Intelligent Speed Assistance: A review of the literature

A report commissioned by the Road Safety Authority (RSA)

Margaret Ryan

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Executive summary

This report was commissioned by the Road Safety Authority of Ireland (RSA) and aims to examine and synthesise current knowledge in the field of Intelligent Speed Assistance (ISA) in motorised vehicles, with an emphasis on the application of ISA technologies in on-road (field) trials. The review focuses on four key themes which emerge consistently in the ISA literature; safety and the impact on driver behaviour, attitudes and acceptance, impact on the environment and ISA implementation.

Road traffic crashes are a major cause of premature death and unnecessary injury globally: Currently over 1.2 million people are killed and 50 million are injured every year (Ando & Mimura, 2015) and this is clearly unacceptable. In 2010 the EU developed an ambitious Road Safety Programme with the aim of halving the overall number of road deaths between 2010 and 2020 (EU Commission, 2010). In parallel, the Irish Government's Road Safety Strategy (2013 – 2020) set a target to reduce RTC fatalities to 25 per million inhabitants (or less) by 2020 in that period. More recently, the EU proposed a new policy framework for 2021 – 2030 which reaffirms the EU's long-term goal of moving close to zero fatalities and serious injuries by 2050 (Vision Zero), with an interim target of reducing casualties by 50% between 2020 and 2030. As part of this strategy the Commission proposed to make vehicle safety and driver assistance features, including Intelligent Speed Assistance mandatory (EU Commission, 2018a).

A vast accumulation of empirical evidence demonstrates conclusively that there is a positive link between speeding and the risk of crash involvement and the severity of crash outcomes. Nevertheless, the use of excessive or inappropriate speed remains prevalent in most driving cultures. Research suggests that the reasons that drivers exceed the speed limit can be broadly classified as instrumental (getting to a destination quicker) and emotional (pleasure, enjoyment, a sense of mastery). Research also suggests that factors such as beliefs and attitudes, social norms, perceived behavioural control and behavioural intentions all influence speeding behaviour and that efforts to reduce speeding should focus on these behavioural precursors. Notwithstanding this, some analysts recommend a more direct approach to tacking speeding and one of the most promising interventions that has been developed in recent years involves the use of Intelligent Speed Assistance (ISA) technology.

Intelligent Speed Assistance (ISA) is the generic term for an in-car Advanced Driver Assistance System (ADAS) that helps drivers to comply with the speed limit. The ISA concept has been developed and tested extensively over the past three decades in many countries. A variety of ISA systems have been developed which can provide information on safe speeds to the driver (*Advisory/Informative* ISA), warn the driver when he/she is exceeding the speed limit (*Supportive* ISA), or control the brakes or throttle to prevent speeding (*Mandatory/Limiting* ISA). Most of the ISA systems that are available currently are based on fixed speed limits. However, there is a growing trend towards the development and testing of more dynamic ISA systems.

Road Safety and Impact on Driver Behaviour

The safety effects of ISA technologies depend on the type of ISA system used, the type of road environment and the penetration level of ISA equipment in the vehicle fleet (OECD/ECTM, 2006). Outcomes from a wide range of field trials conducted in Europe, North America and Australia are reported in this review. However, none of the studies were sufficiently large to provide empirical evidence demonstrating a reduction in crashes as a result of using ISA. Indeed, it is likely that the true effects of ISA will only emerge when a larger percentage of vehicles equipped with ISA are being used.

However, data models which map the relationship between speed and crash risk have been used to assess the likely effects of ISA on road safety. Research outcomes using this approach indicate that substantial reductions in fatalities and serious injuries could be achieved following the introduction of *Mandatory* ISA, with lesser, but still significant reductions expected where *Advisory* and/or *Supportive* systems are used widely. Some individual differences have been reported with respect to drivers' reactions to ISA technology; for example, it seems that younger drivers were less likely to be influenced by *Advisory* ISA systems and were more likely to turn the device off at times. Also, an emerging trend suggests that male drivers, especially young males, tend to have a more negative attitude towards ISA systems than their female counterparts. Nevertheless, a clear consensus emerged from the studies reviewed here which clearly demonstrates the safety potential of ISA technologies in terms of reducing speed and speeding and thereby reducing crash risk.

Some negative aspects of the various ISA technologies were reported in many studies. These include direct effects such as driver distraction, and indirect effects such as behavioural adaptation. Any activity that distracts the driver, or competes for his/her attention while driving, can potentially degrade driving performance and thus have serious consequences for road safety. Thus, careful consideration is needed when deciding on the nature and positioning of in-vehicle warnings and displays. Behavioural adaptation constitutes an unintended consequence following the introduction of innovations such as ISA technologies. It is acknowledged that whereas this phenomenon does not occur consistently, where it does occur, it tends to reduce the size of the expected effects of an intervention, rather than eliminate them altogether. Some negative behavioural adaptations were reported in studies that feature in this review including; frustration, driving faster on road segments where ISA was inactive, using shorter headway and gaps, overreliance on the ISA system, a tendency for non-ISA users to intimidate ISA users, and decreasing impact of *Voluntary* ISA systems on driving speed over time. Some researchers suggest that drivers will come to appreciate the benefits of ISA over time, but others believe that ISA may become less effective over time.

User Attitude and Acceptance

When it comes to the introduction of different in-car systems, public acceptance is hugely important. Without popular support, ISA will not be adopted widely, and it is highly unlikely that any government would decide to mandate ISA without strong support. Attitudinal research featured prominently in many of the studies reviewed. In general, the findings indicate that the majority of drivers tested were in favour of ISA, but that support tended to vary according to the type of ISA system, the type of road environment and the type of driver. Acceptance levels were highest for *Advisory/Informative* ISA systems but tended to decrease as the level of intrusion and control increased and invariably, the most effective form of ISA, *Mandatory* speed limiting, proved least popular with users. Thus, it appears that support was inversely related to the amount of control that the system exerted over driving speed choice; the more controlling the system, the less the drivers favoured it. In general, drivers who participated in ISA field trials were more positive about these technologies than the average driver. Acceptance of ISA differed for different road types, the associated speed limits and driving speeds. Greater acceptance was seen for urban roads with 30km/h and 50km/h speed limits. Research outcomes also suggested that those who would most benefit from ISA (e. g. young, male and/or inexperienced drivers), are least willing to use it. This highlights the risk of self-selection bias if ISA is introduced on a voluntary basis.

Environmental Impact

Speed management strategies are consistent with other important EU and domestic policy goals related to the environment. These include reducing CO_2 emissions, air pollution, and congestion. Currently, transport is the only sector where greenhouse gas emissions have grown consistently over the past two decades. Both fuel consumption and carbon dioxide emissions depend on a vehicle's travelling speed, thus reducing speed and enforcing speed limits is seen as one of the most effective, equitable and potentially popular means to achieving a lower carbon economy (ESTC, 2008). A number of key studies in this review addressed the potential environmental impact of ISA technologies. The results indicate that the introduction of *Mandatory* ISA would result in fuel savings ranging from 1% to 11%.

Travelling time impacts on fuel usage and traffic congestion. One large scale UK study included in this review showed that ISA use resulted in an increase of approximately 4.4% in travel time across the day on national, regional and local roads but no increase on motorways. However, other studies showed that ISA helped to improve traffic flow, which should reduce average travelling times and also traffic congestion. A number of studies also indicated that fitting cars with ISA systems would contribute greatly towards reducing CO_2 emissions in relation to private and commercial motoring activities. Overall, the evidence reviewed suggests that the introduction of ISA would result in reductions in fuel consumption and emissions.

Implementation

Globally, the use of ISA as part of an overall speed management strategy has widespread support among network and safety institutes, government bodies and those who have a stake in this issue. Studies including the EU-funded PROSPER project showed that stakeholders including politicians, governmental institutes, research institutes, pressure groups and commercial groups regarded ISA as an effective safety measure.

