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Intelligent Speed Adaptation: accident savings and cost-benefit analysis

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Abstract

The UK External Vehicle Speed Control project has made a prediction of the accident savings with Intelligent Speed Adaptation, and estimated the costs and benefits of national implementation. The best prediction of accident reduction was that the fitting on all vehicles of a simple mandatory system, with which it would be impossible for vehicles to exceed the speed limit, would save 20% of injury accidents and 37% of fatal accidents. A more complex version of the mandatory system, including a capability to respond to current network and weather conditions, would result in a reduction of 36% in injury accidents and 59% in fatal accidents. The implementation path recommended by the project would lead to compulsory usage in 2019. The cost benefit analysis carried out showed that the benefit-cost ratios for this implementation strategy were in a range from 7.9 to 15.4, i.e. the payback for the system could be up to 15 times the cost of implementing and running it.

Keywords: Intelligent Speed Adaptation; Accidents; Cost-benefit analysis; Implementation strategy

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1. Introduction

Intelligent Speed Adaptation (ISA) is the generic name for advanced systems in which the vehicle "knows" the speed limit and is capable of using that information to give feedback to the driver or limit maximum speed. There has been a continual stream of research on ISA in various European countries since a trial with one vehicle conducted in Lund, Sweden in 1991–2 (Persson et al., 1993). Research projects and trials with ISA are proceeding or have recently concluded in a number of European countries, including Denmark (Lahrman et al., 2001), the Netherlands (Duynstee et al., 2001), Sweden (Swedish National Road Administration, 2001) and the UK (Carsten and Tate, 2000). Sweden currently has several thousand ISA vehicles on the road, most of them with a purely advisory system.

The External Vehicle Speed Control (EVSC) project, funded by the UK Department of the Environment, Transport and the Regions, began in February 1997 and ended in February 2000. Its aim was to review a broad range of factors related to the possible introduction of an automatic system to limit the top speed of road vehicles. Phase I of the project was designed as an introductory stage to prepare for the subsequent detailed design and experimental work. Phase II was the main research phase of the project. Its major work was concerned with the delivery of a prototype vehicle, user trials in a driving simulator and on real roads, simulation modelling to predict network impacts of ISA and a review of how ISA could be put into mass production. The last phase of the project reviewed the implications of the earlier work for implementation and prepared a proposed strategy for implementing ISA. In preparing the strategy, the predictions of the safety benefits of ISA that had been made in Phase I were revised as was the cost-benefit analysis. The aim of this paper is to summarise the work on the safety impacts and costs and benefits of ISA and to review the proposed implementation strategy.

2. System typology

An ISA system can be characterised by how *intervening* (or permissive) it is. Here the variants defined by the project are:

(a) Advisory — display the speed limit and remind the driver of changes in the speed limit;

(b) Voluntary ("Driver-Select") — allow the driver to enable and disable control by the vehicle of maximum speed;

(c) Mandatory — the vehicle is limited at all times.

Both the Voluntary and Mandatory are "intervening" in that the information on speed limit is directly linked to the vehicle control system. An additional possible variant between (b) and (c) is a mandatory system which allows excursions, e.g. for overtaking. Such excursions could be limited in number per unit of time or frequency per length of road.

Another dimension for differentiating ISA systems is that of the *currency* of the speed limits themselves. Here the major typology used in the project has been:

Fixed: the vehicle is informed of the posted speed limits;

Variable: the vehicle is additionally informed of certain locations in the network where a lower speed limit is implemented. Examples could include around pedestrian crossings or

the approach to sharp horizontal curves. With a Variable system, the speed limits are current spatially.

Dynamic: additional lower speed limits are implemented because of network or weather conditions, to slow traffic in fog, on slippery roads, around major incidents, etc. With a Dynamic system, speed limits are current in terms of time.

A third dimension (one that only applies to Voluntary and Mandatory ISA) is the strictness with which the ISA control is applied. To date, the speed-controlled cars built outside the UK have tended to use a haptic throttle, i.e. a throttle pedal that gets more stiff the greater the excursion from the speed limit, and not to apply any braking. This configuration has some shortcomings: feedback is only provided when the driver's foot is on the accelerator pedal; the driver is able to override the feedback quite substantially; deceleration may be very slow so that on entering a slower speed zone the vehicle could be speeding for 0.5 km or even 1.0 km; and the vehicle will be able to overspeed on downward gradients.

