

INTELLIGENT SPEED ADAPTATION ISA: A NEW PERSPECTIVE

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ABSTRACT

This contribution will give a brief overview of past and current European research activities in the area of Intelligent Speed Adaptation (ISA). Next, a series of studies is described in which functionalities of ISA and Adaptive Cruise Control (ACC) were combined. The first study consisted of a driving simulator experiment with an ACC; external speed information was available in either an informative mode or in an intervening mode. The results revealed that ACC yields more consistent longitudinal control: in car-following situations, there is less variation in headway and in speed. Only intervening systems result in a speed reduction on motorway sections with a special speed limit, but at a cost of somewhat higher speeds at non-controlled sections. In critical scenarios (approaching a sudden traffic queue) where ACC could not cope with completely and the driver had to take over control, a somewhat later braking reaction of the driver was found.

In another study, the effect of this system on traffic flow on motorways was examined by means of microscopic traffic simulation. Results showed that as the penetration level of this system increases, the mean speed, standard deviation of speed, and percentage of critical TTCs decreased.

In conclusion, automatic speed limiting by an in-car device seems most promising, although concern about behavioural adaptation mechanisms may apply.

INTRODUCTION

The application of new technologies in road traffic (Advanced Transport Telematics, ATT) may contribute to a more efficient use of the existing infrastructure for traffic and transportation, to improve traffic safety and reduce the environmental impact. Increasingly, advanced systems within cars and along the road, may change the driving task considerably. Systems that inform and support the driver or even take over parts of the driving task are emerging with perhaps a fully automated vehicle guidance concept for the further future (Coëmet et al., 1998). For the moment, the developments especially seem to focus on in-car applications such as navigation, route guidance, Adaptive Cruise Control, Collision Avoidance, and Heading Control. From a systems approach point of view, in the long run a combination of in-car and roadside intelligence may appear the most effective way of controlling and guiding the road traffic.

The occurrence of excessive speed in road traffic is a key factor in determining the frequency and severity of accidents. Several studies indicate that reductions in average driving speed can result in considerable reductions in the number and severity of accidents (see e.g. Salusjärvi, 1990; Koornstra, 1990; Finch et al., 1994). An increase in speed may have an opposite effect as shown in the United States where the introduction of higher interstate speed limits resulted in an increase of fatality and injury rates (TRB, 1998). Moreover, it has been shown that the higher the speed variance the higher the accident rate is on a given type of road (see e.g. Salusjärvi, 1990; Finch et al., 1994; O’Cinnéide & Murphy, 1994). Adequate speed management methods and technologies improve road safety without decreasing mobility unduly, and increase the overall effectiveness of road traffic. ATT systems may help to accomplish these tasks. Specifically, related to speed, Intelligent Speed Adaptation (ISA) is a concept that received increasing attention during the last decade.

Intelligent Speed Adaptation (ISA) is a recent development that ‘comprises processes which monitor the relationship between the current speed of a vehicle and a suitable speed and have a corrective effect when this relationship is incorrect in the vehicle’ (Witziers, 1998). This ‘suitable speed’ may be the (static) legal speed limit, but it may also vary dynamically, dependent on time of day, weather and traffic conditions. The appearance of the ISA system to the driver may vary from just informing him in the car about the speed limit (advisory), stimulating him to slow down e.g. by means of an active gas pedal (supporting), to even preventing him to drive any faster than the limit by limiting the speed of the car (intervening).

The present paper will present a brief overview of ISA developments during the last years. Next, it will focus on some studies with an Adaptive Cruise Control (ACC) system with an Intelligent Speed Adaptation (ISA) functionality added. ACC is an in-vehicle system that automatically regulates a vehicle’s speed and is capable of maintaining a proper following distance behind a lead vehicle. ACCs so far can realise a moderate level of deceleration: in situations that require higher braking levels, the driver must take over control. Short-range communication with the road side offers the option to obtain in-car preview information about relevant conditions on the road ahead (including prevailing speed limits). Some driving simulator studies were conducted to assess the effects of ACC on driving behaviour for both informative and intervening ACC systems. Next, a microscopic traffic simulation was conducted to study the effects of such a system on a traffic flow level.

