

Advanced Cruise Control (ACC)

Summary

Advanced Cruise Control (ACC), also known as adaptive or intelligent cruise control, not only maintains the driver-set vehicle speed, but also adjusts the vehicle's speed to that of a preceding vehicle, and helps to maintain a pre-selected headway time to the vehicle ahead. ACC systems can have a favourable effect on road safety when used on motorways with non-congested traffic. In these conditions ACC has a moderating effect on the driving speed, and decreases the percentage of very short headway times. Negative safety effects can be expected if ACC is used in busy traffic, and on rural and urban roads other than main roads. Furthermore, ACC can have a positive effect on fuel consumption and road capacity. New generations of even more intelligent ACC are being developed.

Background

A decade ago, the car industry introduced the first Advanced Cruise Control systems (ACC) to the market as an extension of the 'conventional cruise control'. ACC was developed as a comfort and convenience system rather than a safety system. However, it has often been hypothesised that ACC systems could also have positive effects on road safety, as well as on traffic efficiency and the environment. This fact sheet gives an overview of the current ACC systems and their effect on safety, the environment and traffic flow, as well as of the expected new ACC generations.

What is ACC?

Advanced Cruise Control (ACC), also known as adaptive or intelligent cruise control, is an extension of conventional cruise control systems. ACC not only maintains the driver-set vehicle speed, but also adjusts the vehicle's speed to that of a preceding vehicle, and helps to maintain a pre-selected headway time to the vehicle ahead. ACC uses a frontal radar/laser sensor to detect vehicles in front and subsequently adjusts the vehicle's speed and headway by controlling fuel flow or by slightly braking. Active braking carried out by ACC can usually reach up to 30% of the vehicle's maximum deceleration. When a stronger deceleration is needed, the driver is warned by an auditory signal. Once the preceding, slower vehicle has moved out of the lane, the vehicle's speed will return to the driver-set cruise speed.

Ten years ago, the first ACC systems that were introduced to the market were a rather expensive option for top-of-the line vehicle models. Today, ACC can be found on a rather wide range of vehicle models of various car manufacturers (ADAS Management Consulting & Bishop Consulting, 2004; Bishop, 2005; Alkim, Bootsma & Looman, 2007). However, the equipment rate within the entire vehicle fleet is still very low. Most of the ACC systems which now are available, function for speeds above 30 km/h, have a detection range of 120m to 150m, and allow for a manually set headway time between 1 and 3 seconds.

What are the effects of ACC on traffic safety?

ACC was developed as a comfort and convenience system rather than a safety system, mostly because of the limited braking and acceleration ranges and related liability issues. However, although considered to be comfort systems, ACC systems are also expected to affect road safety. However, variations in the predicted effects make it difficult to come up with a general conclusion about the extent to which ACC will improve road safety.

In the past decade several studies of ACC effects on driving behaviour were reported, but different studies showed different results. Some studies showed that ACC could have positive impact on road safety, for instance by a reduction of the mean driving speed (Hogema & Jansen, 1996; Hoedemaeker, 1999), a reduction of the maximum speed (Bjørkli et al. 2003), a reduction of speed differences, i.e. increased speed homogeneity, (Tornros et al. 2002; Hoedemaeker, 1999), and a reduction of very short headway times (Alkim, Bootsma & Looman, 2007). However, negative ACC safety effects were also found, like for example increased lane position variability (Hoedemaeker &

Brookhuis, 1998), delayed braking (Hogema, Van der Horst & Janssen, 1994), and colliding with a stationary queue more frequently (Nilsson, 1996).

Differences in operational characteristics of various ACC could result in different effects on driving behaviour. When driving with ACC types that take over more of the driving task and offer more support to drivers in more critical situations (e.g. capability of a complete stop in every situation), drivers seem to adapt their behaviour by increasing their speed (Dragutinovic et al., 2005). Besides, the traffic conditions, i.e. traffic density and road type, play a role in the observed effects. When ACC is used in low-density traffic conditions, the mean driving speed could be expected to decrease and speeds to become more homogeneous. On the other hand, when driving with ACC in high-density traffic conditions, the mean driving speed could be expected to increase, and there are some indications that speeds will be less homogeneous. However, these indications are not as clear as in the case of low-density traffic condition.

Regarding the type of the road, from the road safety point of view, the use of ACC should be avoided on rural roads (with curves and intersections), as well as on the urban roads, due to difficulty in detecting small silhouettes and vehicles out of the line of sight (Hoetink, 2003).

