# Intelligent Speed Adaptation: A Review

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**ABSTRACT**

The implementation of Intelligent Speed Adaptation (ISA) has the potential to significantly reduce the incidence and severity of road trauma in Australia and overseas. Over the last few years there has been a growing interest in ISA, which is reflected in the growing number of ISA research and demonstration trials taking place all over the world. European countries such as Sweden, the Netherlands and the United Kingdom have to date been at the forefront of research into ISA. However, more recently, countries such as Denmark, Finland, Australia, France, Belgium, Spain and Japan have also taken an interest in ISA. This paper provides an up to date review of the literature and trials involving ISA from around the world, with particular emphasis on evaluating the potential road safety benefits and human factors issues associated with the different variants of ISA.

## INTRODUCTION

Speeding is known to be a contributing factor in a large proportion of crashes involving vehicles in Australia. Of the various classes of ITS that are reaching technical maturity, the technology that stands out as having great immediate potential to reduce the incidence and severity of road trauma in Australia and overseas is Intelligent Speed Adaptation (ISA) (Regan, Oxley, Godley & Tingvall, 2001). Intelligent Speed Adaptation is a generic term for a class of ITS in which the driver is warned and/or vehicle speed is automatically limited when the driver is, intentionally or inadvertently, travelling over the posted speed limit for a given location. Specifically, ISA systems compare the current speed and position of the vehicle with the local posted speed limit and respond if the vehicle exceeds this posted limit.

In this paper we provide a current review of what is known about ISA and its potential to enhance road safety. The material reported here is derived from a more comprehensive review of the literature on ISA undertaken by the Monash University Accident Research Centre (MUARC) for Austroads (Regan, Young & Haworth, 2002). The more comprehensive review constitutes the first phase of a multi stage project that is expected to culminate in an on-road study that will evaluate the effectiveness of ISA for heavy vehicles in Australia.

### Intelligent Speed Adaptation

There are two main classes of ISA: speed alerting and speed limiting systems. Speed alerting systems warn the driver if he or she is exceeding the posted speed limit in a given location. While there are many variants of speed alerting systems, the two most common ones are: an "informative" variant, in which the driver is provided with visual and auditory warnings if they exceed the posted speed limit beyond a specified threshold, and an "actively supporting" variant, in which the driver receives a "haptic" warning (with or without a preceding visual warning) in the form of increased upward pressure on the accelerator pedal. This resistance is designed to inform the driver that they are currently exceeding the posted speed limit for their given location (Várhelyi, 2001a). Variable speed *limiting* devices make it impossible for the driver to exceed the posted limit. The maximum speed of the vehicle is limited to different speeds at different locations depending on the posted speed limit. A number of control mechanisms exist to restrict a vehicle to the posted speed limit. These generally consist of two types: speed governors and speed retarders.

For both variable speed alerting and limiting systems, the maximum speed at which the vehicle can travel before the ISA warnings are activated depends on the posted speed limit for the location in which the vehicle is travelling. Information regarding the current position of the vehicle and the speed limit that applies to that location can be obtained in one of two ways. One way is by means of electronic signals to the vehicle from beacons or transmitters attached to speed signs or other roadside infrastructure, such as lampposts. An alternative approach, and the one that is being adopted most widely in ISA trials around the world, utilises global positioning system (GPS) technology. With this approach, information regarding the road network and data about the posted speed limits within it are stored in a digital map database within the vehicle. A GPS receiver fitted to the vehicle locates vehicle position. An on-board computer continuously analyses the location of the vehicle and compares the posted speed limit with the current speed of the vehicle. Warnings are issued when the vehicle is exceeding the speed limit or some other nominated speed threshold for a given location (van Boxtel, 1999).