Because of these shortcomings of the haptic throttle, the project implemented a vehicle using a combination of "dead throttle" and active braking. The initial retardation was achieved not through feedback through the driver's foot but by intervening between accelerator position and engine control (in our case through a combination of ignition retardation and fuel starvation, but more ideally through a throttle-by-wire system). Additionally, a small amount of braking force was applied when the vehicle was determined to be a certain amount over the set maximum. By locating the onset of the retardation, *before* passing into a lower speed zone, the vehicle could be ensured to be in compliance with legal speeds at all locations.

3. System architecture

When the project began at the start of 1997, the general assumption was that a future national or European ISA system would be based on roadside beacons, probably Dedicated Short Range Communication (DSRC) beacons. Once the project got underway, the project team discussed the feasibility of alternative system architectures to provide the same ISA functionality as the beacon-based approach. An approach based on an autonomous architecture in which the vehicle would "know" its location from a GPS-based navigation system and would "know" the speed limit for that location from an on-board digital road map in which the speed limit for each link in the network had been encoded. This concept is illustrated in Figure 1.

Almost as soon as the UK project team had conceived of this alternative architecture, it emerged that a similar path was being pursued in Sweden and that a practical demonstrator of this concept had been being built by the University of Lund. The Dutch trial of Intelligent Speed Adaptation in Tilburg also used the autonomous architecture.

The autonomous architecture is the one that was implemented in the UK project test vehicle and the vehicle proved to be a hugely successful demonstrator of this autonomous ISA concept. To provide the test route, there were no infrastructure maintenance requirements at all (i.e. no physical beacons to service). This allowed speedy implementation of routes for both experimental investigation and demonstration. In addition the vehicle performed with a very high degree of reliability and repeatability throughout the three months of the on-road trials, with no observed failures of the

navigation part of the system (indeed no detected failures at all). This occurred in spite of initial worries about loss of the differential signal, "urban canyons", etc.

The autonomous concept has therefore been shown to be a viable alternative to a beacon-based system, and one that can be reliably implemented with current technology. A number of inferences follow from the autonomous concept:

(a) Geographic roll-out of ISA would be immediate. All equipped vehicles would be provide with ISA support, wherever they were in the network. There would be no need to prefer one type of road over another.

(b) The *public* costs of implementation would be small. The major public cost for the Fixed and Variable versions of ISA would arise from the creation and maintenance of the speed limit database.

(c) Changing speed limits would be very cheap. Traffic calming, as for 20 mph zones, would be accomplished with virtually no infrastructure, i.e. little more than a change in the database. The current negative consequences of traffic calming in the form of the noise, fuel consumption and emissions caused by physical measures would be virtually eliminated.

(d) Deployment would be rapid, thus eliminating confusion about where ISA applied. A national road map containing the speed limits for every UK road could be created for comparatively low cost. Benefits would then be constrained mainly by the number of ISA-equipped vehicle in the fleet and by the configuration of ISA. A small initial public investment would produce a large benefit.

(e) The ISA system would function across Europe, provided appropriate digital road maps were available. Germany has indicated that an autonomous and voluntary ISA would be acceptable (German Ministry of Transport, 1997)

(f) Purchase of an ISA vehicle would bring with it other "free" ITS systems, such as navigation systems. Another way of looking at this is to conclude that, if most future vehicles are equipped with navigation systems as a matter of course, then the incremental cost of providing ISA functionality is greatly reduced.

(g) Based on the experience with the test vehicle, reliability should not be a problem and should approach 100%. Reliability would be enhanced in a production system by map-matching software to compensate for dropouts in the GPS signal. With the beacon-based system, a failure of a vehicle to receive the beacon transmission would mean that, until the next beacon was passed, the vehicle would have incorrect speed limit information. With the autonomous system, there is the possibility of almost immediate recovery from a momentary dropout.