ISA: A SKETCH OF HISTORICAL DEVELOPMENTS

The first field trial with a speed limiter in a car was carried out by Saad and Mallaterre (1982). An in-car system was studied where the driver could set a speed limit, which could not be exceeded unless the driver disengaged the system. In Sweden, Almqvist, Hydén, & Risser (1991) carried out a project consisted of several phases. They started by generating hypotheses about the system, followed by round table discussions and self-observations. This was finalised by a field test in Lund (see also Persson, Towliat, Almqvist, Risser, & Magdeburg, 1993). Results showed that the system yielded speed reductions on roads with highest before-speed. However, higher turning speeds were found on intersections. Driver acceptance increased after having driven with it. In the EU DRIVE project GIDS, several driver support systems were studied, separately as well as in an integrated manner. This included an active gas pedal that could increase its return force as a function of the exceedance of the prevailing speed limit, thus functioning as a support tool preventing the driver from speeding (Michon, 1993). Several driving simulator

studies and field studies have been carried out to evaluate the systems (e.g. Janssen, Verwey, & Kaptein, 1994).

Also in the United Kingdom work on this topic was carried out. For example, Carsten and Comte (1997) conducted experiments in a driving simulator on Automatic Speed Control in Urban Areas. In many respects, driver behaviour improved when speed was limited, although a riskier gap acceptance was observed at intersections. The External Vehicle Speed Control project was carried out in the UK as well (Carsten & Fowkes, 1998). With the aim to review a broad range of factors related to the possible introduction of an automatic speed limiter, the project included a review of literature, technical approaches to implement EVSC, and issues like acceptability, implementation scenarios, and legal implications.

Effects of these small-scale tests typically showed several effects that were in line with the expectations: a reduction of (top) speeds and the speed variance, as well as a reduction of inappropriate speeds at hazardous locations. The research projects also took into account the possibility of compensating effects induced by the system. In some occasions such effects were found: e.g. a slight increase of speed low-speed situations such as turnings (Persson et al., 1993), or the acceptance of smaller gaps in turning (Carsten & Comte, 1997). Nevertheless, on balance the results were promising enough to proceed exploring the topic. Thus, the focus of ISA research shifted gradually from short term effects to longer term effects in terms of attitude and behaviour. For example, Almqvist, Várhelyi, and Hydén (1997) described a study where subjects drove in an ISA-equipped vehicle for 2 months. Later on, a series of large-scale and long-term trials was initiated. In Sweden, four trial areas have been defined: large-scale studies are conducted with various types of ISA, in the cities Borlänge, Lidköping, Lund, and Umeå (see Lind, 1999). In total, several thousands of vehicles will be involved.

In the city of Tilburg, the Netherlands, a field trial is being carried out with 20 vehicles equipped with an intervening ISA system in a built-up area. The project is focussed on testing the technical concept and on acceptance.

Exchange and comparisons of effects and results among several European countries took place e.g. in the EU co-financed project MASTER (Managing Speeds of Traffic on European Roads). Later on, the European Working Group on Speed Control (EWGOSC) was established. Within this group, researchers, other organisations and policy makers involved in ISA exchange information and share results on an informal basis.

COMBINING ACC AND ISA

In addition to the conventional Cruise Control function of controlling a vehicle's speed at a driver-chosen value, an Adaptive Cruise Control system (ACC) in car-following situations maintains a given headway behind slower vehicles ahead. Once an automatic speed control device has been installed, also other options become within reach, for example adjusting the driving speed automatically according to the prevailing speed limit on that particular stretch of road. Such systems basically take over the longitudinal control part of the driving task and change the driver's role from in-the-loop control to out-of-the-loop monitoring of ACC's functioning. Current prototypes and commercially available ACCs only realise moderate deceleration levels (e.g. -1.5 to -2.0 m/s²). Only in situations the system can not cope with, the driver has to take over control. ACCs are considered to be a comfort device, assisting the driver in longitudinal control but with still the driver fully responsible for the control of the vehicle.

The longitudinal control system of the ACC could be extended with an externally determined suitable (maximum) driving speed. The next 2 sections describe 2 studies that were carried out to explore this concept.

Driving simulator experiments

Hogema, van der Horst and Janssen (1994) conducted a driving simulator experiment in which they compared purely informative systems versus actively intervening systems with respect to speed, and also they investigated how the external speed information should be presented to the driver. A detailed description of the TNO driving simulator is given by Hoekstra, van der Horst and Kaptein (1997). Most of the time, subjects drove in a standard situation, i.e. on a 120 km/h motorway; this default limit was not used by the ACC/ISA system. Every now and then, the driver was confronted with a situation where a lower speed limit applied. This limit and its rationale were always made available to the driver as in-car information. The situations were:

- a 100 km/h speed limit for no apparent reason,
- an 80 km/h speed limit due to a relatively sharp curve,
- and a 50 km/h speed limit due to a sudden traffic queue. In the traffic queue scenario the ACC was not capable of dealing with the situation and the driver had to take over braking control.