### Development and Deployment of ISA Systems in Australia

The Transport Accident Commission (TAC) SafeCar Project is to date the only Australian study concerned with the design, development, deployment and evaluation of ISA technologies. It is a joint research project involving the TAC, the Ford Motor Company of Australia and the Monash University Accident Research Centre. The overall aim

of the project is to stimulate demand, initially by car fleet owners and eventually by the general community for in-car ITS technologies that have significant potential to enhance road safety in Australia (Healy, Regan, Tierney, & Williams, 2002). The three systems that are the primary focus of interest in this study are Intelligent Speed Adaptation, Seat Belt Reminder System and a Following Distance Warning System. Fifteen Ford passenger cars have been equipped with these systems along with a reverse collision warning system and daytime running lights. The study is the first to examine the effects of ISA on driving performance in conjunction with other ITS technologies. It will also assess driver acceptability of the systems and their technical reliability.

Two variants of ISA, informative and actively supporting, were fitted to two prototype vehicles as part of the project. However to limit the duration of the project, only one variant – the actively supporting system - was equipped to the 15 test cars and will be evaluated during the on-road trial. Both variants are speed alerting GPS/digital map based systems, which warn the driver when the vehicle exceeds the posted speed limit by 3 km/h or more. The two systems differ according to the types of warnings they issue. The informative variant consists of a two-stage warning system, with each stage comprising both visual and auditory warnings. The actively supporting ISA system, which as noted above will be evaluated in the on-road trial, is also implemented as a two-stage warning system. The on-road study commenced in August 2002 and will run for 12 months. In parallel with the on-road study, several experiments using an advanced driving simulator will be conducted to examine in more controlled conditions the impact on driver workload and distraction of the primary ITS technologies fitted to the 15 test vehicles.

Another recently completed Australian study has gauged the acceptability to Victorian car drivers of a wide range of in-vehicle intelligent transport systems, including ISA (Regan, Mitsopoulos, Haworth & Young, 2002). The study revealed that drivers believed that only drivers who inadvertently speed would benefit from ISA. They were also reluctant to embrace ISA unless they had proof that it saves lives, is reliable, can be over-ridden and is inexpensive to install and maintain.

**Development and Deployment of ISA Systems Overseas**

***Sweden:*** Sweden has been at the forefront of world research into the potential safety benefits of ISA technologies. An early trial of speed limiter technology was conducted in the Swedish city of Eslöv by the University of Lund (Almqvist & Nygård, 1997). The project aimed to examine acceptance of a speed limiter and its affects upon driving behaviour during extended use. A total of 25 drivers had their car equipped with an automatic speed adapter, which made use of an active gas pedal which was set at a maximum of 50 km/h. Once drivers entered a 50 km/h zone, they would feel increased resistance in the accelerator pedal and were unable to increase speed beyond this limit. Radio transmitters installed along roads automatically activated and deactivated the speed limiting device. The results were generally encouraging. Overall, participants experienced the speed limiter as providing safety benefits and did not consider it as an unwelcomed control. Clear differences between the participants' speed patterns with and without the speed limiter were also revealed. Before the speed limiter was installed, initial measurements indicated that the participants regularly exceeded the speed limit. After the speed limiter had been installed for two months, the participants' average speed had decreased and was within the speed limits.

In light of the positive results from this earlier trial involving ISA, a large scale on-road trial is currently being conducted in the four Swedish cities of Borlänge, Umeå, Lund and Lidköping. The trials are being co-ordinated by the Swedish National Road Administration and aim to enhance knowledge of motorists' attitudes towards ISA, the potential traffic safety and environmental costs and benefits of various ISA systems and the integration of these systems into cars. The trials commenced in early 2000 and the on-road phase of the trials concluded in late 2001. More than five thousand cars were equipped with informative and actively supporting ISA systems to assist motorists in complying with the speed limit. A wide range of road users were involved in the trials, including private motorists and professional drivers, such as bus drivers (Lind, Lindkvist, André, & Carlsson, 2001). There were large differences in the design of the trials between cities. In particular, the four cities implemented and evaluated different variants of ISA. Four variants of speed alerting ISA were trialed: an informative ISA system; informative ISA system with display; ISA systems for quality assurance and an actively supporting ISA system (Lind et al., 2001).