A recent ACC field trial performed in the Netherlands showed that ACC could decrease the number of traffic crashes on motorways by about 13% and those on provincial main roads by 3.4%, assuming all vehicles are equipped with ACC (Alkim, Bootsma & Looman, 2007). Some notes were made on the validity of the outcomes concerning the representativeness of the province of Zuid-Holland as an experimental area, and concerning the observed slight increase of the average speed being due to ACC. There were also some concerns about possible bias effects due to self selection of the test drivers - a group of 19 lease drivers with relatively much driving experience -, different types of possible behavioural adaptation, and external factors such as more motorway kilometres being driven in the future.

What are the effects of ACC on the traffic flow?

Several simulation studies investigated the potential impact of ACC on traffic flow. The simulation studies used different ACC algorithms, for instance to get different headway times, applied them in different environments and used different behavioural models. Furthermore, different penetration rates of the ACC technology were used. All these differences strongly influenced the outcomes on traffic capacity and speed, and therefore make comparison between these studies and their results very difficult.

With a 40% ACC equipment rate and a one second headway time, Broqua et al. (1991) estimated throughput gains at 13%. Van Arem et al. (1996) and Minderhoud and Bovy (1998) found a decrease in average speed as a result of a collapse of speed in the fast lane when ACC with headway times of 1.4 s and above were used. Minderhoud and Bovy (1999) performed simulations with headway times as low as 0.8 s and concluded that current ACC using a one second headway time could achieve capacity gains of 4%.

What are the effects of ACC on the environment?

ACC has the effect of decreasing the standard deviation of speed up to as much as 50% which results in more homogeneous driving speeds. This is the main reason that ACC is generally expected to lead to a decrease in fuel consumption and hence to a decrease of harmful emissions.

Bose & Ioannou (2001) used field experiments and simulation models to quantify the environmental effects of ACC. Their results showed that an ACC equipment rate of 10% smoothed traffic flow, resulting in less fuel consumption and lower pollution levels in comparison to manual driving. The recent Dutch 'Rij Assistent' field study (Alkim, Bootsma & Looman, 2007) found a 3% reduction of fuel consumption.

Do drivers accept ACC?

In general, drivers consider ACC to be a useful and comfortable system. Some characteristics of the system itself, like having the freedom to choose different headway times, can significantly affect the acceptance of the system (Hoedemaeker, 1999). Drivers find ACC reliable and easy to use and to drive with, although objective data about the process of learning to drive with ACC is very limited. It seems that two or three weeks of intensive driving are needed to master the operation of ACC and the assessment of the take over situations (Weinberg et al., 2001). Expressed in distance driven, it seems

to take approximately 400 km of driving with ACC to know, understand and anticipate ACC reactions (Brouwer & Hoedemaeker, 2006). Unfortunately, learning to drive with ACC is not part of the official driver training as yet and it seems that, like for the conventional cruise control, most of the drivers do not read the manuals and therefore the most common familiarization method is the salesman's explanation (Portouli et al. 2006).

The use of ACC by drivers is related to the type of the road they are driving on and the traffic conditions. ACC is most extensively used on motorways, somewhat less on provincial roads and almost never in urban areas. And on motorways, drivers primarily use ACC in free flow conditions (speeds higher than 90 km/h), less so in dense traffic conditions (speeds between 70 and 90 km/h) and hardly at all in congested conditions (speeds lower than 70 km/h) (Alkim, Bootsma & Looman, 2007).

What are the new developments?

Progressing technological developments may eventually result in a new generation of ACC systems that may overcome some of the limitations of today's ACC, regarding functionality and driver behaviour. Relevant developments in this field deal with the upgrading of the autonomous ACC system, and with combining different Advanced Driver Assistance Systems (ADAS) functionalities into a more integrated driver assistance system. Some examples of initiatives aiming at features such as better speed support, and better anticipation to dangerous situations beyond the human senses, are reported in Morsink et al. (2006) and are described below.

"*Stop and go*" systems are considered to be the next generation ACC, and they are close to market introduction. Unlike common ACC, this system has the possibility to slow down the vehicle to a complete standstill. To do this "Stop and go" ACC, among other things, has to be capable of detecting other road users or stationary objects at a much closer range than the common ACC. ACC which operates from standstill to the maximum speed is also called '*Full-range ACC*'. Another extended type of ACC that is close to market introduction is called *Predictive Cruise Control (PCC)*. This system issues location specific warnings, such as regarding speed while approaching a dangerous curve (e.g. making use of the on-board navigation system).

The *combination of ACC and Intelligent Speed Assistance (ISA)* in which the ACC takes the current speed limit as its default value is promising. Where ISA reduces the average speed, ACC could reduce tailgating and further reduce speed variations. ETSC (2005) reports a market initiative to launch such a combined system. In fact PCC can also be considered a form of ISA that is functionally integrated in ACC. Another, more advanced, combination of ACC and ISA is known as Responsive ACC (RACC) (Bishop, 2005). The system receives a speed advice from a traffic control centre, taking into account local speed limits and traffic flow in the network. This information is used to adjust the vehicle's speed, allowing fine changes in speed (beyond the control of the driver), independent of time and location. At the moment RACC only exists at a conceptual level.