4. Prediction of accident savings

The modelling approach used to make predictions about the accident savings from the various forms of ISA has started with the presumption that reduced speeds will directly influence both the probability and the severity of accident occurrence. The relationships used have been derived from the best empirical evidence available, as established by a detailed literature review (Tate, 1997). The approach used was essentially a three-stage one. First, a model for the overall relationship between changes in speed and changes in injury accident numbers was applied. For this relationship, the recommendations of Finch et al. (1994) were used. Second, an adjustment was applied to take into consideration the effect of changes in speed variance with certain types of ISA, with the formula

used being obtained from West and Dunn (1971). And thirdly, the resulting predictions of the effects on injury accidents were used to calculate the impacts on more serious accidents using formulae from Andersson and Nilsson (1997).

The numbers used for the relationship between changes in mean speed and overall injury accident risk were that, for each 1 km/h change in mean speed, the best estimate of the change in accident risk was 3% (Finch et al., 1994). From the same source, a low estimate of a 2.35% change in risk and a high estimate of a 6% change for each 1 km/h change in speed was also used in the predictive modelling. An alternative approach, in which different speed-accident relationships would be used for different categories of road was also tested. Research carried out since the review undertaken by Finch et al. (1994) has indicated that the change in accident frequency for each 1km/h reduction in mean speed is inversely related to the current mean speed (Baruya et al., 1999). Reasonable estimates of the accident reduction for different road categories were calculated and applied. However, this more complex approach had little effect on the overall results and therefore it was decided to keep to single relationship for all roads.

The injury accident data used was the national database for Great Britain. The numbers from Finch at al. (1994) were applied to create the estimates for Advisory ISA. Based on findings discussed in Finch et al. (1994), the change in accidents was capped at 25%. For Mandatory ISA, an additional element was introduced, namely the fact that such a system transforms the distribution of speeds by cutting off all speeds in excess of the limit. This creates a spike in the speed distribution at the speed limit, as a consequence of the fact that drivers who formerly exceeded the speed limit are constrained by the mandatory ISA from doing so. One effect of this spike is to reduce speed variance and so

increase the safety of the traffic stream by smoothing flow. The formula applied for the relationship between speed variance and risk was derived from West and Dunn (1971) and was:

$y = 0.0139x^2 + 0.0140x$

where y is relative risk

and x is speed difference of a vehicle from mean speed in mph.

Information on the mean speed and speed variance of traffic on the various categories of road was obtained from the annual statistics published by the Ministry of Transport (Department of the Environment Transport and the Regions, 1999a).

For Advisory ISA, it has been assumed, based on a literature review (Tate, 1997), that the change in mean traffic speed resulting from the provision of speed limit advice is 40% of the difference between the original mean and the new advisory speed. For Voluntary ISA, compliance was based on findings from the user trials conducted in the project (Comte, 1999a; Comte, 1999b). The overall finding of those trials was that the speed change for drivers with Voluntary ISA was half that of drivers using the Mandatory system. It has therefore been assumed that the net effect of Voluntary ISA Driver Select on any factor of interest (accidents, fuel consumption, etc.) is half that of Mandatory ISA.

Variable ISA was modelled as operating to reduce speeds in sharp horizontal curves on rural single-carriageway roads. Results from a New Zealand study of the relationship between approach speed, curve speed and accident rate (Koorey and Tate, 1997) were used to calculate the predicted effect of slowing traffic on the approach to sharp curves. The best estimate of the reduction in accidents at sharp curves was with a Mandatory Variable system was 41%, with low and high estimates of 30% and 74% respectively.

Dynamic ISA was modelled as affecting three groups of accidents on rural roads only: those in darkness, those in rain and on wet roads, and those in snow. Factors for all three groups were obtained from a literature review (Tate, 1997). A range of 23% to 50% was identified as representing the reduction in night-time risk to make it equivalent to daytime risk, and the midpoint of 37% was used for the best estimate. For rainy conditions and wet roads, the reduction to make risk equivalent to that on dry roads was in the range between 10% and 50% with a midpoint of 30%. And for accidents in snow, the reduction was in the range between 33% and 80% with a midpoint of 57%.

