EXPLORING END-USER EXPERIENCES: SELF-PERCEIVED NOTIONS ON USE OF ADAPTIVE CRUISE CONTROL SYSTEMS

Strand, Niklas*°, Nilsson, Josef*#, Karlsson I.C.MariAnne*Ψ and Nilsson, Lena*°
*SAFER Vehicle and Traffic Safety Centre
°VTI Swedish National Road and Transport Research Institute
ΨDivision Design & Human Factors, Chalmers University of Technology
#SP Technical Research Institute of Sweden

ABSTRACT: This paper explores end-user experiences of adaptive cruise control systems. A qualitative approach has been applied and data has been collected by means of focus group interviews. In total the study consists of three focus group session with five to seven participants in each. Themes explored include interaction between user and system, functional limitations and trust, and system effects on driving behaviour. Key findings include reported driving behaviour changes as, for instance, an increasing tendency to stay in the right lane and user conceptions about system functionality regarding which can be concluded that end-users of adaptive cruise control carry rough mental models of the system.

Keywords: Adaptive cruise control, human-system-interaction, driving behaviour, mental models, system development, functional limitations, mode errors

1 INTRODUCTION

In vehicle safety, there has been a shift of focus in recent years: from technology aiming at limiting consequences of accidents (e.g. seatbelts, airbags, etc.) towards advances in technology as a preventive measure (e.g. driver assistance systems). Research launched with a starting point in different aspects and perspectives are adding to the further development of these systems. A holistic view, accounting for engineering sciences as well as for human sciences, has been advocated e.g. by Vicente (2006). A project embracing such a cross-disciplinary approach to the overall purpose of improving systems safety of driver assistance systems is SHADES, 'System safety through the combination of HMI and dependable systems' (see Nilsson et al., 2008, for a project overview). The study reported here is part of the SHADES project.

1.1 Adaptive Cruise Control

Adaptive cruise control (ACC) is an example of a driver assistance system that has been available on the market for more than ten years. Different generations of ACC are today offered by different car manufacturers, such as for example Volvo, Mercedes and Audi. Fundamentally ACC can be described as a radar based system that measures distance to vehicles ahead and based on this information, in cooperation with driver and vehicle input, controls speed and distance (see figure 1). Adding to the basic functionality of the ACC and deriving from the same sensors are features such as a Stop&Go functionality

(i.e. speed control down to and back up from 0 kph) and collision warning/mitigation. ACC systems are undergoing continuous development and functionalities such as lane change support (e.g. Freyer, Deml, Maurer and Färber, 2007) are added to address behaviour adaptations.

The ACC is often characterised — by industry as well as the research community — as a comfort and convenience device (e.g. Stanton and Young, 2005). However, some aspects promoting safety are acknowledged and associated with the system. Vahidi and Eskandarian (2003), for instance, discuss for potential safety benefits associated with reduced workload when using ACC. There have also been some concerns raised regarding negative traffic safety implications of the ACC. For instance Hoedemaeker and Brookhuis (1998) present results from a simulator study indicating behavioural adaptations including increased speed and higher brake force.

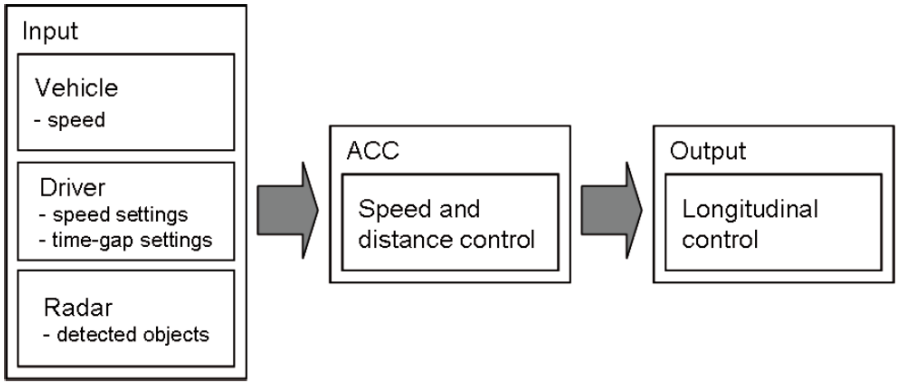

Fig. 1. Simplified outline of adaptive cruise control

1.2 Objectives

ACC systems and their impact on driving behaviour have most often been studied by adopting a quantitative approach and by means of experimental methodology (e.g. driving simulator studies and field experimental studies) and questionnaires.

