DRIVING WITH ADAPTIVE CRUISE CONTROL IN THE REAL WORLD

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Abstract

Scientists and researchers still question safety and reliability of various Advanced Driver Assistance (ADA) systems. One of the central issues remaining is the interaction of ADA equipped vehicles with other road users. Meanwhile, the first ADA systems have been introduced into the marked. This paper presents a framework for a study to get towards a controlled implementation of new or redesigned ADA systems using a systems safety approach. This approach sets the next step of assessing safety of ADA systems already used in real world traffic, improving on the currently used limited prospective and retrospective analyses.

Introduction

Cruise control in vehicles is more and more becoming a standard accessory in modern cars. To remain distinctive several brands of automotive vehicles are introducing its successor on the market: Adaptive Cruise Control (ACC). ACC is a system that combines cruise control with a system for collision avoidance. At first only top models of brands such as Mercedes, Jaguar, and BMW were equipped with this latest development in automation technology for automobiles, but recently other brands, such as Nissan, Renault, Fiat, and Volkswagen introduced ACC in their higher-end models. The system is known under a wide variety of names, such as: Advance Cruise Control (BMW), Distronic ACC (Mercedes) Intelligent Cruise Control (Nissan). It is to be expected that middle-class cars will follow in the coming years as prices of production go down. The same kind of market introduction of systems could also be witnessed with other devices, such as ABS and in-vehicle navigation systems.

It is normal in the Life Cycle of products that at a certain point during the development of a new technology there is a moment that market introduction is considered. Even though not all potential problems with the design have been solved, still there are other criteria that make market introduction desirable, even unavoidable. This also holds true for ACC. There are imperfections in the systems but still they have been considered well enough developed by the car manufacturers to be put on the market.

The development of the system does not stop at the moment of introduction. The life cycle of this type of system is very likely going to be much shorter than the life cycle of the vehicle. Vehicles of more than twenty years old still roam our roads. Fortunately car manufacturers do have the means to implement improvements of the system in their vehicles after sale, either as a service update during maintenance, or, in case of serious failures, by means of a recall. There is however a problem when cars get older: There is a tendency that older cars are not serviced at the dealers of the car manufacturers. This may lead to less than optimal implementation of improvements.
During the development, ACC was regarded as a tool with potential for increased traffic safety. ACC is currently marketed as a convenience system rather than a safety aid. According to some authors (Marsh, 2003) this is done out of fear of potential lawsuits following accidents. Still the system should be regarded in its effect on traffic safety, either positive or negative.

We at the Safety Science Group of the Delft University of Technology have not been directly involved in the development of any ACC systems. This gives us the advantage of being able to look at the new equipment with a more or less naïve perspective. A test drive with a Nissan Primera, equipped with Nissan’s Intelligent Cruise Control presented us an opportunity. The vehicle was lent to our colleagues at the Dutch Institute for Road Safety Research (SWOV) for evaluation for a period of two weeks. In this period several colleagues had an opportunity to test the system in real traffic in the Netherlands. They were allowed a test drive of approximately one hour in which they take the vehicle and test it in normal traffic.

The test rides provided plenty of experiences with the system that warrant a discussion of the safety of the device. First of all, it should be stated that the device provides what it promises: It assists well in maintaining a safe distance to a leading vehicle on a more or less straight, not crowded road at a speed above approximately 40 km/h. But above and beyond these constraints, the system does not perform well. For example the system switches off when the speed drops under 40 km/h, does not detect vehicles in curves and misses bicyclists. All and all the experiences during the test ride raise serious questions about the performance of this system and other ACC systems.

These problems can be divided into three areas: (1) Known but accepted shortcomings of the ACC system (2) Experiences that differ from pre-introduction studies (3) Unknown and unexpected behaviour of the system and the driver. The next paragraph illustrates the three types of problems with situations that were encountered during the first hour of driving the ACC equipped vehicle.

1. It may be known that the ACC switches off at low speeds. Still it comes as a surprise when the vehicle approaches a traffic jam or a red traffic light. Preceding vehicles reduce their speed and come to a standstill. The ACC does not halt, but switches off at 40 km/h. Another disturbing experience is the speeding of the vehicle in curves. This is caused by the fact that the leading vehicle is out of sight, after which the ACC decides to accelerate to the preset speed.