Although ISA technology has been available for some time, and reducing crash risk has been high on the political agenda in Europe, little progress has been made with implementing ISA. Although initial estimates suggested that the date when *Mandatory* ISA is fitted and used in the whole of the European fleet would be around 2035, clearly such targets cannot be met in the absence of strong political backing for ISA. According to RoSPA (2016) two general scenarios are envisaged for implementing ISA; Authority Driven and Market Driven. In an authority driven scenario, adoption of ISA would be encouraged initially and eventually required. In this scenario bodies that could enable quicker up-take of ISA would play a more proactive role, mainly through financial incentives or legal punishment. In a market driven scenario, users choose to have ISA because they want it. This scenario emphasises the role of car manufacturers and the subsequent consumer choices made by fleet managers and private car buyers in the proliferation of ISA equipped vehicles on the roads. Euro NCAP has been awarding points for cars equipped with speed management technologies since 2008. The current Euro NCAP protocol (Euro NCAP, 2017) actively promotes the installation of speed assistance systems. To achieve the coveted 5-star rating, cars will almost certainly need to have a speed assistance system fitted as standard. This constitutes an important step in promoting the large-scale deployment of ISA in the future. A number of financial and non-financial incentives have been proposed to encourage drivers to install and use ISA technology. Financial incentives for the installation of ISA can be provided either by reducing installation costs or through continuous discounting. Non-fiscal incentives examined in this review include increasing the number of penalty points for speeding and also increasing the length of time these points remain on a driver's record. Bundling safety features with more attractive features (e.g. entertainment packages) at the point of sale has also been proposed. Driver willingness to pay some, or even all, of the costs involved in equipping their vehicles with ISA was explored in many of the studies reviewed. The findings suggest that willingness to pay tends to depend on the degree of support that the system provides.

Market penetration is an important issue for ISA implementation and the results reported indicate that *Advisory* ISA would predominate if a *Market Driven* approach is taken to the deployment of ISA technologies. In contrast, in an *Authority Driven* scenario, *non- Mandatory* systems would eventually be superseded by *Mandatory* systems by around 2045. Furthermore, it is estimated that the *Authority Driven* scenario would reduce fatal crashes by 30% and serious crashes by 25% whereas the *Market Driven* scenario would reduce fatal crashes by 13% and serious crashes by 8%. Research suggests that overall, 16% of crashes would be prevented in an *Authority Driven* scenario and 5% of crashes would be prevented under a *Market Driven* scenario.

Implementation of speed control using ISA technologies will require a substantial investment, so comprehensive cost benefit analyses have been undertaken as part of some of the studies reviewed. For safety schemes, a benefit to cost ratio equal to or greater than 3 is generally regarded as a threshold for justifying investment. Since this threshold was consistently exceeded in all the studies examined for this review, it seems that the implementation of ISA on a large-scale is wholly justifiable from a social investment perspective. Furthermore, the more forceful *Authority Driven* scenario seems to represent the best option in financial terms. However, the benefits also depend on the form of ISA used and the rate with which they are adopted.

A number of barriers to ISA implementation have been identified and these have hindered progress in implementing ISA on a wider scale. These include; issues with technical functioning, applicability to the road network, observed benefits to the customer, pricing, liability issues in the event of crashes, violations or malfunctions, user privacy, time needed to renew the vehicle fleet, image of the car industry and the need for additional driver education.

The need for official support for ISA was highlighted in many studies and the EU has acknowledged that it has a clear role to play in creating the favourable conditions for accelerated and coordinated deployment of Intelligent Transport Systems, including ISA. For instance, work is progressing on developing and planning the maintenance of accurate, up-to-date digital speed maps and the harmonisation of speed limits throughout the EU. Nevertheless, considerably more official support will be needed to facilitate the wide-scale introduction of ISA. In this regard, the ETSC (2008) recommended the adoption of European legislation for the compulsory fitting of European cars with *Informative (Advisory)* or *Supportive* ISA systems in the type approval procedures for cars, stating also that the Directive should include technical requirements and an implementation timetable. In 2017, a resolution was passed in the European Parliament that all cars sold in Europe should be fitted with life-saving technologies including ISA. In May 2018, the EU Commission adopted a proposal for a Regulation of the European Parliament and of the Council, suggesting a paradigm shift in standard vehicle safety equipment and this included ISA. The Commission believes that ISA along with other Advanced Driver Assistance technologies not only have the potential to reduce road casualties, but also pave the way for the deployment of Connected and Autonomous Vehicles (CAVs).

Conclusions and Recommendations

The evidence presented in this review demonstrates that ISA technologies are effective in supporting drivers with managing speed. Experts in this field agree that by restricting the vehicle to the posted speed limit, ISA provides one of the most effective strategies for reducing inappropriate speeds, thereby improving road safety (ETSC, 2015). Furthermore, due to rapid advances in the development of low-cost technologies (e.g. GPS and nomadic devices) it is clear that the widespread deployment of ISA to support speed management is entirely feasible. Indeed, from a technical point of view, large-scale implementation of ISA is possible in the short-term. In addition, strong evidence has been presented that indicates that the benefits of implementing ISA greatly outweigh the related costs.

The pace of the uptake of ISA technologies will be dictated by the implementation strategy that is used. The proliferation of ISA would proceed faster in an *Authority Driven* scenario than in a *Market Driven* scenario. *Market Driven* implementation will likely favour the fitment of ISA systems that *Advise* or *Support* drivers, whereas the safer *Mandatory* system could be introduced much faster under an *Authority Driven* scenario.

The roll-out of ISA in Ireland will be contingent on the development and testing of digital speed maps. This process will entail a full review and update of speed limits on national, regional and local roads, possible legislative and regulatory changes, and benchmarking against engineering guidelines and standards. The Department for Transport, Tourism and Sport (DTTAS) are working currently to progress a digital speed database for Ireland as set out in Action 13 in their Speed Limit Review (Department of Transport, Tourism & Sport, 2013).

Successful implementation of ISA depends heavily on driver acceptance of the principle of in-vehicle control generally and on their willingness to install these systems and to use them correctly. Different types of ISA technologies impact differently on driver behaviour and on traffic safety: The more controlling the system, the more effective it is in reducing speed and road safety generally, but the less acceptable it will be to drivers. There is general agreement that the greatest benefits would be derived using *Mandatory* ISA. However, this form of speed control has been shown to be least acceptable to drivers.

More public engagement is required here in Ireland to gauge acceptance of various forms of ISA and to identify the most effective ways to encourage voluntary uptake of ISA by individuals or fleets. For instance, a communication plan should be developed which uses evidence from ISA research trials to explain the benefits of ISA to fleet managers and to the general public. In addition, a survey should be conducted to gauge public opinion generally and qualitative research (e. g. interviews, focus groups) should also be conducted to elicit the viewpoints of key stakeholders so that these can be taken into account when formulating an implementation strategy. Also, since driver willingness to relinquish control over some and eventually all aspects of vehicle functioning will be key to the deployment of Connected and Automated Vehicles (CAVs), and since this review shows that many drivers appear reluctant to relinquish control of speed choice, it seems that more research is needed to identify the instrumental and psychological needs that are fulfilled by driving in general, and speeding in particular for some drivers, and to find ways to address such needs in a safer context.

Currently, much of the focus in terms of in-vehicle technology concerns so-called 'self-driving' cars i.e. vehicles that drive themselves for a large part of the time, vehicles that can drive themselves all of the time within designated areas, and ultimately, fully connected and autonomous vehicles (CAVs). Intelligent Speed Assistance constitutes the first step in the five-step process that is required to develop fully autonomous vehicles. Informed opinion predicts that large scale commercial production of more sophisticated vehicle control technologies will escalate between 2020 and 2025. Analysis conducted by McKinsey & Company (2016) suggests that subject to progress on technical, infrastructure and regulatory challenges, up to 15% of all new vehicles could be fully autonomous by 2030, rising to 80% by 2040. Clearly, however there is still quite a way to go before fully autonomous vehicles designed for commercial and domestic use can be developed, tested, approved, marketed and ultimately proliferate on our roads. The evidence presented in this review shows clearly that ISA technologies that are available currently represent an efficient and effective way of controlling speeding and thus improving road safety **immediately.** Furthermore, these systems are relatively cheap and easy to fit and retrofit. For these reasons, it is recommended that more effort should be invested in promoting and supporting the use of ISA technologies in the short to medium term while we await the widespread proliferation of Connected and Autonomous Vehicles (CAVs).

This approach, when coordinated with existing measures, will undoubtedly help to achieve the targets set out in the Government Road Safety Strategy, 2013 – 2020 in terms of reducing serious injury and deaths on Irish Roads.