The resulting estimates of the accidents savings for the various permutations of ISA are shown in Table 1. ISA systems are divided into the broad classes of Advisory, Voluntary, and Mandatory systems. Each broad class can have speed limits in fixed, variable or dynamic forms (where dynamic also includes variable capability). The best estimate for Mandatory Dynamic ISA is that it will save 36% of injury accidents.

Table 2 shows the best estimates of the accidents savings, at various levels of accident severity, for the permutations of ISA.. The calculations for the effect of ISA on fatal and serious accidents and on fatal accidents has been made by applying, to the results shown in Table 1, the formulae of Andersson and Nilsson (1997). They concluded that, for a given type of road, the injury accident rate changes with the square of the ratio of a change in mean speed, the severe injury (including fatal) accident rate changes with the cube of speed change and the fatal accident rate changes with speed change to the fourth power. The prediction is that the most powerful and versatile form of ISA, the Mandatory Dynamic system, will reduce injury accidents by 36%, will reduce fatal and

serious accidents by 48% and will reduce fatal accidents by 59%. These predictions compare quite well with those of Várhelyi (1996), who used an analogous methodology to predict that for Sweden Dynamic ISA would save in the range of 20–40% of injury accidents. However, the predicted accident saving is considerable larger than that of Perrett and Stevens (1996) who identified a certain percentage of accidents as being "speed-related" and then estimated that ISA would save approximately half of those. This resulted in an estimate of an overall injury accident reduction of 16% for a fully implemented Dynamic ISA. It seems far more correct and intuitive to treat all accidents as being in some way speed-related and to use empirical evidence on the relationship between speed and accidents as the basis for prediction.

5. Other effects and system costs

5.1 Fuel consumption

As part of the project work, microsimulation modelling of the effect of ISA on network efficiency, fuel consumption and emissions was carried out (Liu et al., 1999). Four networks were modelled: an urban network (part of Leeds) in the morning peak, the same urban network in the off-peak situation, a rural two-lane road (the A64 in East Yorkshire), and a motorway (part of the M25 London orbital). The fuel savings predicted by the modelling for the scenario with all vehicles having fixed ISA were as follows: urban peak 8%, urban off-peak 8%, rural road 3% and motorway 1%. Emissions results from the modelling were mixed, and consequently no monetised saving has been calculated.

The annual British petroleum consumption for road transport in tonnes is given in Department of the Environment, Transport and the Regions (1999b) together with the average price per litre. The same publication gives vehicle travel by road category and fuel costs. Using estimates of per-vehicle fuel

use on different categories of road, the total national fuel consumption was allocated to each of five road categories (motorway, major urban, minor urban, major rural, minor rural). Separate estimations were made for petrol and diesel fuel.

Based on the micro-simulation modelling, overall fuel consumption savings with ISA have been calculated. Table 3 shows the resulting savings in fuel consumption with Mandatory ISA and the financial value of those savings. For Advisory and Voluntary ISA, the same adjustments were used as for the accident effects.

5.2 System costs

As stated above, the favoured ISA system is an essentially autonomous system:

(a) An in-vehicle storage device, such as a CD-ROM, contains a digital map of the road network with the speed limits identified.

(b) A vehicle navigation system with a global positioning system (GPS) together with an inertial gyroscope and dead reckoning capability positions the vehicle on the digital map.

(c) The permitted speed limit is read from the in-vehicle map.

(d) The engine control unit (ECU) receives details of the current speed limit while managing the demands of other vehicle systems and controls the vehicle speed through a combination of engine management and active braking/traction control.

The major costs of this configuration of ISA are associated with (1) information supply, (2) system control and (3) the Human Machine Interface (HMI). The information supply part includes all system elements related to providing the vehicle with the current speed limit information. Costs are included here for:

(a) Generation of the digital maps and associated speed limits

(b) The administrative and material costs associated with providing annual updates

(c) The costs of broadcasting current update, and dynamic speed limit data

(d) The storage media and reading capability

(e) The technology the vehicle requires to locate its position on the map database

The management and implementation of speed control within the vehicle will be undertaken by the on-board control unit and the retardation system. The on-board control unit will provide the integrated logic to co-ordinate the ISA control with other vehicle functions. This functionality may be undertaken by a new dedicated unit or incorporated into an existing electronic control unit (ECU). Clearly, as more sophisticated engine management and braking systems are increasingly available, this function will be integrated into the existing engine management system /electronic control unit. It is expected that advanced engine management systems will in the future become standard production items, and that there will be a degree of shared functionality between the main engine management system and the ISA system. The additional costs for an ISA HMI are likely to be marginal, since it is expected that future vehicles will have multimode display capability and ISA will require little in the way of extra switches.