A combination of ACC and Lane Departure Warning (LDW) was tested in the Alkim, Bootsma & Looman (2007) study. Although LDW was found much less effective than ACC, some of the test drivers reported an interesting positive integration effect. With ACC activated, a slight increase in the variation of lateral position in the driving lane was found. The test drivers, however, claimed that the warning issued by LDW effectively compensated for this, and increased their alertness.

Communication between vehicles and between vehicle and roadside is considered the technology that will make a whole new generation of ADAS possible. Several European research projects (e.g. INVENT in Germany, ADASE 2, CARTALK, PREVENT and CVIS) are already working on these so-called cooperative systems, and research activities are increasingly expected worldwide. *Cooperative ACC (CACC)* makes use of communication between a series of successive ACC-equipped vehicles in the same lane. The vehicles exchange their position, speed and deceleration (De Bruin et al., 2004). This may increase safety as the ACC system can optimize its speed support and drivers can get early warnings of braking or of slow vehicles ahead. The potential road safety benefit may be accompanied by a better performance on traffic throughput and emissions on main roads (Malone & Van Arem, 2004). For instance, CACC with 0.5 s headway time would almost enable double the traffic flow at 100% penetration rate (Van der Werf et al. 2002). On the longer term, assuming a further automation of driving tasks, this may be achieved without compromising safety.

Conclusion

ACC systems can have a favourable effect on road safety when used on motorways with non-congested traffic. In these conditions ACC has a moderating effect on the driving speed, and decreases the percentage of very short headway times. An additional positive effect is a reduction in fuel consumption. Negative effects on road safety can be expected if ACC is used in busy traffic, and on rural and urban roads other than main roads. Under these circumstances there will be a potential reduction of the ACC detection capacity. Other issues that may compromise safety are driver behaviour in critical situations, and the effect of specific ACC operating characteristics. However, new developments are likely to improve the effects on safety, traffic efficiency and the environment. Further research is needed to better assess the impact of current and new generations of ACC on traffic safety and the other objectives. Furthermore, it is necessary to develop and formalize training for driving with ACC (and other ADAS) to help drivers learn and understand the benefits and limits of the ACC systems.

Publications and sources

- ADAS Management Consulting & Bishop Consulting (2004). *'The Assisted Driver' Pilot program: Advice regarding project planning and partnership development; Final report*. ADAS Management Consulting, Bregenz, Austria / Bishop Consulting, Granite, MD.
- Alkim, T., Bootsma, G. & Looman, P. (2007). [*De Rij-Assistent; systemen die het autorijden ondersteunen*](#). Studio Wegen naar de Toekomst (WnT), Directoraat-Generaal Rijkswaterstaat, Delft.
- Bishop, R. (2005). [*Intelligent vehicle technology and trends*](#). Artech House, Norwood, MA.
- Bose, A. & Ioannou, P. (2001). [*Evaluating of the environmental effects of Intelligent Cruise Control Vehicles*](#). In: Transportation Research Record, nr. 1774, p. 90-97.
- Bjørkli, C., Jenssen, G., Moen, T. & Vaa, T. (2003). *Adaptive Cruise Control (ACC) and driver performance: effects on objective and subjective measures*. In: [*Solutions for today... and tomorrow: Proceedings of the 10th World Congress and Exhibition on Intelligent Transportation Systems and Services ITS, 16-20 November 2003, Madrid, Spain*](#). ERTICO - ITS Europe, Brussels.
- Broqua, F., Lerner, G., Mauro, V. & Morello, E. (1991). [*Co-operative driving: basic concepts and a first assessment of "Intelligent Cruise Control" strategies*](#). In: Advanced Telematics in Road Transport; Proceedings of the DRIVE Conference, Brussels, 4-6 February 1991, Volume II, p. 908-929.
- Brouwer, R.F.T. & Hoedemaeker, D.M. (eds.) (2006). [*Driver support and information systems: Experiments on learning, appropriation and effects on adaptiveness*](#). Deliverable D1.2.3 of the AIDE project. European Commission, Brussels.
- Bruin, D. de, Kroon, J., Klaveren, R. van & Nelisse, M. (2004). *Design and test of a cooperative adaptive cruise control system*, In: Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, 14-17 June 2004, Parma, Italy, p. 392-396.
- Dragutinovic, N., Brookhuis, K.A., Hagenzieker, M.P. & Marchau, V.A.W.J. (2005). [*Behavioural effects of advanced cruise control use: a meta-analytic approach*](#). In European Journal of Transport and Infrastructure Research, vol. 5, nr. 4, p. 267-280.
- ETSC (2005). [*In-car enforcement technologies today*](#). European Transport Safety Council ETSC, Brussels.
- Fancher, P., Koziol, J. & Baker, M. (1997). [*Preliminary results from the intelligent cruise control field operational test in Southeastern Michigan*](#). In: Mobility for everybody; Proceedings of the fourth world congress on Intelligent Transport Systems ITS, Berlin, 21-24 October 1997, Paper nr. 1025.
- Hoedemaeker, M. & Brookhuis, K.A. (1998). [*Behavioural adaptation to driving with an adaptive cruise control \(ACC\)*](#). In: Transportation Research Part F, vol. 1F, nr. 2, p. 95-106.