Glossary

Term	Definition
Active accelerator	A force feedback mechanism used in some Supportive ISA systems which signals drivers when they are exceeding the speed limit. Also called Haptic Throttle in some studies
ADAS	Advanced Driver Assistance Systems
Advisory ISA (Informative)	System that alerts drivers to changes in the speed limit
Advisory ISA (Warning)	System that warns drivers when they are exceeding the posted speed limit in a given location. Drivers can then decide whether or not to heed the warning and adjust their speed
Authority Driven	Implementation strategy whereby the introduction of ISA is encouraged by legislative or policy changes
AVSAS	Advanced Vehicle Speed Adaptation System
Behavioural Adaptation	Unintended behavioural changes that can occur in response to measures designed to improve road safety
CAVs	Connected and Autonomous Vehicles
CO_2	Carbon Dioxide
Dead throttle	A mechanism used in some Mandatory ISA systems which modifies the fuel supply to the engine in order to prevent speeding
ECTM	European Council of Transport Ministers
EPA	Environmental Protection Agency
EU	European Union
EVSC	External Vehicle Speed Control
GHG	Green House Gasses
GPS	Global Positioning System
Haptic throttle	See Active Accelerator
HGV	Heavy Goods Vehicle
Incentive ISA	A variant of ISA technology that records speeding violations and the resulting data is used to reward or punish drivers for their speed-related behaviour
IRTAD	International Road Traffic and Accident Database
ISA	Intelligent Speed Assistance
Km	Kilometres
Km/h	Kilometres per hour
LAVIA	Limiteur s'Adaptant à la VItesse Autorisée – a Large-scale French ISA project
Mandatory ISA	A variant of ISA which limits the maximum speed of a vehicle automatically to the speed limit in force at any given location
Market Driven	An implementation scenario where the market sets the pace for the introduction of ISA
MASTER	Managing Speed of Traffic on European Roads
Mph	Miles per hour

Term	Definition
NHTSA	National Highway Traffic Safety Administration
Nomadic device	A portable communication or information device that can be brought inside the vehicle to support the driving task and/or the transport operation (e.g. a mobile phone)
NOx	Nitrous Oxide
PAYS	Pay-as-you-speed
PDA	Proportion of distance driven above the speed limit
Penalty Points	Legal punishment for driving offences which are recorded cumulatively on a driver's licence
OECD	Organization for Economic Cooperation and Development
Percentile speed	Speed below which n-percent of drivers were observed to travel e.g. the 85th percentile speed represents the speed below which 85% of traffic is travelling
PROSPER	Project for Research on Speed Adaptation Policies on European roads
ROI	Republic of Ireland
RSA	Road Safety Authority
RTA-NSW	Large ISA field trial conducted in New South Wales
RTC	Road Traffic Crash
Supportive ISA	A variant of ISA technology which supports speed limit compliance by providing haptic feedback using active accelerator
SNRA	Swedish National Road Administration (Vägverket)
TAC	Transport Accident Commission (Australia)
TPB	Theory of Planned Behaviour
UN	United Nations
Url	Uniform Resource Locator which is a reference (an address) to a resource on the Internet
Voluntary ISA	A form of ISA technology that drivers could choose to switch to activate or deactivate
US	United States
WHO	World Health Organisation

1 AIM & METHODOLOGY

The aim of this review was to examine and synthesise current knowledge in the field of Intelligent Speed Assistance (ISA), focussing predominantly on the application of ISA technologies in on-road (field) trials. Although the available information and knowledge covers a wide variety of ISA-related topics, this review focuses on four key themes which emerge consistently in relation to this topic. These themes are; safety (including the impact on driver behaviour), road user attitudes and acceptance, impact on the environment and implementation. A number of review objectives were developed, using these categories (Table 1).

Table 1 Key review objectives

Ref.	Review Objectives

	Impact on safety and driver behaviour
	
	• Crashes
	• Changes in speed and speeding
	• Following behaviour/Gap acceptance
	• Interactions with other road users
	• Individual difference effects
	  ○ Males/females;
	  ○ Younger/older;
	  ○ Habitual speeders/non-speeders
	• Potential negative impacts

	User attitudes and acceptance • Acceptability • Attitudes
	Impact on the Environment • Travel Time • Fuel savings • Emissions
	Implementation • Implementation scenarios • Cost and benefits • Barriers to implementation • Policy implications

This synthesis does not try to produce an exhaustive account of all ISA research conducted to date but focuses instead on providing in-depth coverage of the lessons learned (as reported by researchers) from key studies.

The information used for this review was gathered through general internet searches and also specific searches on websites and electronic databases. Initial searches were based on the following terms "Intelligent speed adaptation OR assistance; on-road field trials". A number of key individuals and organisations were also contacted directly for information on current developments in the field of ISA. A full list of the websites accessed, and the people and organisations contacted is provided in Appendix A.

The data gathering exercise yielded 197 papers, including literature reviews, observational studies, surveys and intervention studies. Results of some relevant ISA studies could not be accessed directly, and a small number were not translated into English. Where possible, reliable secondary sources were used to fill in these gaps.

1.1 Information management

The following set of databases were set up to facilitate information management;

1.1.1 Literature review database (Endnote)

An Endnote database was compiled which contained details of papers and reports identified as part of the information gathering process, including;

- ID number
- Reference (author, year, name and source)
- File name
- Study abstract
- URL (where applicable)

1.1.2 A summary table of on-road trials

This table was based initially on work done at Monash University (see Young & Regan, 2002). This table was expanded as part of this review and the updated version which is presented as Appendix B includes information in the following categories;

- Location
- Authors
- Study name
- Study type
- Road types
- Study duration
- Drivers/vehicles
- Interventions: ISA functionality
- Mechanisms: Measures investigated
- Outcomes

- Safety Benefits
- Negative aspects
- Acceptability

2 BACKGROUND AND CONTEXT

Intelligent Speed Assistance technologies are designed to improve speed management and thereby to improve road safety.

2.1 Current trends in road safety

Road traffic crashes (RTCs) constitute a modern-day ‘epidemic’ with over 1.35 million people killed and 50 million people injured globally each year (WHO, 2018). It is estimated that this level of impact imposes financial costs of between 1 and 3 percent of GDP in most countries (IRTAD, 2015). However, the full impact of this level of trauma on individuals, families, communities and society is generally impossible to quantify. The World Health Organization has also predicted that deaths resulting from RTCs will represent the fifth leading cause of death by 2030 unless urgent action is taken (WHO, 2015).

The United Nations (UN) launched the Decade of Action for Road Safety in 2011, with the objective of stabilising and reducing RTC fatalities by increasing road safety activities conducted at national, regional and global levels. Member states were encouraged to ensure that national action plans were developed organised around the five pillars of the “Safe System” approach which are shown in Figure 1.

Figure 1. Five pillars of road safety.

Road safety is also seen as a major societal issue in Europe: in 2010 the EU Commission adopted an ambitious Road Safety Programme which aims to half the overall number of road deaths between 2010 and 2020 (EU Commission, 2010). Records show that there were 25,300 deaths and no fewer than 135,000 injuries on EU roads 2017 with an estimated socio-economic cost of €120 billion in that year alone (European Commission, 2018a). Although the number of road deaths fell by 20% from 2010 to 2017, it is clear that it will be difficult to reach the ambitious target set out in the current Road Safety Programme. Nevertheless, the EU have now proposed a new policy framework for 2021 – 2030 which reaffirms the EU’s long-term goal of moving close to zero fatalities and serious injuries by 2050 (Vision Zero), with an interim target of minus 50% between 2020 and 2030. As part of this strategy the Commission proposes to make vehicle safety and driver assistance features, including Intelligent Speed Assistance mandatory on vehicles (EU Commission, 2018a).

The Irish Government also set out a Road Safety Strategy (2013 – 2020) including the following targets;

- A target to reduce RTC fatalities to 25 per million inhabitants or less by 2020
- Specific targets for reducing speed and increasing restraint use (EU Commission, 2016).

In recent years, there has been a general downward trend in RTC-related fatalities in Ireland, with the numbers decreasing from 472 in 1997 to 156 in 2017[1]. This constitutes a three-fold decrease in this 20-year period. In order to meet the target of 25 per million population (i.e. 124 deaths per year by 2020), a further 21% reduction in fatalities is required by the end of 2020.

2.2 Risk-increasing factors

It is widely-acknowledged that three types of factors; human factors, environmental factors and vehicle factors give rise to increased risk of RTCs (Haddon, 1968). Furthermore, research shows consistently that human behaviour, in the form of driving errors and/or violations are major causal factors in upwards of 90% of all RTCs. For instance, human behaviour was cited as a causal factor in 92% of fatal RTCs in Ireland in 2009 (RSA, 2010). Such findings indicate that efforts to reduce RTCs need to be focussed on improving road user behaviour.