For each variant of ISA, it is possible to establish the systems costs in terms of an initial establishment cost to set up the system and an annual cost. The costs used here are based on discussion with experts and in particular estimates obtained from the technology provider in the External Vehicle Speed Control project, the Motor Industry Research Association (MIRA). Table 4 presents these costs both for an implementation now and for the future year 2010. Linear interpolation was used to establish the costs in any intermediate year. The estimated costs for 2010

have been used for all subsequent years, including years following compulsory fitment. Although this approach assumes a reduction of manufacturing costs over time and with mass production, costs have not been reduced to reflect the possibility of shared use by other telematics applications. In other words, the conservative position has been taken that all the costs of the electronics and infrastructure required for ISA should be attributed to ISA. In practice, many of the electronic systems required for ISA are likely to become standard components of vehicles over the next five to ten years.

6. Cost-benefit analysis

For the economic evaluation of ISA, the net present values (NPV) of costs and benefits are calculated to provide a measure of the economic viability of the project. For each future year of the project the benefits and costs are predicted taking into account the expected increase in the volume of travel, and the increases in GDP which increase the value of time spent travelling or lost through accidents (Department of Transport, 1996). It has been assumed that the accident rate remains constant at the 1998 level. This assumption is valid since the costs associated with black spot treatments, enforcement and educations programmes have not been included in the "Do Minimum" scenario. The annual values for the costs and benefits are then discounted to base year sums, and the ratio of benefits to costs is calculated. For ISA, costs include infrastructure costs, maintenance costs, in-vehicle costs, and updating costs. Benefits include accident reductions and fuel savings.

6.1 Assumptions

A set of assumptions has been made about the timings of the events required to implement ISA. This timetable is discussed in more detail below in section 7. The key points of this timetable which impact on the economic evaluation are:

(a) The base year for the analysis is taken as 2005, the year in which it is assumed a decision to implement ISA is made.

(b) The analysis period is 30 years from that date.

(c) The phased implementation would begin in 2013 with new vehicles being fitted with ISA. The assumption here is that there will be a period of further research until 2005, followed by a national decision to move ahead with one or other form of ISA. A further five years is then required to agree on standards for such issues as map formats, communications (if needed), and vehicle control parameters (where relevant). A three-year period is then estimated for setting up manufacture and support functions.

(d) The benefits have been calculated in proportion to the ISA penetration from 2013 through until 2019 when it is expected that fleet penetration will be sufficient (60% or more) that the full benefits of ISA will be realised. The 60% figure is drawn from the network simulation modelling of Liu et al. (1999), which indicated that almost all the impacts of mandatory ISA were realised at a 60% penetration level. To achieve 60% penetration into the fleet, a six-year period for phasing-in with voluntary use has been assumed, on the basis that roughly 10% of the British vehicle fleet is currently renewed each year.

(e) The digital maps and associated administrative structure would be developed over the three years 2010 to 2013.

(f) Maintenance costs would accrue from 2013.

Any benefits and costs from pre-2013 fitting of ISA on a voluntary basis have been ignored. This is in part because it is not possible to estimate take-up rates, but also because the impacts on safety at a national level are likely to be so small as not to be detectible.

The economic evaluation has been undertaken using the following assumptions:

(a) A discount rate of 6% is used (Department of Transport, 1996).

(b) Costs are expressed to a base year of 2005 in terms of 1998£.

(c) Forecast growth in travel is based on Transport Statistics Great Britain (Department of the Environment Transport and the Regions, 1999b) Table 4.10 and indexed to 1998.

(d) The value of accidents has been considered under the high and low growth scenarios for GDP (Department of Transport, 1996). Under the high growth scenario, travel is expected to increase at 2.9% per annum; under the low growth scenario, it is expected to increase at 1.8% per annum.