2. The reaction of the driver to the ACC in our test sometimes differs from simulation studies. A study of Hoedemaekers (1999) shows that drivers with an ACC tend to overtake more and keep to the left lane on the motorway in an attempt to maintain their preferred speed. We experienced a tendency to follow the lead vehicle while the ACC was functioning almost unnoticed. This has a positive effect on traffic: it is more quiet, more environmentally friendly, and safer. The difference may be the result of a different setting of the implemented ACC from the one tested in the research mentioned.

3. There was at one situation in our test ride where the behaviour of the ACC was completely opposite of what a human driver would do. This was very disturbing and could have been dangerous. The situation was as follows: We were driving on the motorway. The preset speed of the ACC was at 100 km/h (maximum speed limit at that point). We were following a vehicle at approximately 85 km/h at a safe distance of two seconds. At one point there was a vehicle overtaking us. As we approached an exit on the motorway, the vehicle overtaking us entered the gap in front of us, in order to take the exit. At the moment when this vehicle was right in front of us, the ACC decided to increase our speed, thus decreasing the gap and the space available
for the overtaking vehicle (see Figure 1). Although the situation did not become very
dangerous, the driver at that moment was shocked, when the vehicle autonomously
started to gain speed. The hazardous potential of the situation was clear and it took
us quite a while to understand what had happened exactly: At the moment the
overtaking vehicle was in front of us, its speed was more than ours. The ICC
interpreted this as an opportunity to bring the speed of our vehicle back to the preset
speed of 100 km/h.

Figure 1: Example 3, Three-way interaction

Driving the ACC equipped vehicle only for a few hours made it clear that there are still many
safety issues unsolved with this vehicle. At the introduction of a system there will always be
remaining uncertainties. These uncertainties need to be addressed by means of a controlled
introduction. From a safety management perspective this controlled introduction consists of
the following instruments: identify safety issues of the ACC system according to the three
types above, determine the acceptability of these issues and decide about actions to be
taken. Instead of waiting for accidents to happen with ACC equipped vehicles involved, it is
better to start studying these issues right now.

The Safety Science Group and SWOV plan to set up an evaluation study of ACC in the real
world to get to a controlled implementation of new or redesigned ADA systems. This paper
presents the theoretical framework for such a study using a systems safety approach.

System safety approach

The examples in the introduction show the diversity of safety aspects that may relate to ACC.
Some of the aspects relate to the proper functioning of the system, while others deal with
the context of the traffic network in which ACC is used by a number of road users. Using a
system safety approach one can distinguish four different system levels at which safety
effects may occur. These levels are: the functional safety level, the driver safety level, the
level of safety of interaction and the traffic safety level. A number of frameworks addressed
the first, second and fourth system level (e.g., Carsten, 1993; Morello, 1995), however a
‘meso’ traffic level at which road users interact with each other in these frameworks is
lacking. The four levels can be defined as follows (Carsten, 1993; Morello, 1995; European

- Functional Safety Level: covers safety problems that result from the hardware and
  software design of the measure, in particular the technical reliability, probability of
  system failures and the potential of it getting into a dangerous or unexpected mode.
• Driver Safety Level: focuses on the interaction between the user and the measure under study. This level covers the appropriateness of the design, possible distraction of the user and adequate support in performing a safe trip.
• Safety of Interactions: focuses on the interaction of drivers and of the measure under study with their close environment, including other road users, vehicles and the infrastructure.
• Traffic Safety Level: covers the effects of the measure under study on safe operation of the traffic system. This system incorporates macro safety effects on the whole network, such as the number of accidents and the accident severity.

For the driver safety level Carsten and Morello mention a restricted definition, which mainly focuses on the appropriate design of the human machine interface (HMI) of an advanced driver assistance system (ADAS) in order not to distract the user from the driving task (European Transport Safety Council, 1999), and by that go into the needs of the user for the particular ADAS. However, Heijer and Wiersma (2001) argued that this level should also incorporate adequate choice of measures in order to support the user in performing a safe trip. The difference between the level of ‘safety of interaction’ and the macroscopic ‘traffic safety level’ is that the interaction level focuses on a limited part of the traffic system in which participants make decisions about their traffic goals and the actions of others in their neighbourhood. Safety aspects on the traffic safety level deals with the entire network and focuses on the macroscopic outcomes.