The Borlänge trial tested an informative ISA system with display and the ISA system for quality assurance (consisting of a unit that registers and stores any speed violations). These systems were installed in 400 test vehicles and were GPS based, with the local speed limits stored in a digital map database. A visual display located on the dashboard displayed the applicable speed limits at all times. Once the current speed limit had been exceeded by 2 km/h or more, a lamp on the dashboard would flash and an audio signal was issued. The informative ISA system was installed in 200 vehicles driven by private and professional drivers. The ISA system for quality assurance was equipped to around 200 vehicles including school buses and transport for the disabled. The test drivers were exposed to the ISA systems for approximately 12 months. Results from the before-measurements (taken before drivers were

exposed to ISA) indicate that 94% of the drivers exceeded the speed limit on main streets with a 30 km/h limit. The preliminary results of the Borlänge trial revealed that the test vehicles exceeded the speed limit only 6.6% of the time and, when excessive speeding occurred, it was generally within 5 km/h of the posted speed limit (Lind, 2000).

In the city of Lund, 290 vehicles were equipped with an actively supporting ISA system, which provided resistance in the accelerator if the driver attempted to exceed the speed limit. A differential GPS receiver and a digital map of speed zones were also installed to identify the position of the vehicle and provide information regarding the current speed limit. The test area included the entire area of Lund. Driving data, such as speed, position and time and date were logged by data logging facilities and flash memory cards, both before and after the system was activated. To date, only results of the before observations and preliminary results from the in-car observations have been released. The results from the baseline questionnaire administered to the public revealed that road safety is the most important issue facing drivers in urban areas (Várhelyi, 2001a). Results from the in-vehicle observations revealed that there was a 6% increase in yielding behaviour at stop signs and in giving way behaviour at bicycle and pedestrian crossings when drivers drove a car equipped with ISA. Studies on the system effects of ISA revealed that there were no changes in speed levels or time headways of non-ISA cars while ISA vehicles were circulating in traffic, however, there was a general increase in red light violations during the test period.

The Umeå trial focused on a large number of participants in order to achieve a measurable impact on the speed distribution in the road network. Approximately 4,000 vehicles were equipped with an informative ISA system. When the vehicle exceeded the posted speed limit, a lamp flashed and an auditory signal was issued. Information regarding the current speed limit was transmitted to the test vehicles via beacons mounted to street lamps and speed signs along the roadside. Participants were interviewed on three occasions during the trial period: after one month, after six months and after 12 months. This was done to evaluate their attitudes towards the system as a driving aid. Measurements of the test vehicles' speed profiles, time gaps and the effect of ISA on driving behaviour and interaction with other road users at intersections were also obtained. At present, only results from the 1-month investigation have been released. The majority of participants (72%) indicated that it was easier to adhere to speed limits on 30 km/h roads with the ISA system installed. In addition, 67% of the drivers claimed that they totally avoided speeding after an ISA warning was issued. Overall, 88% of drivers claimed that they supported the ISA system. However, the drivers also indicated that they felt the pleasure of driving had decreased, that they felt frustrated by the slower speeds and that they experienced an increase in travel times. Results from the speed measurements revealed a significant decrease in speed and speed variance within the test area (Sundberg, 2001).

Two variants of ISA were tested in the city of Lidköping, an informative ISA system with display and an actively supporting ISA system. Approximately 280 test vehicles were equipped with these systems. Half of the vehicles were equipped with the informative system with display and half with the actively supporting system. Information regarding local speed limits was transmitted to the vehicles via a dGPS receiver and a digital map of the road network. Private motorists, drivers of company cars and drivers of municipal authority vehicles tested these systems in approximately equal numbers (Vägverket, 2002). To date, the results from this trial have not been released.