(e) The resource cost of fuel has been projected over the analysis period using the COBA values (Department of Transport, 1996).

(f) No residual values are assumed at the end of the analysis period.

The increase in travel time, which is potentially a negative benefit of ISA, has not been counted in the cost-benefit analysis, on the grounds that time saved through speeding is an illegal benefit and therefore not appropriate to count. The exclusion of time saved through speeding is in line with UK Department for Transport policy on road safety schemes.

6.2 Costs

The discounted costs for both the Advisory and Mandatory ISA configurations are given in Table 5 and Table 6 respectively. The cost of a Driver Select system is the same as for a Mandatory system since the vehicle functionality is the same in both cases. The bulk of the costs are associated with the

vehicle. The in-vehicle equipment accounts for roughly 97% of the discounted costs while the annual updating of the digital maps accounts for a further 2%. Finally the additional cost of providing Dynamic speed limit information over Fixed speed limit information is only 1%.

6.3 Benefit-cost ratios

The benefits of ISA are the discounted savings from reduced accidents and from reduced fuel consumption. The resulting benefit-to-cost ratios are shown in Table 7. It is here assumed that fitment of the Advisory version does not include the vehicle control elements required for Driver Select and Mandatory ISA. Clearly a Dynamic Mandatory system provides the most attractive solution under both GDP growth scenarios.

All the benefit-to-cost ratios are in excess of 5.0. Mandatory ISA has considerably higher benefit-cost ratios than the Advisory or Driver Select systems. The largest ratios are for the Mandatory Dynamic system: 12.2 for the low GDP growth scenario, and 16.7 for the high GDP growth scenario.

7. Proposed strategy for implementation

7.1 A path to full implementation

The main dimensions in EVSC deployment are *how intervening* the system should be in operation and *how current* the speed limits themselves should be. The predicted accident savings from ISA were presented in Table 2. The predicted impact of ISA on injury accidents along these two dimensions is shown in **Error! Reference source not found.**. It can be seen from that the scale of the effect of ISA on safety is larger along the *Intervention* dimension (down) than along the *Currency*

dimension (across), although the difference is not huge. Public concern about ISA will also be mainly about the Intervention aspects. In addition, cost of implementing ISA are more affected by the *Currency* dimension than by the *Intervention* dimension. The greatest benefit gains are therefore along the Intervention dimension. All this suggests that the first-order decision in arriving at an implementation strategy should about the *Intervention* aspects.

From the analysis of accident reduction and from the cost-benefit analysis, it can be seen that the clear advantage lies with Mandatory ISA. A strategy has therefore been proposed in which the end goal is mandatory usage in the UK of ISA on vehicles that are fitted. A number of prerequisites are required to reach this goal, and it is possible to associate time frames with each of these prerequisites.

Figure 2 shows the major prerequisites and stages to implementing mandatory ISA. The stages and decision points are:

2000 – 2005	Further research, including larger-scale trials
2005	Decision to move forward towards full implementation
2005 – 2010	Preparation and enactment of standards
2010	Promulgation of standards
2010 – 2013	Preparations for production on new vehicles
2013	Mandatory fitment on new vehicles
2013 – 2019	Voluntary usage
2019	Requirement for mandatory usage

This timing is based on the presumption that all the steps are sequential.. The end date could be brought forward if, for example, standards work is begun before the end of the research phase.

7.2 Target System

Error! Reference source not found. shows that the accident savings from the Fixed Mandatory ISA can be almost doubled if the Variable and Dynamic facilities are incorporated. The full Dynamic Mandatory system is slightly more costly overall than the Fixed Mandatory (0.65% more costly). In terms of public (government) cost, the dynamic variant is significantly more expensive, costing 2.9 times as much as the fixed variant. But the increased benefits would seem to justify such additional expenditure. The long time frames to implementation provide the opportunity to carry out further research on sensors to detect problems, algorithms for altering maximum speed and broadcast technologies for transmitting those speeds into vehicles. New broadcast technologies such as fourth-generation mobile phone (also known as Universal Mobile Telecommunications System) and DAB (Digital Audio Broadcast) are likely to provide the bandwidth and coverage required for reliable transmission of dynamic speed messages. There is every likelihood that, by 2019, much of the supporting infrastructure could be in place. It therefore would seem sensible that, if the decision is made to move towards Mandatory ISA, the goal should be to have the Dynamic capability in operation by 2019.