The objectives of the study reported here was to investigate more in-depth end-user experiences of use and traffic safety implications of driver assistance systems. Questions posed were: (i) When and how do end-users use ACC systems? (ii) Do they experience that ACC systems influence their driving behaviour? and (iii) Do they associate any risks with using ACC systems?

2 METHOD

2.1 General approach

Given the objectives, a qualitative approach was chosen embracing focus groups as data collection method (e.g. Vaughn, Schumm and Sinagub, 1996). In total the study consisted of three focus group sessions (A, B and C). All sessions were held in regular meeting rooms and run after working hours. In order to support the interview, an interview guide was developed, defining the

overall procedure to be followed and the themes to be addressed. All focus group interviews were run according to this same procedure.

2.2 Participants

Each focus group session included five to seven participants, 18 participants in total (see table 1 for an overview of group composition). All participants were drafted from the Swedish car registry. Only people residing in major cosmopolitan areas of Sweden (Gothenburg and Stockholm) and owning cars equipped with ACC (two different manufacturers) were subject for selection. The majority drove cars with an automatic gearbox, year models 2008-2010, and estimated their annual driving distance to exceed 2500 km. All cars were equipped with additional driver assistance systems including, for instance blind spot monitors, lane departure warning systems, collision warning systems, brake support systems, and fatigue alert systems.

Table 1. Focus group composition

Focus group	Men	Women	Age distribution of participants in years		ACC usage Experience in months	
A	5	0	39 - 69	M = 50.8 SD = 11.39	6 -12	M = 9.6 SD = 2.61
B	6	1	40 - 63	M = 45.86 SD = 7.95	4 -17	M = 11.29 SD = 3.99
C	6	0	47 - 74	M = 58.67 SD = 10.25	7 - 46	M = 15 SD = 15.31
Total	17	1				

2.3 Procedure

Each focus group began with a brief introduction explaining the purpose, recording praxis, confidentiality and rules of conduct (e.g. to use a friendly tone, no specific order of speech, not interrupting each other). The participants were informed that they were supposed to keep the discussions going around questions presented by the moderator. It was also emphasized that it was their experiences of ACC usage that was the focus of the interview, with the addition that they were allowed to talk about experiences concerning other driver assistance systems too if considered relevant. Next, a clarification of key terms and definitions regarding driver assistance systems were settled in agreement with the participants. Before moving on to the first theme a short assignment was completed to get the participants to feel at ease and to get started. The assignment was conducted in pairs and consisted of a task in which the participants were asked to write down the pros and cons of driver assistance systems in general.

The focus group then revolved around three main themes:

1. Usage: The overall questions were "What are your general impressions of these systems and in particular the adaptive cruise control?" and "Why and in which situations do you use them?"

2. Functional limitations and trust: The overall questions were "Does the ACC or any of the other systems behave in a way that you were not expecting?" and "If so, provide an account for what happened."

3. Driving behaviour and safety: The overall question was “How do you feel that your car driving and safety behind the wheel have been affected by using these systems?” All themes were ended with the open question: “Would you like to add something before moving on to the next theme?” Besides these general questions, prepared probes were used to elicit more detailed answers when needed (e.g. “Would you like to elaborate on that?” and “Being more specific, why do you use it this way?”).

At the end of each session a brief survey was conducted in order to collect background information on the participants and to quantify some key aspects of their interaction with and use of the systems. Any remaining questions or concerns were addressed before ending the discussion. The participants received a cinema ticket for their participation.

One head moderator – carrying the main responsibility – asked the questions, monitored the group activity and, when needed, intervened in the discussions. A co-moderator had the responsibility of taking notes, handling practicalities, and at some occasions asking complementary questions.

The focus group interviews lasted for between 1 ½ and two hours. All sessions were taperecorded for later transcription and analysis.

2.4 Analysis

A qualitative content analysis (e.g. Krippendorf, 2004) of the collected data was carried out.

The analysis was based on predetermined categories following the themes of the interview guide. From these main categories (usage, trust, functional limitations and impact on driving behaviour) summarizing statements capturing central ideas were elicited and interpreted.