Hoedemaeker, M. (1999). [*Driving with intelligent vehicles; Driving behaviour with Adaptive Cruise Control and the acceptance by individual drivers*](#). TRAIL Thesis series T99/6. Delft University Press, Delft.

Hoetink, A.E. (2003). *Advanced Cruise Control in the Netherlands; A critical review*. In: [*Solutions for today... and tomorrow; Proceedings of the 10th World Congress and Exhibition on Intelligent Transportation Systems and Services ITS, Madrid, Spain, 16-20 November 2003*](#). ERTICO - ITS Europe, Brussels. Paper nr. 4082. Based on SWOV report [R-2003-4](#).

Hogema, J.H., Horst, A.R.A. van der & Janssen, W.H. (1994). [*A simulator evaluation of different forms of intelligent cruise control*](#). TNO report TNO-TM 1994 C-30. TNO Human Factors Research Institute IZf TM, Soesterberg, the Netherlands.

Hogema, J.H. & Janssen, W.H. (1996). [*Effects of intelligent cruise control on driving behaviour: a simulator study*](#). TNO report TM 1996 C-12. TNO Human Factors Research Institute TM, Soesterberg, the Netherlands.

Minderhoud, M.M. & Bovy, P.H.L. (1998). *Impact of intelligent cruise control strategies and equipment rate on road capacity*. In: Towards the new horizon together; Proceedings of the 5th world congress on intelligent transport systems, held 12-16 October 1998, Seoul, Korea, Paper nr. 2145.

Minderhoud, M.M. & Bovy, P.H.L. (1999). [*Development of a microscopic simulation model for AICC*](#). In: ITS: smarter, smoother, safer, sooner; Proceedings of 6th World Congress on Intelligent Transport Systems (ITS), held 8-12 November 1999, Toronto, Canada.

Malone, K.M. & Arem, B. van (2004). *Traffic Effects of Inter-Vehicle Communication Applications in CarTALK 2000*. In: [*ITS for a livable society; Proceedings of the 11th World Congress on ITS, 18-22 October 2004, Nagoya, Japan*](#). ITS Japan / ITS America, Tokyo / Washington.

Morsink, P., Goldenbeld, Ch., Dragutinovic, N., Marchau, V., Walta, L. & Brookhuis, K. (2006). [*Speed support through the intelligent vehicle; Perspective, estimated effects and implementation aspects*](#). R-2006-25. SWOV Institute for Road Safety Research, Leidschendam.

Nilsson, L. (1996). [*Safety effects of adaptive cruise controls in critical traffic situations*](#). (Reprint from 'Steps Forward'; Proceedings of the Second World Congress on Intelligent Transport Systems, 9-11 November 1995, Yokohama, Japan, p. 1254-1259). Swedish Road and Transport Research Institute VTI, Linköping.

Portouli, E. et al. (2006). [*Long-term phase test and results*](#). Deliverable D1.2.4 of the AIDE project. European Commission, Brussels.

Törnros, J., Nilsson, L., Östlund, J. & Kircher, A. (2002). [*Effects of ACC on driver behaviour, workload and acceptance in relation to minimum time headway*](#). In: ITS - enriching our lives; Proceedings of the 9th World Congress on Intelligent Transportation Systems ITS, 14-17 October 2002, Chicago, Illinois. ITS America, Washington, D.C.

Weinberg, M., Winner, H. & Bubb, H. (2001). *Adaptive cruise control field operational test - The learning phase*. In: JSAE Review, vol. 22, p. 487-494.

Arem, B. van, Hogema, J. & Smulders, S. (1996). *The impact of autonomous intelligent cruise control on traffic flow*. In: Proceedings of the 3rd World Congress on ITS, Orlando, Florida, Paper nr. 2032.

Vanderwerf, J., Shladover, S., Miller, M. & Kourjanskaia, N. (2002). [*Effects of adaptive cruise control systems on highway traffic flow capacity*](#). In: Intelligent transportation systems and vehicle-highway automation 2002; Transportation Research Record TRR 1800, p. 78-84.