7.3 European aspects

ISA is at the moment being considered in a number of European countries, so it is sensible to consider whether implementation should be national or European. From a purely *legal* point of view, it may be possible for an individual country such as the UK to move forward with ISA implementation on a purely national basis. But such an approach to implementation would have a number of drawbacks: it would impose extra manufacturing costs for vehicles sold into national

market and would therefore be resisted by vehicle manufacturers; unit costs would be higher because of smaller production runs; the full integration of ISA into vehicle design might not be achieved, making tampering and removal easier; cross-border would not be equipped; vehicles might not be supported when being driven elsewhere in Europe; different systems with different standards might be implemented in various European countries, leading to reduced interoperability across Europe.

There is a clear case, therefore, for the overall specification and standards for ISA to be written at a European level and where appropriate at an UN-ECE level. This does not imply that *usage* needs to be mandated at a European level. There are clear issues of subsidiarity here, which would have to be resolved at a political level if the EU decided to move ahead with mandatory usage. More acceptable to the various Member States would be a staged process in which European standards were agreed for ISA operation, particularly in regard to the architecture for informing the vehicle of the speed limit. Subsequently there could be agreement that there should be mandatory *fitment* if ISA on all new vehicles sold in the EU after a certain date, with each country able to make its own decisions about whether the system should be enabled and, if so, whether and when it should be enabled in advisory, voluntary (Driver Select) or mandatory configuration.

Such an implementation path is very similar to the one used in the past for seatbelts. Cars initially had the capability for seatbelts to be installed, but it was up to the vehicle owner whether or not to install them. Subsequently, fitment became mandatory on new vehicles (and eventually also on older ones). Finally, usage became mandatory.

On this basis, it is sensible to proceed at a European level, with the various standards required to enable ISA. Such standards need not at this stage presuppose that the end target is mandatory usage,

but equally they should not prevent that option from being achievable. The standards work needs to take into account the communications aspects of ISA, as well as the equipment needed on board the vehicle. Within a few years, it is likely that new mobile communications systems will allow a configuration in which there is no physical on-board map: the map would be downloaded into the car as it was driven into the area. This architecture is already being used ins some navigation systems. This would mean that, on the vehicle, there would be little practical difference between Dynamic and Fixed ISA, thus making it more attractive to move directly to the Dynamic system. It would also make the system more tamper-proof.

8. Conclusions

ISA has very large potential to eliminate accidents and reduce the severity of those that do occur. Indeed it can be considered to be the most powerful collision avoidance system currently available, with the promise of saving accidents on all classes of road and in many if not most collision situations. It is clear from the benefits and cost analysis that the economic of the system are considerable, that the benefits considerably outweigh the costs, and that the benefits of any version of ISA will be maximised with 100% fitment. In terms of how "strong" is the operation of an ISA, the mandatory variants provide the greatest savings in accidents and the highest benefit-to-cost ratios. Accident savings and the cost-effectiveness of ISA would be substantially enhanced by incorporating a dynamic element in the system.

There are a number of practical steps that need to taken if ISA is to be implemented, and the sooner that work starts on the standards front, the sooner that the benefits can be realised. Of course, as has

been the case with many other safety measures, there may be initial public antagonism to ISA, but is to be hoped that the safety benefits to be realised will be persuasive.

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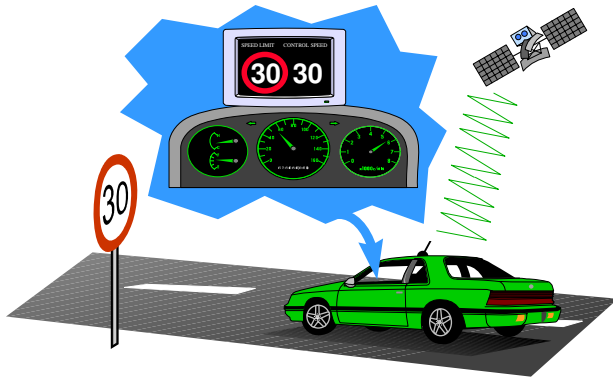
Figure 1: Concept of Autonomous ISA system.