Together with the in-car information, roadside (speed) information was always given via Variable Message Signs on gantries above the road present at every 500 m along the motorway. Such an automatic incident detection system has now been implemented on most major motorway connections in the Netherlands. Subjects got the instruction to keep the ACC on as much as possible, but always had the possibility to overrule the system, either by a switch on the steering wheel column, or by releasing the gas pedal (in this study also with ACC on the driver had to keep his foot on the accelerator pedal).

Results of mean free-driving speeds revealed that, apart from an obvious effect of scenario, the presence of ACC reduced the mean free-driving speed in the 'queue' scenario but increased speed on standard road sections (120 km/h speed limit not supported by the ACC), see Figure 1.

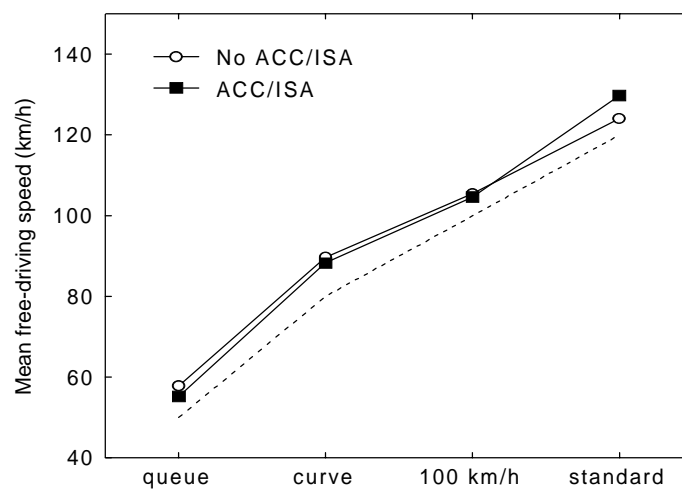


Figure 1 Mean free-driving speed as a function of scenario and presence of ACC (Hogema, van der Horst & Janssen, 1995).

Figure 2 illustrates the effects of informative versus intervening ACCs on mean free-driving speeds. The *informative* ACC revealed no effect in any of the three critical scenarios and a slight speed increase on the 'standard' road sections. The *intervening* ACC resulted in significant lower mean free-driving speeds in the curve and queue scenario, but in higher speeds on the standard road sections. The speed increase on the standard road sections was higher for the intervening ACC than for the informative version.

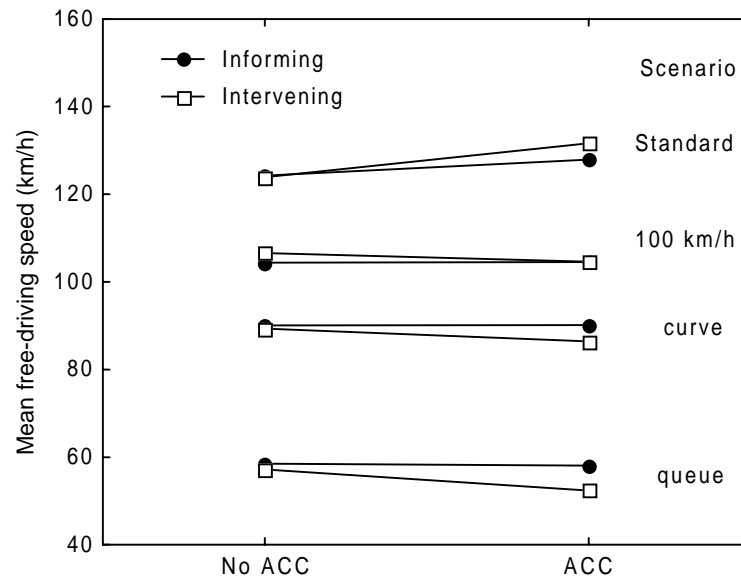


Figure 2 Mean free-driving speed as a function of presence of ACC and scenario (Hogema, van der Horst & Janssen, 1995).

An analysis of behaviour while approaching the stationary traffic queue in terms of Time-To-Collision (TTC) resulted in a decrease of TTC at the moment the accelerator pedal was released, of TTC at the moment the brake pedal was applied, and of the minimum TTC value over the entire approach manoeuvre when ACC was present. As also the distances at which these TTC moments occurred were lower, together with higher speeds, the smaller TTC values with ACC present can be attributed to later reactions of the driver.