2.3 The problem of speed

Speeding, which encompasses excessive speed (driving about the speed limit) and/or inappropriate speed (driving too fast for the prevailing conditions) is inherently dangerous (Fuller et al., 2008). A wealth of scientific evidence confirms that speeding is a major risk factor in RTCs. It is generally accepted that speeding is a causal factor in approximately one third of fatal RTCs (OECD/ECTM, 2006). This relationship was famously modelled by Nilsson (2004), who showed that the risk of crashing increases exponentially as speed increases, to the extent that we can reliably predict that a 1% increase in speed will result in a 3% increase in fatal RTCs and a 5% to 6% increase in serious and fatal injury crashes (for details see Aarts & Van Schagen, 2006; Elvik, Høye, Vaa, & Sørensen, 2009; Nilsson, 2004). Research conducted in Australia by Kloeden and his colleagues further clarified the relationship between speed and crash likelihood (Kloeden, McLean, & Glonek, 2002; Kloeden, McLean, Moore, & Ponte, 1997; Kloeden, Ponte, & McLean, 2001). Their research focused on quantifying the risk of being involved in a casualty crash relative to travelling at the average traffic speed (i.e. 60 km/h in a 60 km/h speed limit zone on urban roads and between 80-120 km/h on rural roads). The main findings, shown in Figure 2, demonstrate clearly that travelling at speeds slower than the average speed did not increase the risk of involvement in a casualty crash. However, once the speed limit of 60 km/h was exceeded on urban roads, the risk of being involved in a casualty crash increased exponentially i.e., the risk doubled (approximately) with each 5 km/h increase in travelling speed. Based on this analysis, it was estimated that if none of the vehicles in the study had exceeded the 60 km/h speed limit on urban roads, then 50% of the crashes in the 65 km/h zone might have been avoided (or been reduced from a casualty crash to one not requiring an ambulance), increasing to 98% of the 85 km/h crashes and almost all of the crashes where vehicles were travelling above 87 km/h. It was further estimated that on rural roads, a reduction in speed of 5 km/h would result in a 30.5% reduction in casualty crashes, increasing to 46.5% and 59.6% where speed is reduced by 10 km/h and 20 km/h respectively.

[1] Please note, this is a provisional figure, and may be subject to change.

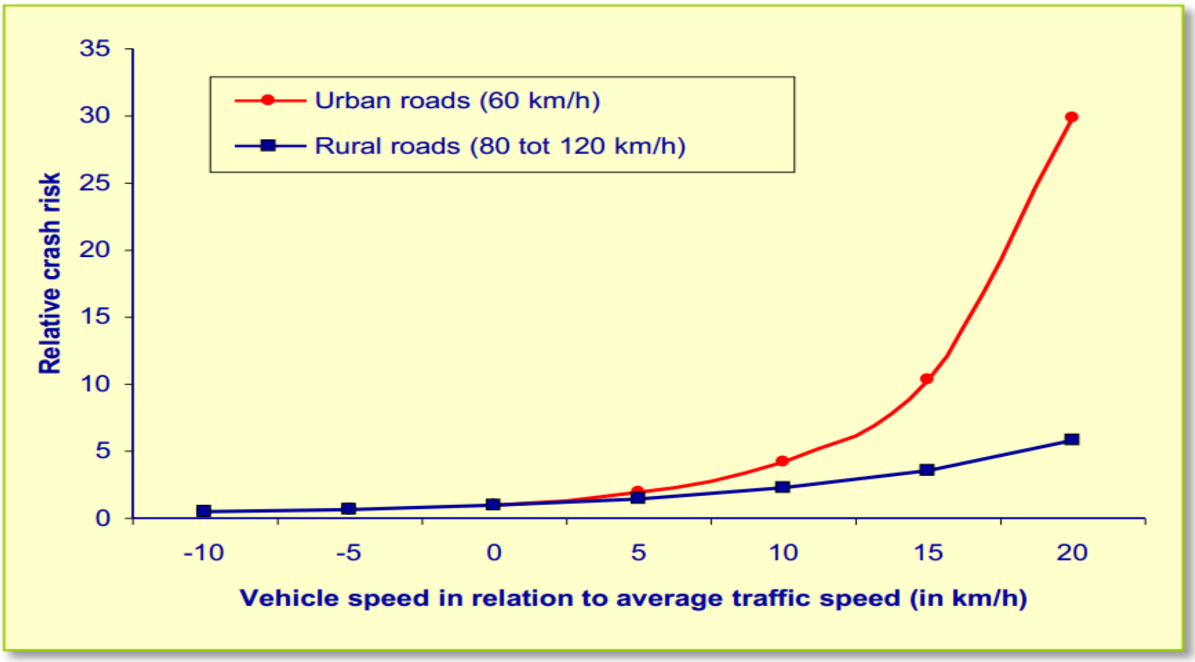

Figure 2. The relative risk of involvement in a casualty crash on urban roads (Kloeden et al., 2002) and rural roads (Kloeden et al., 1997; 2001) for vehicles driving faster or slower than the average speed on that road (=0 km/h deviation). (Source SWOV (2015)).

2.3.1 Speed Limit Compliance

Despite the evident risk, and irrespective of efforts to encourage speed limit compliance by means of improved engineering, enforcement and education, speeding remains a ubiquitous feature in most driving cultures (OECD-ECTM, 2010; OECD - ECMT, 2006a; RSA, 2011; United Nations Road Safety Collaboration, 2011). For instance, the OECD estimated that 50% of individuals who are driving in OECD member countries are exceeding legal speed limits at any given moment, albeit that most of these drivers were exceeding the limit by just a few km/h. The OECD also reported that speeding constitutes the biggest road safety problem in many regions, contributing to approximately one third of fatal crashes, while simultaneously constituting an aggravating factor in all crashes (OECD/ECTM, 2006).

Similarly, speeding represents a significant challenge when it comes to improving safety on Irish roads. An in-depth analysis of fatal collisions that occurred in Ireland from 2008 to 2012 showed that excessive speed for the road and conditions was the main contributory factor in one in three fatal collisions during that period (RSA, 2016). Observational research conducted periodically by the RSA “The Free Speed Survey” provides some insight into the nature of speeding in Ireland. Free speeds represent speeds at which drivers choose to travel when unconstrained by environmental factors. Of the 17,591 vehicles observed in 2016, more than half (57%) of car drivers were observed exceeding the posted speed limit on urban roads and more than one in five drivers were recorded exceeding the speed limits on rural roads (22%), motorways (21%) and dual carriageways (28%). Speeding was even more prevalent among professional drivers. On urban roads, 55% of rigid and articulated truck drivers and 38% of single deck bus drivers were speeding. Significant levels of speeding were also recorded on rural roads, where over 1 in 3 rigid truck (36%) and articulated truck (38%) and 11% of single deck busses were observed speeding. These findings show clearly that speeding is a widespread problem in Ireland and for that reason, speeding has been identified as a key target in the Irish Government's Road Safety Strategy 2013 – 2020 (RSA, 2013).

2.3.2 Characteristics of drivers who tend to speed

The National Highway Traffic Safety Administration (NHTSA) (2003) reported results of a survey that they conducted to define the nature and scope of speeding in the US. This showed that whereas a majority of drivers of all ages admitted to speeding, compared to older drivers, younger drivers reported more speeding on a monthly basis, with eight in ten admitting to speeding on all types of roads. Males were 50% more likely to report driving over the posted speed limit than females. Similarly, a national survey of drivers in the Republic of Ireland found that drivers under the age of 25 were more risky in terms of rule violations and speeding behaviours than those over 25 (Sarma, Carey, Kervick, Bimpeh (2013).

2.3.3 Speed choice: Why drivers exceed the speed limit

At a societal level, speed is generally perceived as an asset. In the transport sector, technological advances have made it possible to travel faster by car, train and aircraft, thus significantly decreasing travel time and supporting efficiency and greater mobility.

In principle, increased driving speeds result in a reduction in travel times. However, the perceived gains of time, particularly on short journeys, is much larger than the actual (objective) gain in time, which in reality is merely marginal (see Table 2). This is poorly understood by drivers and motorcyclists. In addition, higher speeds result in more crashes, which in turn lead to traffic congestion (SafetyNet, 2009).