3 RESULTS

The results from the focus group study show congruencies on different aspects of humansystem interaction among the persons taking part. Various notions were revealed on trust in systems, functional limitation and related safety aspects, and overall effects on driving behaviour.

3.1 Usage

According to the participants, the ACC was used mainly on rural roads with a speed limit exceeding 70 kph. However, there were some discrepancies between different participants regarding when and how to use the system. Some participants said that they used the ACC in high density traffic, while others said that they avoided using it in this type of traffic. Even those using it in high density traffic had some concerns about the tendency of other roadusers to overtake and pull in between their vehicle and the vehicle ahead. In some cases this led to hard breaking and activation of collision warning systems.

3.2 Trust

The participants' perceived trust in the ACC appeared to be fairly high. One participant stated, for instance, that he trusted the system and that he would not use it otherwise.

Another explained his trust in the manufacturer saying that they would not sell the system if it was not to be trusted. Yet another participant conceived the ACC as a system that always adopts fail safe behaviour – if it is to fail at all – thus never leading to fatal consequences.

With growing experience (i.e. time of usage and mileage) and knowledge about the system, an increase in trust was reported. The participants experienced more trust when they got to know the ACC system and were able to better decide when, where and under which weather and traffic conditions to use it.

3.3 Functional limitations

Some functional limitations connected to environmental conditions were reported for the ACCs used. For instance, the ACC was conveyed not to function in a satisfying way in heavy fog, snowfall or rain. Even though this phenomenon is warned for in the user's manual the participants implied that the behavioural adaptation (i.e. not to use ACC) was put into practice first after being exposed to the lack of functionality when driving with the ACC under these conditions. Although perceived as annoying it was clear that the participants tolerated the limitation, possibly because it was easy for them to understand. However, they still wanted the traditional cruise control functionality to be an option under these circumstances (i.e. be able to keep constant speed).

Experiences of functional limitations were reported also when driving on curvy roads and in roundabouts. For instance when a vehicle ahead makes a turn the ACC loses its target and as a consequence the car starts to accelerate. Another example concerning the same traffic situations was that when the ACC finds a target, moving in the same direction but in the adjacent lane, it forces the car to brake. Both situations can be assigned as non-beneficial traffic safety aspects of ACC usage with potential incidents and accidents as outcomes.

Overtaking was yet another concern for the participants. They perceived a delay for some seconds before the car started to accelerate and requested a more direct response. The phenomenon was attributed as "thinking time" for the ACC. The participants felt that when they decided to overtake another vehicle, they already knew that it was clear headway.

However, the ACC was not able to assess these situations until later, i.e. when they already had changed lanes, the system thus being slower than the human mind. Even if the participants appeared dissatisfied they still demonstrated an understanding of the problem and discussed what consequences could follow in other situations, such as curvy roads and roundabouts, if the system were to react faster. One person described an overtaking situation this way: "When I reach a vehicle ahead of me it (the system) slows down too early, before I have changed lanes, and when I have changed lanes it takes time for it to accelerate again". In order to cope with this type of situations different strategies appeared

to be adopted, for instance to temporarily use manual control and the gas pedal to override the system. Another notion on this situation and the functionality of the ACC was that the function is linked to the indicator and that using the indicator when overtaking would force the car to start its acceleration more directly.

One person stated that he actively 'pushed' the system in order to get to get to know its functionality and limits. The participants' awareness of a functional limitation due to, for example environmental factors such as weather conditions and road design, appeared to change how and when the participants used the ACC system. As a consequence of this awareness the dominating coping strategy when encountering a problem was to shut the system down. Still, some participants reported that when they were new to the system and first began to use it other strategies, such as restarting it or stopping the car in order to get out and clean the sensors, were evaluated. One solution proposed by several participants was the option to test-drive the system, accompanied by an instructor or a salesperson, before receiving the car in order to get familiar with the system in question.

3.4 Impact on driving behaviour

The results from the focus group interviews also indicate that ACC use had a positive safety effect on the participants' overall driving behaviour. It was, for instance, reported that it was more convenient to stay in the right lane when using the ACC compared to not using it. The argument was that it takes less effort to change lane and overtake another vehicle than it is to manually adjust speed and distance over a period of time in relation to a vehicle ahead.

