SWOV Fact sheet

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 and content
In the late 1990’s, 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 next ACC generations.

What is ACC?
Advanced Cruise Control (ACC), also known as adaptive, active or intelligent cruise control, is an addition to 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, helping 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 maximally 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.

The first ACC systems that were introduced to the market in the late 1990’s were a rather expensive option for top-of-the line vehicle models. Today, ACC can be found on a much wider range of vehicle models. However, the equipment rate within the entire vehicle fleet is still very low. Most of the ACC systems now 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 road 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. Although considered as comfort systems, ACC systems are also expected to affect road safety, but there are variations in the predicted effects.

In the past decade, several studies of ACC effects on driving behaviour were carried out, but different studies showed different results. Some studies showed that ACC has a positive effect on road safety, for instance through a reduction of the mean driving speed (Hoedemaeker, 1999), a reduction of the maximum speed (Bjørkli et al. 2003), a reduction of speed differences, i.e. increased speed homogeneity (Hoedemaeker, 1999), and a reduction of the number of very short headway times (Alkim, Bootsma & Looman, 2007). However, negative ACC safety effects were also found, for example increased lane position variability (Hoedemaeker & Brookhuis, 1998), delayed braking, and crashing into a stationary queue more frequently.

Differences in operational characteristics of various ACC can also have 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).
The traffic conditions, such as traffic density and road type, also play a role in the observed effects. When ACC is used in low-density traffic conditions, the mean driving speed is expected to decrease and speeds are expected to become more homogeneous. On the other hand, when ACC is used in high-density traffic conditions, the mean driving speed is expected to increase, and there are some indications that speeds will be less homogeneous in this situation. Yet these indications are less clear than in the case of low-density traffic conditions.
From the road safety point of view, ACC should not be used on rural roads with curves and intersections, or on urban roads, because of difficulties in detecting small silhouettes and vehicles out of the line of vision on these road types (Hoetink, 2003).

An 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 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 traffic flow?
Several simulation studies have investigated the potential impact of ACC on traffic flow. The simulation studies used various ACC algorithms, for instance to get various headway times, and applied them in various environments, at various penetration rates using various behavioural models. All these differences strongly influenced the outcomes on traffic capacity and speed, and therefore they make it very difficult to compare these studies and their results.

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 & 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 & 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% smooths traffic flow, resulting in less fuel consumption and lower pollution levels in comparison to manual driving. The Dutch ACC field trial (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. 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 as yet part of the official driver training and since most of the drivers do not read the manuals 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 rural roads and almost never in urban areas. 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 latest developments?

Progressing technological developments may eventually result in a new generation of ACC systems. Relevant developments in this field are the upgrading of the autonomous ACC system, and the combining of different Advanced Driver Assistance Systems (ADAS) functionalities into a more integrated driver assistance system. Some initiatives aiming at features such as better speed support, and better anticipation to dangerous situations, are reported in Morsink et al. (2007) and are described below.

"Stop and go" systems are considered to be the next generation ACC. 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 is called *Predictive Cruise Control (PCC)*. This system issues location specific warnings, such as warnings regarding speed while approaching a dangerous curve (e.g. by making use of the on-board navigation system). PCC is also used in lorries in order to reduce fuel consumption; the PCC system then receives geographical information, for example on rising and falling gradients, and uses this information to reduce the fuel consumption through speed interventions.

The *combination of ACC and Intelligent Speed Assistance (ISA)* (see also SWOV fact sheet *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 can reduce tailgating and further reduce speed variations. In fact PCC can also be considered a form of ISA that is functionally integrated in ACC.

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 such as SAFESPOT, COOPERS and CVIS are already working on these so-called cooperative systems. *Cooperative ACC (CACC)* uses communication between a series of successive ACC-equipped vehicles in the same lane and/or communication with roadside systems. The vehicles exchange information on 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 doubling of 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 is 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 limitations of the ACC systems.

Publications and sources

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.

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., et al. (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., et al. (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.

Dragutinovic, N., et al. (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.

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.

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.

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.

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.

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.

Morsink, P., et al. (2007). *Speed support through the intelligent vehicle; Perspective, estimated effects and implementation aspects*. R-2006-25. SWOV Institute for Road Safety Research, Leidschendam.

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

Werf, J. van der, 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.