***Netherlands:*** An alerting ISA system was trialed in the Netherlands by Brookhuis and de Waard (1999). The trial aimed to examine the effects of feedback from the ISA system on speeding behaviour, cognitive workload and acceptance of the system. The system tested received information regarding the local speed limit via tags attached to traffic signs. Immediately after the vehicle exceeded the speed limit, visual and auditory warnings were provided. Twenty-four participants drove the test vehicle in normal traffic on various road types. During the trial the experimental group received feedback from the system regarding speed violations, while the control group received no feedback. The results revealed that the extent to which the speed limit was exceeded on the second trial was on average 4 km/h lower for the experimental group and nil for the control group. The results also revealed a significant reduction in speed variability (0.5 km/h) for the experimental, but not the control group. Perceived levels of mental workload and ratings on the acceptance of the system did not differ significantly between the two groups.
A large on-road trial of intelligent speed *limiting* technology was recently completed in the Dutch municipality of Tilburg (Duynstee, Katteler & Martens, 2001). The trial evaluated: societal attitudes to and acceptance of ISA limiting systems; the effects of ISA on driving behaviour and the technical feasibility of the implementation of ISA. Twenty Volkswagon Boras were equipped with an ISA limiting system, which restricted fuel flow to the engine making it impossible for the vehicle to exceed the posted speed limit. Vehicle location and the applicable speed limit were determined by a dGPS receiver and a digital road map. Over the course of the one year trial period, a total of 120 people participated in the study. In addition, a passenger bus was also equipped with the ISA limiting system, so that professional drivers could also gain experience with ISA. Residents of a sub-district of Reeshof, called Campenhoef, were recruited as test drivers. Information on the acceptability of ISA was collected by means of

questionnaires administered to road users before and after the introduction of the system, including the test drivers and inhabitants of Campenhoef and other cities (Duynstee et al., 2001).

Results from the acceptance study revealed that the majority of test drivers (64%) reported a positive attitude towards ISA. In addition, 90% of the 20 bus drivers indicated that they were positive about the ISA system equipped to the bus. The general public also reported that they held a positive or a neutral attitude towards ISA, and this support increased with greater exposure to the ISA system. Data from the data loggers revealed a decrease in average speeds and more homogenous speed patterns. Half the drivers reported that they did not speed outside the test area to compensate for their reduced speeds in the test area. However, test drivers did report that they experienced irritation, such as tailgating, from other drivers and that they felt embarrassed about this situation. Overall, however, the results of the trial are very encouraging given that researchers have generally found that the acceptance of speed *limiting* as opposed to speed *alerting* systems, is usually quite low (Várhelyi, 2001b).

***United Kingdom*** As part of the MASTER (MAnaging Speeds of Traffic on European Roads) project, Várhelyi, Comte and Mäkinen (1998) evaluated several variants of variable speed limiters in a field trial and in an advanced driving simulator located at the University of Leeds. The experiment aimed to evaluate the positive and negative effects of speed limiting devices on speed behaviour, travel times, traffic violations, and driver workload and acceptance. In the simulator trials, two speed limiter systems were evaluated against an advisory system (which provided information about the current speed limit and hazardous conditions ahead) and a baseline control. The "fixed" system automatically limited vehicle speed to the posted speed limit, while the "dynamic" system further reduced vehicle speed in hazardous situations. A total of 60 participants drove along a 25km simulated road network with one of the three speed control systems or no system (control group) operating. Speed measurements were taken and data on driver workload, time headway, overtaking, traffic light violations and collision measures recorded. Results revealed several benefits of the limiting systems, including reductions in speed and speed variance and better speed adaptation in hazardous situations. However, a number of negative effects of the systems were also observed, such as shorter time headways, delayed braking, and a higher incidence of collisions. Results from the subjective measurements revealed that perceived mental workload did not differ across speed control systems.