Table 2 Extra time taken for a 10 km journey when speed is reduced by 5 km/h (Source: ETSC (1995))

Original speed	50 km/h	70 km/h	90 km/h	110 km/h	130 km/h
Extra time taken (minutes)	1.33	0.66	0.39	0.26	0.18

In terms of individual drivers, speed can also represent a source of pleasure for some, providing a sense of freedom and excitement (OECD/ECTM, 2006). Delhomme and Cauzard characterised speeding as 'an ambivalent dimension', because, besides being an indicator of pleasure, sensation and driving ability, it is also a source of risk to drivers (2000; as cited in Delhomme, Verlhiac, & Martha, 2009). For instance, the results from the EU SARTRE 3 study (2004) showed that more than 80% of European drivers believed that driving too fast is 'often', 'very often' or 'always' a contributory factor in RTCs. Nevertheless, the available evidence shows clearly that many drivers persist in exceeding the posted speed limits. Many do so out of choice often for instrumental reasons (e.g. getting to a destination quicker) or for emotional reasons (e.g. pleasure, enjoyment and/or a sense of freedom).

2.3.4 Theoretical perspective on speeding: The Theory of Planned Behaviour

Several theories have been used in an attempt to explain the psychological basis of speeding, most notably Ajzen's Theory of Planned Behaviour (TPB; Ajzen, 1991). The TPB focuses on rational decision making and models the relationship between a range of behavioural determinants including behavioural beliefs (attitudes), normative beliefs and control beliefs and behavioural intentions. Behavioural beliefs represent subjective estimates of the likely consequences of a particular behaviour, which in turn give rise to an attitude towards that behaviour. Normative beliefs describe the normative expectations of others, which give rise to perceptions of social pressure, which are described in terms of a subjective norm. Control beliefs are derived following an evaluation of factors that may make the performance of the behaviour either more or less likely and measurements on this scale describe perceived behavioural control (Francis et al., 2009). These three determinants operate in tandem to form a behavioural intention, the strength of which is dictated by variations in attitude and subjective norm, combined with perceptions of control. A review of 185 TPB studies conducted by Armitage and Connor (2001) found that attitudes, subjective norms and perceived behavioural control accounted for 39% of the variation in intentions and that intentions accounted for 31% of variation in actual behaviour.

Compelling evidence has been produced that demonstrates the relationship between TPB variables and drivers' intention to speed. Early studies conducted by Diane Parker and her colleagues (Parker, 1997; Parker, Manstead, Stradling, & Reason, 1992) found that attitudes, subjective norms and perceived behavioural control together accounted for 47% of the variance in intentions to speed. Furthermore, these three variables accounted for between 47% and 56% of the variance in intentions to exceed the speed limit in 30mph, 40mph and 60mph speed zones.

An analysis conducted by Brown and Cotton (2003) further highlighted the importance of TPB components in relation to speeding as follows;

Beliefs and attitudes: Speeders (compared to non-speeders) believed that speeding was less likely to result in negative outcomes, particularly when they themselves were speeding Stradling (1999). Speeders believe that they get to their destination quicker and that speeding makes the journey more pleasant (Parker, Manstead, Stradling, Reason, & Baxter, 1992; SARTRE 4, 2011; Wallén Warner & Aberg, 2008).
Social norms: In comparison with drink-driving, speeding entails less stigma and may be viewed as a normative behaviour engaged in by the majority of drivers (Stradling, 1999).
Perceived behavioural control: Many speeders have an illusory sense of control over their driving. For instance, drivers speeding in urban areas believed that they are better adjusted to speed of other drivers (Parker, Manstead, Stradling, & Reason, 1992).

2.3.5 Improving speed limit compliance – speed management

Many strategies are adopted to improve speed limit compliance (see Elvik et al., 2009 for a comprehensive review), including;

- Infrastructural interventions (e.g. roundabouts, speed bumps)
- Legislative measures (e.g. reduced speed limits, higher fines for speeding violations)
- Stricter enforcement of existing legislation (e.g. more speed cameras)
- Educational initiatives (e.g. public awareness campaigns, education programmes for learner and novice drivers, schools and in the community generally)

Furthermore, when the OECD asked leading road safety practitioners to identify key measures to reduce speeding (see OECD - International Transport Forum, 2008) they recommended;

- Enforcement of existing speed limits can provide immediate safety benefits, and do so more quickly than any other single safety measure
- Ensuring that speed limits are appropriate for the prevailing environmental conditions
- Mobilisation of public support for reduced speed limits

Clearly, none of these measures can be applied everywhere and at all times. Therefore, it is not realistic to expect conventional anti-speeding measures to ever be applied to such an extent that compliance with speed limits approaches 100% (Vaa, Assum, & Elvik, 2014).

2.4 Intelligent Speed Adaptation/Assistance (ISA)

Intelligent Speed Assistance (ISA) is the generic name for an in-car Advanced Driver Assistance System (ADAS) that helps drivers to comply with the speed limit (European Commission, 2016). The ISA concept has been developed and tested extensively over the past three decades in many countries. It is important to note however, that none of the studies selected for inclusion in this review were sufficiently large to provide empirical evidence demonstrating a reduction in crashes as a result of using ISA.

2.4.1 Core elements of ISA systems

ISA systems require four basic elements (see Figure 3).

1. A speed limit database to provide detailed information on the speed limit in force in each section of the road. Since local or national authorities are responsible for determining speed limits, it follows that they should also play a major role in the development of such databases.
2. The means to determine the position and direction of travel of a vehicle which is usually achieved using GPS technology. However, more advanced so called ‘dynamic’ ISA systems can also use information from vehicle sensors or roadside information systems.
3. Actual speed is measured by the vehicle’s own speed measurement system.
4. Determination of the relationship between the appropriate speed and the actual speed. This dictates how, when and in what way the ISA system is activated.

Figure 3. The ISA concept (Source: Vlassenroot et al., 2004).

Elements 2-4 are generally developed by those who manufacture the equipment, so, it is likely that multiple diverse systems will be developed and evolve unless standardised requirements are mandated by appropriate standard-setting bodies.

2.4.2 Technology options for ISA

Different types of ISA systems have been developed, which provide different levels of support and feedback to drivers. These fall into three general categories, *Advisory*, *Supportive* and *Mandatory* ISA systems, as outlined in Table 3. *Advisory* systems provide drivers with information about speed limits, *Supportive* systems warn the driver if he/she is exceeding the speed limit in a given location. *Mandatory/Limiting* devices make it impossible for the driver to exceed the posted speed limit.

Table 3 Overview of different types of ISA (Adapted from Morsink et al. (2006))

Level of support	Type of feedback	Definition
Advisory/Informative	Mainly visual	The speed limit is displayed, and the driver is alerted to changes in the speed limit
Advisory/Warning (open)	Visual/auditory	The system warns the driver if he/she is exceeding the posted speed limit at a given location. The driver then decides whether to use or ignore this information to adjust his/her speed
Supportive/Intervening (half-open)	Haptic throttle/Active accelerator (moderate/low force feedback)	The driver receives force feedback via the accelerator if he/she tries to exceed the speed limit. By applying sufficient force, drivers can still exceed the speed limit
Mandatory Limiting/ Automatic control (closed)	Haptic throttle (strong force feedback) & Dead throttle	The maximum speed of the vehicle is automatically limited to the speed limit in force. Drivers' requests for a speed beyond the speed limit are simply ignored

A further variant of *Advisory* ISA, *Incentive* ISA, has been developed which records speeding violations and the logged data is used subsequently to reward or punish drivers for their speed-related behaviour.

ISA systems can use speed limits in various ways (see Carsten & Tate, 2005);

- Static speed limits – The driver is informed of posted speed limits.
- Variable speed limits – The driver is additionally informed about lower speed limits at specific locations (e.g. road construction sites, pedestrian crossings, sharp curves etc.), thus the speed limit information is dependent on location.

- Dynamic speed limits – This system uses speed limits that account for the actual road and traffic conditions (weather, traffic density). Thus, in addition to depending on location, the dynamic speed limits are also dependent on time.

Most of the ISA systems that are available currently are based on fixed speed limits. In some cases, they may also include location-dependent (*Advisory*) speed limits. However, there is a growing trend towards the development and testing of dynamic ISA systems (European Road Safety Observatory, 2016).