If we link the problems areas indicated by the ACC real world test ride to these safety levels, it is noticeable that the ‘known but accepted shortcomings’ connect to issues on the functional safety level and to the driver safety level as far as dealing with the HMI design. The problems concerning ‘experiences that differs from pre-introduction studies’ relate to the driver safety as far as describing issues for individuals (e.g., possible changes in overtaking behaviour) and to traffic safety level for the other issues. Finally, the ‘unknown and unexpected behaviour of the system and the driver’ describe problems on the level of interaction (as is clearly demonstrated by the third example of the overtaking vehicle) and on the traffic safety level. Apart from a difference in the safety levels relevant for the three problems areas there is a difference in whether or not the problems have all been addressed in safety assessments before approval. While the first problem area concerning ‘known but accepted shortcomings’ consists of all kinds of problems that have been assessed, the problems relating to the second and third area have not been considered or are considered based on contradicting predictions in deciding upon approval of ACC in our daily traffic.

Approving ADAS technologies in daily traffic requires an assessment of possible safety impacts on all levels. In doing so one should keep in mind a learning-curve for a new technology. For one, the ADAS in traffic will be used among different circumstances. For users of ACC to be exposed to all these circumstances a considerable time of using the ACC is required. At least one year is required for users to learn about the applicability of ACC in the four seasons. Secondly, users require a considerable time for getting used to the ACC. In a German study it was found that 15 test drivers with an average mileage of 1,400 km per week required on average about two weeks to get to know the system (Weinberger, Winner & Bubb, 2001). These test drivers travelled more than five times the average number of kilometres driven by German and Dutch drivers (Weinberger, et al., 2001; Central Bureau voor de Statistiek, 2002). Based on the results of Weinberger et al. a learning phase of two or three months seems conceivable. Combining these two learning periods we should add that the user is still getting to know the system during the first season the ACC is available to the user. In this period the user is (re)considering his/her attitude towards the ADAS and trying out in what circumstances the use the ADAS is pleasant. Both use and attitude cannot be assumed constant in this period. As a result these two aspects add to each other increasing the period in which users are still learning about the application.
This learning-curve conflicts with the life cycle of the ACC technology and the currently used introduction strategy by car manufactures. Currently, mainly prospective analyses are used, sometimes supplemented with a small-scale retrospective field experiment. In experiments however the assessment is aimed at a number of pre-defined hypotheses. As a result these (controlled) experiments mainly go into the ‘known but accepted shortcomings’, the other two problem areas may be found by coincidence. This introduction phase does not cope with a period to get used to the ACC and if necessary adjust the ADAS. From a system safety perspective however it is desired to cope with these problems and have knowledge on possible effects on all four safety levels before deciding upon approval. Can we come up with a satisfying approach to cope with this friction?

What’s lacking?

Although in a system safety approach problems on four safety levels need to be assessed, this paper focuses on the issues relating to ‘experiences that differ from pre-introduction studies’ and ‘unknown and unexpected behaviour of the system and the driver’. These problems are mainly related to the system levels driver safety and interactions between road users. In general the problems address attitude and use of ACC at the short and long term. These four criteria may be further specified for a particular evaluation. For our discussion we are interested to what extend these criteria have been addressed and what kinds of methods were used to do so.

In a limited literature review a total of 20 evaluation studies going into aspects of attitude or use of Adaptive Cruise Control (ACC) or Intelligent Speed Adaptation (ISA) were selected (Bianchi, 2003). Different from ACC, ISA has not yet been introduced to the market, although a number of manufactures provide an option to set one maximum speed limit into the board computer of their vehicles. ISA has been added to the literature review as in recent years a number of experiments with ISA in real traffic conditions were performed. Table 1 shows the methods that were used to address attitude towards ACC or ISA or use of ACC or ISA. As most of the studies describe more than one of the criteria, the total number of entries in the table is lager than the number of selected studies. The table shows that the evaluation studies mainly address criteria on the short term. Most of the studies found in literature relate to testing of the intended use and status of the systems. However, a lot of safety problems relate to deviations of such intended use and status. The problem we experienced during our test drive with a third vehicle changing lanes to exit the motorway is an example of such a deviation. If we fill in Table 1 only for problems relating to unknown and unexpected behaviour of the system and the driver most cells will be empty. This is mainly caused by the lack of an approach to identify such possible deviations before to set up the scenarios for a safety assessment. The use of hazard and operability studies (HAZOP) could be used to for defining these scenarios (see, Jagtman, 2002).