The field trials of Várhelyi et al.'s (1998) study were carried out in Sweden, the Netherlands and Spain. The participants included 20-24 drivers from each of the countries, who drove an instrumented car equipped with a speed limiter along a 20-30km test route. The speed limiter gradually increased the counter-pressure on the accelerator as the vehicle approached the maximum speed and restricted the engine fuel injection system once the vehicle reached the local speed limit. Information regarding the current speed limit was relayed to the car via transmitters attached to speed signs. Results revealed that the speed limiter significantly reduced driving speeds by up to 5 km/h. Other positive effects of the speed limiter were decreases in speed variance, smoother approach speeds at roundabouts, intersections and curves and increased time gaps between cars.

A more recent trial known as the External Vehicle Speed Control (EVSC) Project was conducted in the United Kingdom by the University of Leeds (Carsten & Tate, 2001). The project aimed to review a broad range of factors related to the possible introduction of a speed control system which limits the top speed of vehicles. The work was carried out in an advanced driving simulator and with a specially modified car in real traffic situations. For both the simulator and on-road trials, two major variants of ISA systems were tested. The first system was a voluntary system termed "Driver Select", in which drivers have the option of being limited to the advised speed limit, overriding the system or ignoring the system. The second system was the "Mandatory" system, in which the vehicle is permanently limited to the maximum posted speed limit. As with the Driver Select system, visual and auditory signals are issued to the driver upon entering a new speed zone. Finally, a "Variable" system was also evaluated. This system was only implemented in the simulator trials and had the additional function of being able to lower the speed of the vehicle when approaching dangerous curves or pedestrian crossings.

The simulator trial aimed to evaluate driver behaviour using the three ISA systems. Forty participants took part in the trial. Each participant drove along a 22 mile simulated road network on four different occasions. The results suggest that the speed control systems had little impact on mean speeds, however they did reduce maximum speeds and this was particularly pronounced for the Mandatory system. Several negative behavioural changes were revealed in the trial. When driving with a speed control system operating, drivers tended to accept smaller gaps at junctions and adopted shorter headways when following a slow lead car in both rural and urban areas. Subjective mental workload data revealed that drivers perceived greater time pressure and increased frustration when driving with the ISA systems (Carsten & Tate, 2001).

The on-road study required participants to drive a predetermined test route in a Ford Escort car equipped with two variants of ISA, the Mandatory and Driver Select systems. The position of the car was determined via a dGPS

receiver, while a digital map provided information about speed limits. A total of 24 drivers participated in the trial and drove the test car on three occasions. The results revealed that, although the use of the Driver Select system was high, drivers were prone to disengage the system in areas where speeding is the norm. The Mandatory system was successful at reducing excessive speeds and resulted in improved following behaviour and less abrupt braking. There was no evidence of any negative behavioural effects of the systems, although drivers did report that their frustration levels rose, as did time pressure when driving with ISA. With regard to driver acceptance, drivers indicated that the Driver Select system was more useful as a safety instrument than the Mandatory system (Carsten & Tate, 2001).

***Denmark:*** Aalborg University in Denmark has recently conducted an on-road ISA trial (Lahrmann, Madsen, & Boroch, 2001). This project had two objectives: first, to develop an on-board unit for a GPS based ISA system and, second, to have this system tested by drivers in order to obtain user reactions towards the system. The project utilized an advisory ISA system and GPS/digital map technology. If the vehicle exceeded the posted speed limit by more than 5 km/h, the system responded with auditory and visual warnings. A total of 24 drivers participated in the trial and drove around for a period of six weeks within the municipality of Aalborg. The speed data indicated that mean speeds were lower during the test period compared to the before period. There was also a clear decline in speed violations in the test period. Results from the acceptability data revealed that 75% of the test drivers held positive attitudes towards ISA as a speed-monitoring device. Many of the drivers also reported that the lower speeds when using ISA did not lead to longer travel times.