Microscopic traffic simulation study

To study the effects of this ACC/ISA system on the traffic flow level, a microscopic traffic simulation study was conducted. This was carried out using the simulation model MIXIC (Van Arem, Hogema, & Verheul, 1995). MIXIC operates on a link level in a network. Traffic is simulated at the individual driver-vehicle level. Vehicles are initiated one by one at the entry point of a simulated road section based on real-world traffic observations (loop detector data at the individual vehicle level). Given this input of traffic flow, MIXIC simulates the traffic behaviour in this link and keeps traffic statistics.

To allow realistic switching between driver-controlled to ACC-controlled driving, a separate driver model, vehicle model and ACC model were distinguished. The inputs to the vehicle model were defined at a detailed level (pedal positions and gear state). When the vehicle had no ACC or when the ACC is off, the driver set the input to the vehicle model. When a vehicle has ACC, the driver model determined when the ACC is activated and deactivated,

taking into account the limited deceleration capabilities of ACC. After a driver had switched the ACC on, the vehicle inputs were determined by the ACC. The task of the driver then changed from actively controlling the vehicle's longitudinal motion to supervising the ACC's control behaviour. When necessary, the driver model could disengage the ACC and thus take over control.

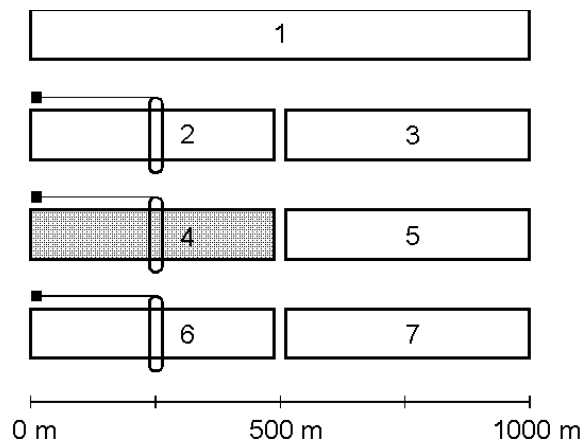
The in-vehicle ACC system was combined with a roadside system that could influence the target speed of the equipped vehicles by means of a beacon communication system. The roadside system was designed to perform a homogenising function. This means that when traffic volume increased and speed therefore decreased, the beacon started to influence traffic upstream to try to create a homogeneous, steady traffic stream. This should prevent a breakdown of traffic as long as possible, i.e. the available road capacity is fully used. To be able to simulate roadside-vehicle communication in MIXIC, some minor adjustments were made to the model. Hogema and Van der Horst (1999) gave detailed results in terms of traffic safety, traffic performance, and noise and exhaust-gas emissions, all at a microscopic and a macroscopic level. In this paper, only some results related to safety at the microscopic level will be discussed.

The experiment contained the following conditions.

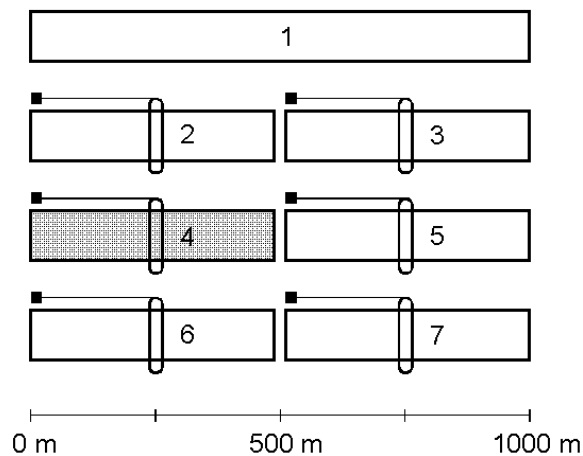
- The level of ACC penetration in passenger cars: 0, 20 and 40%.
- The ACC target headway setting at 100 km/h: 1.0 and 1.5 s.
- The beacon distance: 500 and 1000 m.

In total, this yielded 9 runs. A vehicle injection file obtained from real-world inductive loop detector data was used to start vehicles at the beginning of the first link. This file contained a large variation in traffic flow (from medium to high volume), representative for Dutch motorway traffic conditions.

In total, 4 km of road length was simulated in each run. The first link, which had a length of 1 km, was always without a beacon. The remaining three km consisted of 6 links of 500 m each, with a beacon distance of either 1000 m or 500 m (see Figure 3). To allow a fair comparison of link measurements between the 1000 m and the 500 m beacon distance conditions, all 1000 m beacon distance sections were realised as two 500 m links, with a beacon only at the first one.



A. Beacon distance 1000 m



B. Beacon distance 500 m

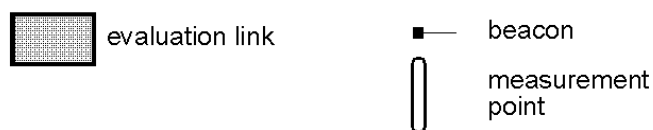


Figure 3 Road network lay-out. A: beacon distance 1000 m. B: beacon distance 500 m.