3 ISA FIELD TRIALS

Research on Intelligent Speed Assistance (ISA) technologies began in 1982 when French researchers, Saad and Malaterre, tested an in-vehicle speed limiter. Drivers using this system set the desired maximum speed, which could not be exceeded unless the driver actively disengaged it. The results showed that drivers generally set the maximum speed limit significantly higher than the legal speed limit. Drivers also reported that the system was too effective and thus limited their freedom to manoeuvre (Saad & Malaterre, 1982).

The systematic investigation of ISA systems began in earnest in the early 1990s in Sweden (Almqvist & Nygård, 1997; Persson, Towliat, Almqvist, Risser, & Magdeburg, 1993). Subsequently, from the late 1990s to the mid-2000s there was a continual stream of research in various European countries including Sweden (Swedish National Road Administration (Vägverket), 2002), the UK (Carsten & Tate, 2000), the Netherlands (Duynstee & Martens, 2001), Denmark (Lahrmann, Agerholm, Tradisauskas, Berthelsen, & Harms, 2012), France (Driscoll, Page, Lassarre, & Ehrlich, 2007), Belgium (Vlassenroot et al., 2004) as well as EU-funded research projects e.g. MASTER (Varhelyi, 1998) and PROSPER (Cunningham & Sundberg, 2006). Thereafter, large-scale projects such as the "ISA-UK" initiative have progressed knowledge about the effects of ISA (Carsten, Fowkes, et al., 2008). A number of ISA trials have also been conducted in Australia (see Barnes et al., 2010; M. A. Regan et al., 2006) and in North America (see Waibl et al., 2013). A list of trials and their key results originally developed by Young & Regan (2002) at Monash University was extended and expanded as part of this current review and appears as Appendix B to this document.

3.1 Sweden

3.1.1 Lund and Eslöv

A series of field trials conducted in the 1990s placed Sweden at the cutting edge of research in ISA, beginning with two small studies, one in Lund and the other in Eslöv. The Lund study involved 75 motorists, who drove a Volvo car for one hour on a test route. The vehicle was equipped with an *Advisory* speed limit display and a *Mandatory* ISA system (active throttle), which limited speed to a maximum of 50 km/h. Upon entering a 50 km/h zone, drivers would feel increased resistance in the accelerator pedal and were unable to increase speed beyond this limit. General speed reductions were recorded during the trial as well as reduced incidences of red light running. However, some speed increases were recorded on approaches and in turnings and driver behaviour worsened during interactions with other road users. Driver acceptance of the ISA systems improved after they tested the system (Persson et al., 1993). A similar ISA system was used in the Eslöv trial, which was also set at a maximum speed of 50 km/h. The outcome of this study was generally encouraging. There was a general reduction in speed and speeding and driver behaviour improved in interactions with other road users. Travel times increased by 5%. Driver attitudes towards ISA improved after they had used the system. Also, participants tended to believe that the speed limiter provided safety benefits and did not perceive it as providing unwelcomed control. Clear differences emerged between participants' speed-related behaviours with and without the speed limiter. Initial measurements revealed that the participants regularly exceeded the speed limit.

However, two months after the installation of the speed limiters, the participants' average speed had decreased and was within the speed limits (Almqvist & Nygård, 1997).

3.1.2 Umeå: Borlänge: Lidköping: and Lund

The earlier trials paved the way for the world's largest ISA trial which was initiated to provide the Swedish government with advice as to which system to select to improve road safety. The study was conducted in four cities: Umeå: Borlänge: Lidköping: and Lund, involved several thousand vehicles and was coordinated by the Swedish National Road Administration (Vägverket) (2002). The objectives of the studies were to increase knowledge about motorists' attitudes towards ISA, assess the potential traffic safety and the environmental costs and benefits of various ISA systems. The project commenced in 1999 and the ISA-equipped vehicles were in operation from August 2000 to December 2001. More than five thousand cars were equipped with *Advisory (Informative)* and *Supportive* systems to help motorists (including over 10,000 private and professional drivers) to comply with the speed limit. The design of the trials varied substantially between the cities. Notably, each city implemented and evaluated different variants of ISA: An *Advisory* ISA (audio and visual warning signal) was tested in Umeå; an *Advisory* ISA with additional display indicating existing speed limit was used in Borlänge; a *Supportive* (active accelerator) ISA system was examined in Lund and a combination of *Informative* and *Supportive* systems was used in Lidköping (Swedish National Road Administration (Vägverket), 2002).

The results of this study showed that there was a clear reduction in average speed, speed variations and lower speeds approaching intersections. Table 4 provides an overview of the reductions in average speeds in Lund and in Borlänge at the end of the trial (post period 1) and then again one month later (post period 2).

Table 4 Average driving speed changes in Lund and Borlänge for one pre-ISA and two post-ISA periods (Adapted from Swedish National Road Administration (Vägverket) (2002))

Driving speeds	Speed (km/h)		
	Pre-activation period	Difference, post period 1	Difference, post period 2
Lund (Supportive - Active accelerator)			
30km/h	21.9	-0.8	-0.2
50km/h	36.4	-1.1	-1.2
70/km/h	58.7	-2.0	-2.0
Borlänge (Advisory – informative)			
30km/h	25.3	-0.6	-0.6

Driving speeds	Speed (km/h)		
	Pre-activation period	Difference, post period 1	Difference, post period 2
50km/h	38.7	-1.5	-1.5
70/km/h	58.7	-2.8	-3.0
Driving speeds	Speed (km/h)		
	Pre-activation period	Difference, post period 1	Difference, post period 2
90km/h	84.4	-2.5	-3.4
110km/h	97.3	-1.1	n.a.

In post period 1, the lowest reductions were recorded in 30-50km/h zones and the highest reductions occurred in 70km/h zones. Overall, the effect shown here is clear but small. However, it should be noted that speeds in the pre-activation period were already well under the legal speed limits. Also, there is a clear trend evidencing the diminishing effects of ISA on driving speeds over time. Somewhat surprisingly, the speed reduction with the *Advisory* system was greater than that achieved with the *Supportive* system, however this difference only amounted to 0.3-0.4km/h in 30-50km/h zones which were the main focus of the trial. This was likely due to the fact that users found the audio warning irritating and often attempted to override it. Speed variation was reduced by 40% on 70km/h roads and approaches at 50km/h. Variation in general speeds on 30 and 50km/h roads was reduced by between 30-35%. The reduction in speed variation was significantly lower in Borlänge compared to the active accelerator test in Lund. Journey times were unaffected due to the fact that there were less stopping and fewer braking situations with ISA.

Approximately 10% of the trial vehicles were public or commercial transport vehicles and professional drivers and those driving company cars generally held more negative attitudes towards ISA. Acceptance in this group was low: Compared to private motorists, professional drivers graded the usefulness of ISA as somewhat lower and its attractiveness as much lower. Warning ISA was seen as disturbing, especially when driving with passengers. This lower acceptance might be explained by workplace stress, for instance bus drivers yielded less often at pedestrian crossings, which could be interpreted as an attempt to compensate for lost time due to slower speeds elsewhere. However, sufficient evidence was not found to support a definite conclusion on this. Most of the professional drivers (65%) agreed that speed limits should be observed in densely built-up areas, however the remainder believed that the rhythm of traffic often demands higher speeds than the one stipulated. Even so, very few drivers objected to making ISA compulsory for certain groups e.g. school and ordinary busses and vehicles transporting sick and elderly people.

3.1.3 Stockholm

The "ISA for Stockholm" project tested a *Supportive* ISA system, based on active accelerator pedal technology which was installed on 20 vehicles (130 drivers). The trial lasted for 6 months at the end of which, average driving speed decreased especially on roads with higher speed limits and speeding violations were reduced by 30%. Although two-thirds of drivers reported some frustration when using the system, driver acceptance was good e.g. 75% of users wanted to keep the system at the end of the trial. After the trials, the City Council of Stockholm decided to set a target to have ISA in all vehicles driving in the city before 2010 (Transek & SWECO VBB, 2005).