***Finland:*** Another recent field trial involving ISA was conducted in Finland (Päätalo et al., 2002). The trial aimed to evaluate three different variants of ISA, "informative", "compulsory" and "recording". An instrumented car was equipped with a GPS receiver, a route navigation system and the three ISA systems. The informative system provided information regarding the current speed limit on a visual display and issued an auditory warning if the vehicle exceeded the speed limit. The compulsory system limited the maximum speed of the vehicle to the posted limit. Finally, the recording system displayed the percentage of the total driving time that was spent speeding on the visual display. A total of 24 participants drove the instrumented car along a test route on four separate occasions. Results revealed that drivers spent less time speeding when driving with one of the ISA systems operating and this reduction was most pronounced for the compulsory system (6.7 km/h). Results from the workload data revealed that drivers found driving with the compulsory system most demanding with regard to required attention and concentration. Drivers also felt increased time pressure, frustration and insecurity with the compulsory system. The authors concluded that while the compulsory system seemed to be the most effective means of speed reduction out of the three systems, it was this system that was rated as least acceptable by the drivers.

**Planned ISA Trials**

Several large-scale ISA trials are currently being considered in several European countries, including the Netherlands, Finland, Belgium and France. In addition, researchers at Chiba University in Japan (Oguri, 2001) are developing a car equipped with an ISA limiting system which limits speed according to prevailing weather and road conditions and displays this speed on the outside of the car for other road users to see. A follow up ISA project being conducted in the United Kingdom began in January 2001 and will run for 52 months. The project aims to: investigate driver behaviour with ISA through a set of field trials; study overtaking behaviour with ISA in a driving simulator; investigate ISA for motorcycles and large trucks; prepare a system architecture for mass production of ISA and further investigate the costs and benefits of ISA. A three-year long European Commission-funded project called PROSPER (Project for Research On Speed adaptation Polices on European Roads) is also commencing in Hungary and Spain. This involves conducting an investigation of the legal situations surrounding the development of implementation strategies for Europe.

**THE FUTURE**

Overall, both intelligent speed alerting and limiting systems appear to have a number of expected road safety benefits, including reductions of 5 km/h and more in mean speeds as well as a reduction in speed variance and speed violations. Unlike speed *limiting* systems, there is little evidence that drivers engage in compensatory behaviours when using speed *alerting* systems and driver acceptance of them is generally quite high. There is no evidence to date to suggest that use of speed alerting and limiting systems increases cognitive workload or distracts the driver. However, there is some evidence that alerting and limiting systems lead to a decrease in driving pleasure, increased frustration at lower speeds and increases in travel times. Overall, it appears that while variable speed limiting systems are more effective than alerting systems in reducing speed, they are less acceptable to drivers than alerting systems.

Australia has lagged behind Europe in the development, deployment and evaluation of ISA technologies. Only one Australian study, the TAC SafeCar study, is concerned with evaluating the effectiveness of this technology as a

means of enhancing road safety, however it is concerned only with the use of the technology by drivers of corporate fleet cars. Another promising development in Australia is the proposed Austroads-funded evaluation of ISA in heavy vehicles (Regan, Young, & Haworth, 2002). In their comprehensive review of ISA developments around the world, Regan, Young and Haworth (2002) recommend ways in which Australia should proceed in exploring the potential benefits of this technology. The primary need identified by them is the development of a coordinated national strategy to guide the selection, deployment and evaluation of ISA technologies in Australia, which encompasses both light and heavy vehicles. In their report they provide a conceptual framework which identifies the relevant deployment issues to be considered, including fundamental research needs, which could serve as the basis for the development of such a strategy. We recommend that road authorities and other key stakeholders in the ITS community give careful consideration to the recommendations in that report and that they monitor closely the European Commission-funded PROSPER and Speed Alert projects, which are concerned with standardising the approach to ISA deployment in Europe.

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