Other claims were that the ACC promoted a smoother and less stressful driving style. One participant explicitly said "I am more inclined to stay in the right lane and keep my position in the queue". However, this behaviour can also be partly attributed to their experiences of overtaking. If the described delayed response is regarded as a discomfort, then it would most probably also lead to an increasing tendency to stay in the right lane.

The participants had some concerns about how their driving was perceived by other roadusers. This concern stemmed partly from their awareness of the brake-light activation associated with ACC usage but also from their own experiences of being followed by other vehicles. Questions raised by the participants were, for example if other road-users would perceive their driving as jerky or nervous and, as an outcome, would be more inclined to overtake. These notions indicate that the participants, even though reporting trust in the system, might have some concerns and not always feel at ease when handing over control to a technical system.

The participants also indicated that they had developed a better sense of how to adjust their own distance to the vehicle ahead when not using the ACC; this opinion is attributed to the use of ACC (and in some cases use of collision warnings). Another reported notion was the transfer of the effects (e.g. behaviour associated with choice of distance to vehicle ahead) also when driving other vehicles not equipped with these systems. In addition, some users reported on negative effects when changing cars. They claimed to be so used

to their own car and the ACC-system that when they drove a car with a traditional cruise control they expected it to function as the ACC. This resulted in them taking action later than they normally would in situations where they needed to brake and manually adjust their speed.

Some found it so confusing that they never used the cruise control and other systems when not driving their own car.

Finally, various aspects on settings of the ACC were discussed. The participants all agreed that they wanted more options for setting the distance. They did not think that the available alternatives were enough to cover all types of driving conditions. One option requested was more personalized settings. One person mentioned that his time-gap settings for the ACC were connected to his collision warning system (probably referring to a distance alert system that uses the same displays as the collision warning system which in turn is not affected by time-gap settings). He argued that he wanted a longer distance for the ACC which he used on motorways, whilst at the same time a shorter distance for the collision warning system. He believed that the long time-gap for his ACC forced the collision warning system to warn too early when driving in urban traffic.

A general opinion apparent in the discussions of all three focus group sessions was that further progress in the development of driver assistance systems is something positive; the participants regarded such progress as an important part of vehicle safety.

4 DISCUSSION AND CONCLUSIONS

The objective of the study was to explore end-users' experiences of ACC use and the implications for traffic safety.

Effects of system usage over time were found in (stated) driving behaviour, for instance an increased tendency to follow the traffic pace which in turn can have positive effects on traffic safety. Some results presented, for instance the tendency to follow the lead vehicle and stay put in the right lane, stand in contrast with earlier findings by, for example Hoedemaeker and Brookhuis (1998), but are at the same time in support of conclusions by Jagtman and Wiersma (2003). It is obvious, even though ACC-systems have been on the market for over ten years, that further knowledge and hence more research are required on the actual effects of these kinds of systems as they develop.

It can be concluded that the participants perceived a sense of control by being aware of the functional limitations of the system and by developing strategies to cope with them. If functional limitations (or design deficiencies) are apparent, the results indicate that an increased exposure to such limitations promotes more elaborated coping strategies. When users learn how an ACC system behaves in specific traffic situations they can adjust their own behaviour. The situation can be controlled in such a way that unwanted consequences do not appear. One example is to use manual control of speed in overtaking situations where the ACC takes time to accelerate. This type of behavioural adaptations can be ascribed as one underlying explanation to the enhanced trust in the system The participants' call for traditional cruise control functionality (i.e. keep

speed constant) when functional limitations due to weather conditions are apparent is interesting, especially when weighed against their experiences when driving vehicles not equipped with ACC. The observation can be discussed from the perspective of mode errors. Norman (1983) explains mode errors as errors that occur when a person operates a system as if it were in another state than it actually is. This means that if manufacturers would design cruise control systems that could be operated and used both as traditional cruise control and as cruise control with ACC-functionality this could fuel the attendance rate of mode errors (i.e. the driver fails to control speed and distance when driving with traditional cruise control functionality because he/she believes he/she is in a mode where ACC-functionality is available and expects the system to control speed and distance). Mode errors when using adaptive cruise control in a driving context might lead to increased risk for collisions as timespan to lead vehicles can be very limited, particularly in high density traffic. On the other hand, it can be argued that ACC systems, which do not account for stationary objects, are function equivalent to a traditional cruise control, thus forcing the driver to take manual control over speed and distance control. Nevertheless, if this path is chosen the design of the system must cope with potential safety issues. Besides the obvious solution to entirely dismiss the use of different modes in this type of system, other countermeasures by design are available. Norman (1983) discusses for instance distinctively marked modes, not using the same commands in different modes and the use of feedback.