3.1.4 Gothenburg

Trials involving 16 busses that were equipped with *Supportive* (active accelerator) ISA were held in Gothenburg from November 2002 to April 2003. The route used passed through speed zones including 15, 20, 30, 50 and 70km/h and the drive took 42-49 minutes in total. The use of ISA reduced speeding, especially in the lower speed zones, where the proportion of speeding was highest before the trials. There was no perceived increase in travel times using the system. Some drivers reported pain and discomfort in their calves and knees due to the pressure from the active accelerator and this was most acute in the transition from 50-30km/h. Drivers also expressed some negative attitudes towards the system. Whereas 10% said they would feel uncomfortable with this level of 'supervision' at the start of the trials, one-third expressed this attitude at the end of the trial. Just 10-20% of drivers though that in-vehicle technology was a good way of reducing speed. Many suggested external measures (e.g. variable message signs and physical street design) as equally good or even better alternatives. On the positive side, drivers expressed the greatest acceptance for ISA on 30km/h roads and were in favour of using ISA as grounds for changing the existing bus timetable. In contrast to the drivers, many passengers (40%) expressed confidence in new technology in vehicles for preventing speeding. All age groups were predominantly positive about the use of ISA on public transport. No gender differences in attitudes were observed (Transek, 2003).

3.2 The Netherlands

3.2.1 Groningen

Field trials of ISA in the Netherlands began with a study conducted in Groningen (Brookhuis & de Waard, 1999). Twenty-four volunteers drove a vehicle equipped with an *Advisory* ISA system which provided auditory and visual warnings when the speed limit was exceeded by 10%. The route taken included motorways and built-up areas with speed zones of 50, 70, 80, 100, 120km/h. Each trial took approximately 35 minutes to complete. Workload was measured using heart rate monitors and a questionnaire. A 4% decrease in speeding was recorded as a result of using the ISA feedback and this effect was strongest in zones where the drivers tended to violate speed limits regularly (e.g. 50km/h). Significant reductions in speed variability were also recorded. Some slight increases in mental workload were reported in the questionnaires but this was not reflected in the physiological data. Driver acceptance varied according to the type of ISA feedback that was provided. Drivers preferred to receive continuous feedback.

3.2.2 Tilburg

ISA research in the Netherlands began in 1999 with a nationally funded field trial in the city of Tilburg (Duynstee & Martens, 2001). This one-year trial involved 20 cars (120 drivers) and one city bus (20 drivers) which were equipped with a *Mandatory* form of ISA, based on 'active accelerator' technology, which automatically restricted the fuel inlet when the speed limit was exceeded. An 'escape' was installed to allow drivers to override the system in case of emergency. Three speed limits were used; 30, 50 and 80 km/h. The study examined driving behaviour, user ergonomics, user acceptance and public support. Because this was a relatively small-scale trial, it was not possible to demonstrate significant effects of ISA on road safety, emissions and energy consumption.

The data from the trial showed that this *Mandatory* system prevented speed limit violations completely within the trial area. Average speeds decreased significantly (-3% to -8.3%). Table 5 shows the 95th percentile speed differences between ISA and non-ISA driving, with recorded reductions of 6.7, 9.7 and 2.8 km/h in 30, 50 and 80 km/h zones respectively. More homogeneous speed patterns were also achieved. It was also noted that the effect of ISA increased where there were no traffic calming measures.

Table 5 Speed reductions in Tilburg (Adapted from Duynstee & Martens, 2001).

Speed Limit (km/h)	Unrestricted v95 (km/h)	ISA v95 (km/h)	Difference v95 (km/h)
30	44.4	28.9	-6.7
50	57.0	47.3	-9.7
80	77.9	75.1	-2.8

Note: Underlined results were statistically significant at the level $p<0.05$.

The results of a driver survey showed that one quarter of test drivers reported lower speeds within the speed limit, committed fewer other traffic violations and kept more distance from other road users. Half of the test drivers reported hardly any speed compensation outside of the ISA test area. Outside of the test area, some ISA drivers reported irritation from other road users (tailgating) which caused them to feel embarrassed. Contradictory findings were reported regarding the effect of ISA on driver attention: Almost a third of test drivers reported a reduction in attention to the driving task, while an equal number reported an increase in attention.

User acceptance was measured also, and the results showed that whereas the majority of the car drivers experienced ISA-equipped driving as less enjoyable (52%) a larger percentage were in favour of ISA use (64%). The majority of the bus drivers tested experienced the ISA system as more enjoyable (60%) and most of the bus drivers were in favour of ISA use (90%). User support was determined by surveying attitudes towards ISA before and during the trial. Although there was a slight decrease from 'slightly and very positive' to 'neutral' over the course of the trial, the majority of the test drivers continued to support ISA (55%), 19% were 'neutral' and a minority of drivers (16%) had a negative attitude towards ISA by the end of the trial. Public support was assessed by surveying attitudes towards ISA before and during the test. The results showed that the majority of the public held a 'neutral' to 'positive' attitude towards ISA (79%) before the test, which decreased slightly during the test (67%).

In sum, the results from Tilburg trials demonstrated that *Mandatory* ISA had a positive effect on driving behaviour and speed patterns, notwithstanding that interactions with non-ISA drivers sometimes lead to risky manoeuvres (passing and tailgating). Users are generally in favour of ISA, and the majority of the public were either not averse or positive about the speed limiting systems (van Loon & Duynstee, ND).

3.2.3 ISA for serious speed offenders

A field trial was conducted in the Netherlands in 2011 to investigate the potential for using restrictive ISA as a penalty system for serious speed offenders (van der Pas, Kessels, Vlassenroot, & van Wee, 2014). Two forms of ISA were tested; a speed monitoring device (Speedmonitor) and a more restrictive speed limiting system (Speedlock). Fifty-one, known speed offenders drove cars equipped with one of these systems over a total of 650,000kms. Effects on traffic safety were calculated (e.g. Kloeden et al., 1997; Nilsson, 2004). Depending on the type of road, the results predicted reductions in serious injury crashes of between 7-25% for Speedlock and of between 3-33% for Speedmonitor. Speedlock produced an 11-35% reduction in the likelihood of a fatal crash and Speedmonitor produced a 4-47% reduction. Reductions in speed variation were also reported. System users reported that they engaged in less tailgating and reduced abrupt and hard braking, fast acceleration and also that they anticipated more. Some negative behavioural adaptation by other drivers were reported, including increased tailgating and more frequent overtaking.

3.3 Finland

In Finland, on-road ISA trials were conducted in 2001 with 24 drivers, who used *Informing (Advisory)*, *Mandatory* or *Recording* ISA technologies (Päätalo, Peltola, & Kallio, 2002). The former have been defined previously, and the latter consisted of a system that recorded driving speed so that it could be inspected at a later stage. All systems had the effect of reducing the amount of time spent speeding, especially excessive speeding. The *Mandatory* system was most effective in reducing speed producing reductions of 3.4km/h in average speed and 74% in speeding violations. The *Informing* system was also effective, resulting in reductions of 2.8km/h in average speed and a 39% reduction in speeding violations. Smaller reductions were seen with the *Recording* system. User acceptability was inverse to the level of control exerted; the *Recording* system was most popular, followed by the *Informing* system but the *Mandator*y system was found least enjoyable. Drivers approved of the *Informing* system more because they felt that they still had control of their car, although they found the voice alerts annoying. They also felt that the *Recording* system would be most useful in the future, although it should be noted that no actual penalties were applied when drivers exceeded the limit. Mental demand, frustration and insecurity levels was higher when using the *Mandatory* system.

3.4 Denmark

3.4.1 INFATI

A trial involving *Advisory* (audio warning) ISA was conducted in 2001, in Alborg. Twenty-four drivers used this system for four weeks and during that time there was a clear decrease in the

85th percentile for speed violations (- 5% to -6%) in that group. The decrease was larger in rural as opposed to urban areas. Users reported that the feedback provided by the system was accurate. They understood that the concept of freedom in the context of speeding is about ‘freedom to break the law’ and they did not feel that ISA had limited their freedom. Drivers also reported increased awareness of speed and speeding violations and a reduction in mental effort from not having to actively monitor speed limits. However, acceptance was lower in lower speed zones than in higher zones. Drivers became annoyed with the warnings when they were busy and tended to increase speed, despite the warnings, in such situations (FOT-Net Data, 2016).

3.4.2 Pay-as-you-speed

As a result of positive reactions from drivers involved in the earlier INFATI project and in order to simulate a market introduction of ISA, the Pay-as-You-Speed (PAYS) concept was trialled in Jutland from 2007 to 2009. The PAYS concept linked three key factors; ISA technology, driver behaviour and incentives. An *Informative/Recording* ISA system was used to monitor speed-related behaviour and the participants were offered an economic incentive, amounting to a 30% discount on their insurance premium, for driving below the speed limit. When drivers exceeded the speed limits they received penalty points, which in turn reduced the amount of discount awarded. This project was designed initially to study the effects of incentives on younger drivers (under 24-year-olds) to reduce the danger for this high-risk category and also in an effort to instil good speed choice habits. Initially, however, this market-driven approach did not seem appealing to the target group. Apparently, the discount offered was not enough to encourage a sufficient number of young drivers to take part in the trial and so the participant base was widened to cover the broader driving community (Lahrmann, Agerholm, Tradisauskas, Næss, et al., 2012).