Measurements from the fourth link (from 2000 to 2500 m) were used to study the effects of ACC in the case study. The purpose of the other links was to avoid transient effects of the beginning and end of the road network, and of the beginning of road sections with a beacon. For each run, 35 5-minute intervals were included in the analysis.

The results showed that the mean speed decreased with increasing penetration levels (see Figure 4).

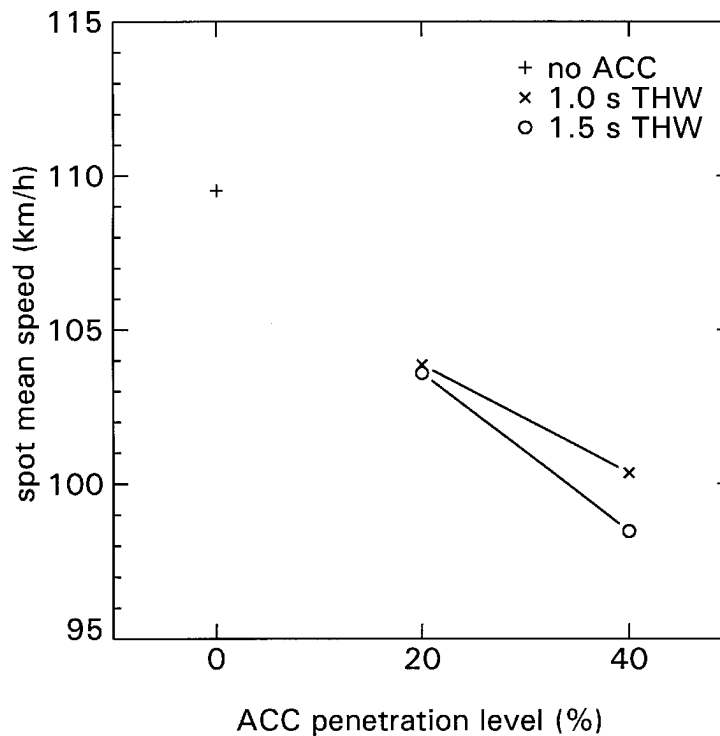


Figure 4 Spot mean speed as a function of ACC penetration level and target headway.

The standard deviation of speed was significantly smaller at 40% ACC (10.8 km/h) than at 0% (11.6 km/h) or at 20% ACC (11.9 km/h). The percentage of critical TTCs (i.e. < 4 s) was lower in the 40% ACC condition (4.2%) than in the 20% ACC condition (5.1 %). It was also lower compared to the condition without ACC (5.0%). Finally, the number of shock waves per 5-minutes interval was smaller in the 1.5 s target headway condition (0.02) than in the 1.0 s target headway condition (0.11).

DISCUSSION AND CONCLUSIONS

As can be expected, the application of a combined ACC/ISA system results in a more consistent longitudinal control: speed and following distance are controlled with less variation, compared to a human driver. Only intervening systems resulted in a speed reduction on motorway sections with a special speed limit, but at a cost of somewhat higher speeds at non-controlled sections. In critical scenarios (approaching a sudden traffic queue) where ACC could not cope with completely and the driver had to take over control, a somewhat later braking reaction of the driver was found. Apart from definite positive safety effects of ACC, also some negative behavioural adaptation effects may apply. With respect to car-following in the ACC mode, a lower percentage of short time headways (< 1s) occurred, as is to be expected from a system that aims at maintaining a headway of 1.5 s. However, the mean headway was not significantly affected by ACC. This implies that the gain in safety is not necessarily at the cost of reduced traffic efficiency.

Once effects of the new system on individual behaviour have been identified, these findings can be used to feed traffic simulation models. A microscopic simulation study

revealed that as the penetration level of this system increases, the mean speed, s.d. of speed and percentage of critical TTCs decreased. A 1.5 s ACC target headway resulted in a lower percentage of vehicles with critical time headways and a lower number of shock waves than a 1.0 s target headway.

The concept of Intelligent Speed Adaptation (ISA) has gained increasing attention during the last decade. After several simulator and classical instrumented vehicle studies, also field trials have recently started and will continue the coming years. Continuing attention should be given to some negative side effects of behavioural adaptation. There appears to be a trade-off situation: so far, most studies indicate that drivers prefer the informative version of ISA over the intervening one whereas the intervening type is more effective. Further research should be focussed on long-term effects of speed limiters in large-scale demonstration trials.

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