Adopting an extended design perspective, Woods and Sarter (1995) stress the need for developing appropriate mental models of system functionality in order to cope with mode error. Bernstein, Penner, Clarke-Stewart and Roy (2003) describe a mental model as “A cluster of propositions representing our understanding of objects and processes that guides our interaction with those things” (p.8). A user’s mental model can also be referred to as knowledge of how to use a system and how the system works (Preece, Rogers, & Sharp, 2002). Norman (1988) explains that mental models are shaped by experience, training, and instructions. If a mental model is insufficient or erroneous it is more likely that errors will be made (e.g. Bernstein, et al., 2003 & Preece, et al., 2002). Needless to say, mistakes in a complex traffic system may lead to potentially critical situations. Many of the participants’ testimonials on system usage and functionality appeared to be based on somewhat rudimentary mental models. It can be argued that manufacturers should take measures in order to help users to develop a working mental model of the system’s functionality. This could be done by designing the ‘user interface’ so that it facilitates the user to develop a correct mental model but also looking over instructions provided at the time of purchase, educating retailers in order to feed-forward correct information to customers, and providing training programs for customers.

The results presented here are of interest for system development but perhaps first and foremost of relevance for further research. It would for instance be valuable to use the information a basis for a larger study, e.g. a survey, to quantify and statistically establish the results regarding usage patterns, trust as well as e.g. behavioural adaptions. It is also of interest to use the information from this study to design controlled experimental studies, i.e. simulator studies,

in order to study more in detail drivers' responses to described functional limitations.

5 ACKNOWLEDGEMENTS

The authors would like to acknowledge Henrik Lind (Volvo Cars) and Eva-Maria Elstner (Audi Sverige) for valuable contribution.

6 REFERENCES

Bernstein, D. A., Penner, L. A., Clarke-Stewart, A., & Roy, E. J., (2003). Psychology (6th ed.). New York: Houghton Mifflin.

Freyer, J., Deml, B., Maurer, M., & Färber, B. (2007). ACC with enhanced situation awareness to reduce behavior adaptations in lane change situations. Proceedings of the 2007 IEEE Intelligent Vehicles Symposium.

Hoedemaeker, M., & Brookhuis, K. A. (1998). Behavioural adaptation to driving with an adaptive cruise control (ACC). Transportation Research Part F, 1(2), 95-106.

Jagtman, H. M., & Wiersma, E. (2003). Driving with adaptive cruise control in the real world. Proceedings of the 16th ICTCT workshop.

Marsden, G., McDonald, M., & Brackstone, M. (2001). Towards an understanding of adaptive cruise control. Transportation Research Part C, 9, 33-51.

Krippendorff, K. (2004). Content Analysis: An Introduction to Its Methodology. 2nd edition, Thousand Oaks, CA: Sage,

Nilsson, J., Falcone, P., Vinter, J., Sjoberg, J., Nilsson, L., & Jacobson, J. (2008). A brief paper on improving active safety systems via HMI and dependability analysis. IET Conference Publications, 2008(CP542), 5B2.

Norman, D. A. (1983). Design rules based on analyses of human error. Communications of the ACM. 26(4), 254-258.

Norman, D. A. (1988). The design of everyday things. New York: Basic Books.

Preece, J., Rogers, Y., & Sharp, H. (2002). Interaction design: beyond human-computer interaction. New York: John Wiley & Sons.

Sarter, N. B., & Woods, D. D. (1995). How in the world did we ever get into that mode? Mode error and awareness in supervisory control. Human factors, 37(1), 5-19.

Stanton, N. A., & Neville, M. S. (2005). Driver behaviour with adaptive cruise control. Ergonomics, 48(10), 1294-1313.

Vahidi, A., & Eskandarian, A. (2003). Research advances in intelligent collision avoidance and adaptive cruise control. IEEE Transactions on Intelligent Transportation Systems, 4, 143-153.

Vaughn, S., Schumm, J. S., & Sinagub, J. (1996). Focus group interviews in education and psychology. Thousand Oaks: Sage.

Vicente, K. (2006). The human factor: revolutionizing the way people live with technology. New York: Routledge.