Table 1: Methods used to address evaluation criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>inquiry</th>
<th>driver simulator</th>
<th>field trial</th>
</tr>
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<tbody>
<tr>
<td>attitude (short term)</td>
<td>++++</td>
<td>0</td>
<td>0</td>
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<tr>
<td>attitude (long term)</td>
<td>+</td>
<td>0</td>
<td>0</td>
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<tr>
<td>use (short term)</td>
<td>0</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>use (long term)</td>
<td>0</td>
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Inquiries are used to go into the attitude of the user, while both driver simulator studies and field trials are applied to evaluate the use. The inquiries were held multiple times in each case at least a before and after measurement. In some studies apart from the test drivers involved in a related experiment, other road users were asked to fill out a inquiries as well.

Driver simulators and field trials are both applied to study the use of ACC or ISA by test drivers. An advantage of driver simulators compared to field tests is the possibility to have all subjects drive in the exact same conditions (Nilsson, 1993; Hoedemaeker, 1999). However in field trials test drivers are exposed to realistic situations that not all can be imitated in a simulator. Furthermore driver simulators make it possible to test ADAS already in the conceptual phase (Nilsson, 1993) and can therefore contribute in earlier stages in design than field trial. As a result most of the driver simulator studies expose the user to multiple alternatives based on variation in the parameter settings (e.g., minimum headway setting, deceleration of the system) and variation in type of assistance (e.g., information, warnings or intervention in vehicle control). Field experiments, executed later in the design process, are required to verify the effects in real world conditions and to go into questions of long-term use (Biding & Lind, 2002). As a result only field experiments are able to overcome the problems relation to the learning phase. Despite this opportunity offered by field trials, only the Swedish ISA experiments, performed in the period 1999-2002, were set up to incorporate study of long term use.

Discussion

Ideally, one would perform a number of experiments to study the attitude and use of drivers on the short term at early stages of development of ADAS followed by an extensive field test period long enough to get knowledge on possible changes in attitude and use after the learning phase has passed. However, it is questionable if the expenses for such long term field trials can brought in with the increasing number of such systems that are expected to come to the market. Secondly, it is impossible to foresee all possible consequences of the use of ACC in the real world in advance, either positive or negative. At the introduction of a system there will always be remaining uncertainties. At some point however these uncertainties may be qualified as limited to an acceptable level for market introduction.

One question is whether safety assessments of ACC and other ADAS systems should be limited to the pre-introduction phase only even though we know that not all effects on safety can be foreseen in advance. If critical review of these systems stops after introduction a number serious problems notified by the user or accidents including vehicles with an activated ACC will be the first indications for manufactures that the systems still have significant problems. Instead of waiting for accidents to happen with ACC equipped vehicles involved, it is better to start studying these issues right now. The Safety Science Group and SWOV plan to set up an evaluation study of ACC in the real world to get to a controlled implementation of new or redesigned ADA systems. Such an implementation strategy follows owners of ACC equipped vehicles to learn from their experiences with ACC. One study, commissioned by AVV, going into the experiences of owners of an ACC equipped vehicle has recently been carried out by Pol and Perdok (2003). In order to address the criteria both on the short and long term during this controlled implementation, the owners’ experiences at least needs to be analysed at the following moments:

- First acquaintance with the system (shortly after purchasing the vehicle)
- Short term experiences in attitude and use with the system during the phase of getting to know the system (at the end of the learning phase period of the operation of ACC, depending on a number of driving characteristics, two or three months after purchasing the vehicle)
• Long term experiences in attitude and use (timing based on duration of phase to get to know the system and using the system under all circumstances, two years after purchasing the vehicle)

From a safety management perspective we are interested in experiences and the possible change of these experiences as a certain point the system is no longer novel to the owner and latter the system is part of normal options of the owners’ vehicle. Especially by approaching the users multiple times we can learn from the experiences for further developments and possible improvements of the system. In an ideal controlled implementation course the last analysis moment is timed at a moment that the user of the equipped vehicle had the opportunity to use the system in a wide variety of circumstances, only by doing so the problems relating to unknown and unexpected behaviour of the system and the driver can be caught.

References


