to the following results.

A. Use of systems

LDW is used more than ACC. Approximately 75% of the participants use LDW always or most of the time. Road type, weather and traffic conditions barely have an effect on the use of LDW. This also has to do with the fact that LDW automatically switches on when driving over 40 km/h, it does not require the driver to decide whether or not to use the system. ACC on the other hand has to be activated by the driver. Consequently we see that ACC is predominantly used on highways and provincial roads during free flow conditions and heavy traffic (but not congested).

B. Getting used to the systems

Driving with LDW is easier to learn than driving with ACC. Learning to operate both systems is equally simple in the eyes of the drivers. Regarding LDW approximately two thirds of the participants were able to operate and drive with the system almost immediately. Approximately half of the participants were able to operate and drive with ACC within a short period (one week).

The reason that drivers are used to driving with LDW earlier than driving with ACC, even though operating both systems is regarded equally simple, is that LDW only gives you warnings where ACC actually takes over part of the driving task. The latter forces the driver to learn to cope with these situations and in some case to adjust his driving style. For example, when driving with ACC activated and approaching a slower vehicle, the system might react sooner than the driver would do resulting in the car slowing down before the driver changes lanes for an overtaking maneuver. In order to prevent this from happening drivers either start their overtaking maneuver sooner or use the accelerator to temporarily override the system until they start overtaking.

C. Driving behavior

As mentioned before the use of ADA systems can cause drivers to change driving behavior. These changes indicated by the drivers themselves regarding LDW are better lane keeping (less unintentional line crossings) and better use of the indicators (half of the number of participants).

Regarding ACC more than half uses the shortest headway setting (1.0 s). Overall the average headway increases due to the use of ACC. Approximately half of the participants indicate that they start their overtaking maneuvers sooner in order to prevent ACC from “kicking in” as described above. Also one quarter stays longer in the left or middle lane compared to driving without ACC.

Most participants indicated that they are more inclined to use their hands for secondary tasks (smoking, drinking, eating, calling) when ACC and/or LDW is switched on. The number of participants who say so increased slightly after three months.

D. Appreciation

Overall the participants appreciate ACC more than LDW and asked (after three months) to choose between ACC or LDW all participants would prefer ACC over LDW. In only one aspect LDW is regarded as superior over ACC and this is vigilance. In general LDW can be described as annoying but effective (increases vigilance). For all other aspects such as useful, enjoyable, effective, etc., ACC is regarded to be better. In general the participants expressed more confidence in ACC and they think it is more useful for them. This has much to do with the fact that ACC actively supports the driver without giving warnings whereas LDW only gives warnings and requires the driver to react.

E. Safety

When asked about the potential contribution of the systems for traffic safety most of the drivers feel that ACC decreases the chance of an incident more than LDW.

However a safety increasing effect for both ACC and LDW are assumed, only larger for ACC.

F. Conclusions

Keep in mind that the aforementioned results are all based on what the drivers think about ACC and LDW based on their personal experience of driving with both systems for four months. Therefore the results are subjective and not necessarily true. That does not mean that the results are not valuable, on the contrary it gives a good indication of possible changes in driver behavior due to ADA systems.

Participants are more satisfied with ACC than LDW. They have more confidence in it and think it has more effect on traffic safety. LDW improves vigilance more than ACC, it is not a comfort systems but it is effective. If given a choice participants would choose ACC over LDW. Getting used to driving with ACC takes longer than with LDW

After approximately three months of driving with the systems participants are used to the systems and are able to concentrate better, anticipate better and have increased vigilance. But participants also are more inclined to perform secondary tasks.

V. Full Traffic – Traffic Impact

During the months February, March, April, May and June in 2006 data loggers have collected a lot of information regarding the vehicle's dynamics, location and the ACC and LDW with a frequency of at least 1 Hz up to 10 Hz. A complete overview of collected data and calculated indicators will not be given in this article but contains amongst others: location (type of road; highway, secondary roads, city roads), speed, relative speed of lead vehicle, current speed limit, acceleration, deceleration, headway, ACC status including settings for desired speed and headway, LDW status, indicator status, warnings given by LDW (left/right), lane crossings (left/right) distance to lane markings (left/right), lane width, fuel consumption.