Table 1
Estimates of accident savings by ISA type

System Type	Speed Limit Type	Predicted Injury Accident Reduction		
		Low Estimate	Best Estimate	High Estimate
Advisory	Fixed	2%	10%	21%
	Variable	2%	10%	22%
	Dynamic	3%	13%	27%
Voluntary	Fixed	5%	10%	21% [a]
	Variable	6%	11%	22% [a]
	Dynamic	10%	18%	27% [a]
Mandatory	Fixed	11%	20%	31%
	Variable	12%	22%	33%
	Dynamic	19%	36%	50%

[a]The high estimates for Voluntary ISA have been increased to the levels for Advisory ISA, rather than half the estimate for Mandatory ISA.

Table 2
Best estimates of accident savings by ISA type and by severity

System Type	Speed Limit Type	Best Estimate of Injury Accident Reduction	Best Estimate of Fatal and Serious Accident Reduction	Best Estimate of Fatal Accident Reduction
Advisory	Fixed	10%	14%	18%
	Variable	10%	14%	19%
	Dynamic	13%	18%	24%
Voluntary	Fixed	10%	15%	19%
	Variable	11%	16%	20%
	Dynamic	18%	26%	32%
Mandatory	Fixed	20%	29%	37%
	Variable	22%	31%	39%
	Dynamic	36%	48%	59%

Table 3
Annual (1998) fuel savings from mandatory ISA

	Petrol	Diesel
Fuel Savings (10^6 litres)	2323.26	1484.10
Non-Tax Savings ($£x10^6$)	198.127	116.720

Table 4
ISA system costs (1998£)

System	Year	Fitment Cost per Vehicle 1998£	Establishment Cost 1998£m			Annual Cost 1998£m		
			Fixed	**Variable**	**Dynamic**	**Fixed**	**Variable**	**Dynamic**
Advisory	2000	1464	8.0	12.0	46.0	2.25 +£5/veh	2.25 +£5/veh	4.84 +£5/veh
	2010	293	8.0	12.0	43.0	2.25 +£1/veh	2.25 +£1/veh	4.534 +£1/veh
Intervening	2000	2361	8.0	12.0	46.0	2.25 +£5/veh	2.25 +£5/veh	4.84 +£5/veh
	2010	372	8.0	12.0	43.0	2.25 +£1/veh	2.25 +£1/veh	4.534 +£1/veh

Table 5
Discounted costs of an advisory ISA system 1998£m

Item	Fixed	Variable	Dynamic
Infrastructure (Digital Maps and sensors)	4.87	7.30	26.17
Maintenance (Digital Maps and Sensors)	13.62	13.62	27.44
In-vehicle Equipment (New Vehicles)	3694.15	3694.15	3694.15
Issue of Annual Map Updates	116.71	116.71	116.71
Total	**3829.34**	**3831.78**	**3864.46**

Table 6
Discounted costs of a mandatory ISA system 1998£m

Item	Fixed	Variable	Dynamic
Infrastructure (Digital Maps and sensors)	4.87	7.30	26.17
Maintenance (Digital Maps and sensors)	13.62	13.62	27.44
In-vehicle Equipment (New Vehicles)	5231.02	5231.02	5231.02
Issue of Annual Map Updates	116.71	116.71	116.71
Total	**5366.22**	**5368.65**	**5401.34**

Table 7
Benefit-to-cost ratios for variants of ISA

System	Low GDP Growth[a]			High GDP Growth[b]		
	Fixed	**Variable**	**Dynamic**	**Fixed**	**Variable**	**Dynamic**
Advisory	5.0	5.3	7.0	6.9	7.2	9.6
Driver Select	3.7	4.0	6.1	5.0	5.4	8.3
Mandatory	7.4	8.0	12.2	10.0	10.9	16.7

[a]Annual vehicle kilometres of travel is predicted to increase by 1.8% per annum.

[b]Annual vehicle kilometres of travel is predicted to increase by 2.9% per annum.