The data has been divided in 5 periods. The first period from February 1st – March 8th (reference period, systems off), the second period from March 9th – April 1st (transition period, systems on) and the following three periods coincide with the months of April, May and June (systems on). Also a distinction was made in traffic status: free traffic ($v > 90$ km/h), busy traffic (70 km/h $< v <$ 90 km/h) and congested traffic (40 km/h $< v <$ 70 km/h). When cars were driving slower than 40 km/h the collected data has not been used for analysis since this is a situation in which neither LDW nor ACC works.

The used methodology for impact analysis is based on starting with general assessment objectives and consequently specific assessment objectives as described in Zhang et al [10]. This means that the following order of answering research questions has been followed:

- How do drivers use ACC and LDW?
- What is the effect of driving with these systems on individual driving behavior?
- What impact have changes in individual driving behavior on
    - Traffic flow?
    - Traffic safety?
    - Fuel consumption and emissions?

The results of the analysis are described below in that particular order.

A. Use of the systems

LDW is seldom switched off; it is practically always active independent of road type, traffic condition or weather condition.

ACC is primarily used on highways (more than 40% of the time spent on highways) and ACC is seldom used in urban areas (4% of time spent). On secondary roads ACC is used approximately 22% of the time spent. ACC is predominantly used during free flow and heavy traffic, respectively more than 50% of time spent and more than 35% of time spent. During congestion ACC is seldom used, less than 8% of time spent.

ACC is usually switched on some time after drivers enter the highway. As time passed by during the FOT drivers started using the ACC more actively, time between entering highways and activating ACC became shorter. Deactivating ACC is usually done by slightly applying the brakes, and sometimes by hard braking.

In the first month of the FOT drivers experiment with different headway settings but after some time almost all of them stick with one setting, regardless of traffic conditions or type of road. Most drivers choose the shortest headway of 1.0 s, sometimes headways of 1.4, 1.8 and 2.2 s are chosen and seldom are larger headways selected. There is a (weak) correlation between headway setting and normal car following behavior, drivers who usually follow at a large distance select a headway setting of 1.4 or 1.8 s instead of the shortest. The choice of desired speed is depending on the speed limit. The average difference between actual speed and speed limit is 5 km/h (under free flow conditions). There is a relation between selected headway and desired speed: drivers who choose short headways usually select higher desired speeds.

B. Change in individual driving behavior

The number of unintentional lane crossings decreases with 35% for secondary roads and 30% for highways due to the use of LDW. To prevent warnings drivers keep a better course (less swerving), which seems to increase the concentration level. There is also a dependency between the distribution of lateral position and whether ACC is active or not. This could indicate a reduction of mental load when ACC is active. The indicators are also used better and more often. Contrary to what was expected there are not less lane change maneuvers due to driving with ACC and LDW. But as expected drivers do stick longer in the left and middle lanes, mainly to avoid ACC from "kicking in" during relative busy traffic.

The main effect on car following behavior is that the average headways with ACC active are larger, approximately 0.2 s. Also the variation in headways is smaller when driving with ACC and the number of (very) short following distances decreases substantially as can be seen in figure 1.

No better compliance to the speed limit with ACC has been noted although the distribution of speeds decreases. The average difference between speed limit and actual speed is 5 km/h. Also the distribution of acceleration is more even when ACC is active which leads to a positive effect on fuel consumption and related emissions.

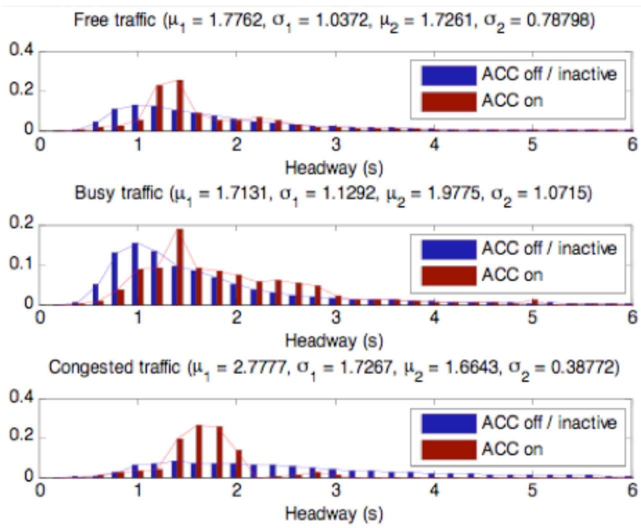

Figure 1 distribution of headways

C. *Impact on traffic flow*

Although the average difference in headways between driving with and without ACC is about 0.2 s, the average headways remain practically the same for the reference period and the testing period. The use of ACC is mainly during free flow and heavy traffic. Thus when (larger) headways would have the most influence on traffic flow, during congested conditions, ACC is not being used and therefore there is practically no direct effect on capacity per lane. For LDW there has been no direct effect on traffic flow noted since the effects of driving with LDW are mainly of a lateral order.

However, for both LDW and ACC positive secondary effects on traffic flow could occur because accidents with resulting congestion can be prevented.

D. *Impact on traffic safety*

Driving with ACC and LDW has a positive effect on traffic safety. This effect is not due to a change in (average) speed, this remains practically the same. But other safety indicators change for the better when driving with ACC and LDW. A decrease of the number of very short headways due to the use of ACC leads to less critical and thus dangerous situations. Also a more even distribution of speeds improves traffic safety because of a reduced number of high speeds. Due to driving with LDW less swerving and unintentional lane changes occur which, in combination of a better use of indicators, lead to a safer traffic flow.

In order to quantify these effects for the situation in The Netherlands, the following approach has been followed. First an overview was made of different categories of accidents per road type in the province of Zuid-Holland and consequently a selection of type of accidents related to the specific functionality of ACC and LDW [11, 12]. The assumption was made that this situation is representative for the Netherlands as a whole. For ACC this means that the main contribution to accidents is distance keeping (headway too short or unexpected hard braking) and for LDW not using the indicators correctly and unexpected line crossings. In addition to these causes we assume that due to the use of ACC and LDW: no increased number of overtaking maneuvers take place, no cutting off of traffic occurs, no increased speed during overtaking maneuvers takes place, the average speed remains the same and no behavioral change during merging occurs.

Based on the aforementioned methodology and accident data we have calculated a safety potential for highways and secondary roads (in and outside of build up areas) per ADA system. This assumes a penetration level of 100% and that all accidents will be avoided due to the continuous use of the systems. For ACC the safety potential is a reduction of accidents of 48.8% on highways and 24.9% on secondary roads (18.7% in build up areas). For LDW the safety potential is a reduction of accidents of 4.7% on highways and 13.3% on secondary roads (11.6% in build up areas).

In order to calculate a more realistic impact on traffic safety we estimated what part of the calculated potential can actually be achieved if drivers would behave and use the systems as we have observed in this FOT. The data shows that ACC is used 43.1% of the time spent on highways and 22.5% on secondary roads. For LDW this is approximately 100% for both types of roads. In addition to this we have also calculated that using ACC and LDW leads to a decrease of hard braking (90%), a decrease of very short (less than 0.7 s) headways (60%), an increase of better using the indicators (20%) and a decrease in unintended lane departures (20%). Combining these figures leads to an estimated reduction of accidents of 13.8% on highways (ACC 12.9%, LDW 0.9%), 6.1% on secondary roads outside of build up areas (ACC 3.4%, LDW 2.7%) and 2.8% on secondary roads within build up areas (ACC 0.5%, LDW 2.3%). This leads to a total number of 7.6% less accidents due to the use of ACC and LDW on highways and secondary roads in The Netherlands.

E. *Impact on fuel consumption*

There is an average decrease of fuel consumption of 3% when driving with ACC. A similar conclusion goes for the associated emissions; up to 10% less emissions when driving with ACC. The latter has not been measured but estimated by using a model [13] and using the measured fuel consumption as input.

VI. Conclusion

Driving with ACC and LDW seems to improve traffic safety with approximately 8% without negatively influencing traffic flow directly. Indirectly traffic efficiency may increase due to avoided accidents and resulting congestion. The fuel consumption decreases approximately 3% and the associated emissions could decrease up to 10%. The results are also positive from a user perspective, almost all participants were positive about both ADA systems. They preferred ACC over LDW and indicated that driving with ACC definitely made driving more comfortable.

All and all positive results. Although this pilot did not intend to give statistical representative opinions and scientific results, the indications this pilot has given about the way road users in the Netherlands use and appreciate certain ADA systems is relevant for impact assessment about these systems. The more results we get from pilots like these, the easier it is to influence policy about it.

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