The data collected in this trial covered almost 1 million kilometres of driving. Participants used information only, incentive only and a combination of both successively, in a baseline (normal) and three experimental phases. The overall effect of the PAYS systems on driver speed choice across all speed zones, in terms of the proportion of distance travelled at 5km/h or more over the speed limit (PDA), is illustrated in Figure 4. This shows that participants in all of the test groups tended to exceed the speed limits at the start of the trial i.e. before the PAYS systems were operational. Following activation, significant reductions (-3.6% to -8.5%) in speeding were recorded when the *Information* system and the *Incentive* scheme were in force. The reductions seen when all participants were using a combination of *Information* and *Incentive* are quite convincing. These show that the proportion of distance driven above the speed limit (PDA) dropped from 16% to 4% in the first period. The greatest effect was seen on 80km/h roads where a drop of 9% in the PDA was recorded during the first period. However, the PAYS system had no educational effects: Speeding behaviours returned to their previous level when the system was turned off. No statistically significant gender or age effects were found in behavioural responses to the PAYS system. Travel times did not increase when the system was operational (Lahrmann, Agerholm, Tradisauskas, Berthelsen, & Harms, 2012).

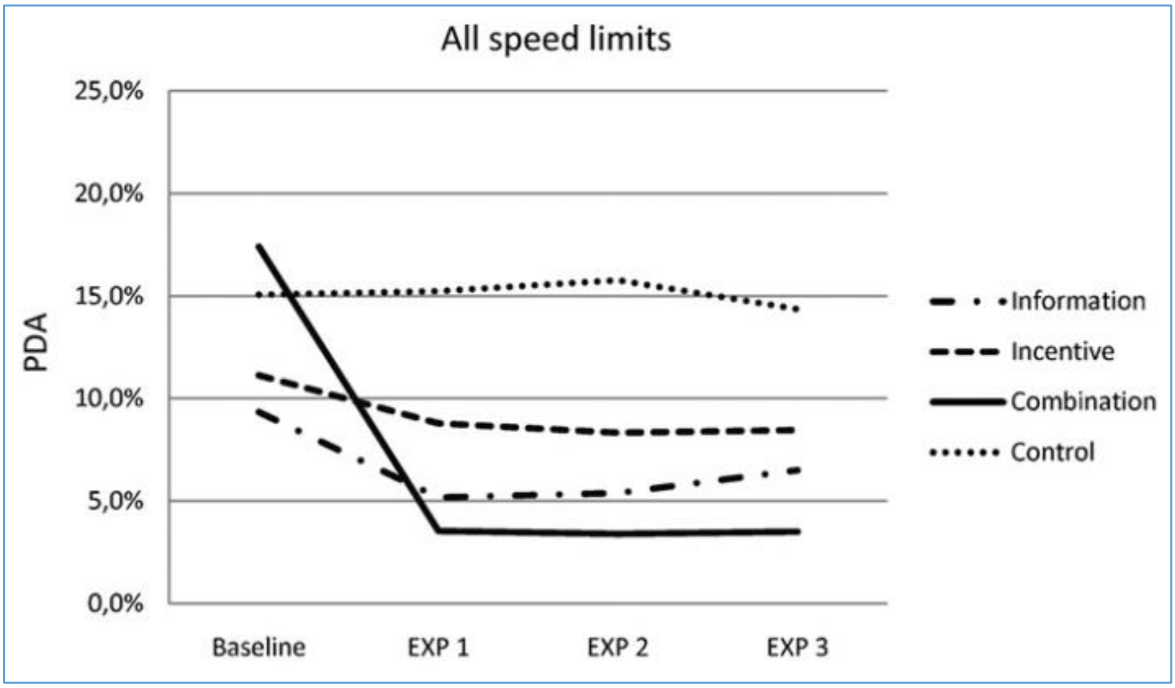

Figure 4. Proportion of distance driven above the speed limit +5km.h (PDA) for each group across all speed zones (Source: Lahrmann et al. (2012)).

3.5 Belgium

3.5.1 Ghent

ISA testing in Belgium began in October 2002 and involved 34 cars and 3 busses which were equipped with a *Supportive* (active accelerator) ISA system. The study assessed the effects of ISA on speed change, traffic safety, driver attitudes, behaviour and acceptance (see Vlassenroot et al., 2004). The results showed that the ISA technology had little impact on average speed, apart from the 90 km/h zone where a reduction of 1.1 km/h was recorded. The effect in 30 km/h zones was minimal and speeding violations were rife. As a result, it was concluded that the counterforce exerted by the pedal wasn't strong enough to discourage drivers from exceeding the speed limit. Indeed, speeding appeared to increase (+0.7km/h on average) during the trial, especially in low speed zones. Large differences between users were recorded. For instance, the distance spent speeding varied between 3% and 50%. The average speed for less frequent speeders tended to increase as drivers accelerated faster to the speed limit and drove exactly at the speed limit rather than below it. Nevertheless, the average speed for most frequent speeders tended to decrease. Half of the drivers said that they found it easier to maintain a constant speed and that they overtook less when using the ISA system. Driver attitude towards speeding was measured before, during and after the trial. Before the trial, 20% of drivers agreed that "driving fast saves time", during the trial this fell to just 5%, but rose again to 10% after the trial. After the trial, private motorists could choose to keep the ISA-system in their cars and 44% chose to do so, which indicates their acceptance of the system (Broekx, Vlassenroot, De Mol, & Int Panis, 2005).

3.6 France

3.6.1 LAVIA

The French LAVIA[2] project commenced in 2001 and involved prototype vehicles supplied by Renault and PSA (10 vehicles each). These cars were equipped with an ISA system that had three active modes; *Advisory*, *Voluntary* and *Mandatory*. The *Advisory* mode informed the drivers of the current speed limit and provided an auditory warning when this limit was exceeded. In *Voluntary* mode, the driver was free to activate and deactivate a speed limiter at will. With the *Mandatory* system, the fuel supply to the engine was restricted until the posted speed limit was reached. Twenty test vehicles, used by 92 households were driven for approximately 130,000km during the trials. There were an equal number of male and female drivers, 31% were under 30-years-old, and 13% were above 50-years-old. Substantial reductions in mean travelling speed were recorded using all three modes; -0.8km/h (-7%)) for the *Advisory* mode, -2km/h (-23%) for the *Mandatory* mode, and -1.4km/h (-13%) for the *Voluntary* limiting mode. The highest reductions in speeding were recorded on inter-urban and motorway networks. Drivers using the system perceived increased pressure from other drivers. The *Voluntary* system was deemed more acceptable than the *Mandatory* system, which was even considered dangerous by some drivers (Erlich et al., 2003; Saint Pierre & Erlich, 2008).

The potential safety benefits of the different LAVIA modes were assessed using a simulation model which calculated the number of serious or fatal injuries that could be saved in speed-related RTCs if all vehicles were equipped with an ISA system (see Driscoll et al., 2007), based on the speed distributions observed in the field trials. The results, presented in Table 6, suggest that following the introduction of the various ISA systems trialled in this LAVIA project, savings of between 2% and 13% could be made in serious and fatal injuries arising from frontal impact RTCs and savings of up to 16% could be made in serious and fatal injuries arising from side impact RTCs. For the most part, the driver activated *Voluntary* system produced the highest percentage savings, ranging from 6% to 16%. The estimated benefit of the *Mandatory* system was also substantial, up to 16% for fatal injuries on motorways. The *Advisory* system produced the lowest percentage savings, ranging from 0% to7%. Overall, the benefits were generally higher in terms of reduced fatalities than for serious injuries and in side impact RTCs.

[2] LAVIA is the acronym for Limiteur s'Adaptant à la VItesse Autorisée (Limiter which adapts to the authorised speed).

Table 6 LAVIA safety gains estimates (Source: Driscoll et al., (2007)).

Network Type	LAVIA Model	Frontal Impact		Side Impact	
		Serious Injury	Fatal Injury	Serious injury	Fatal injury
Urban	Informative	4%	4%	3%	4%
	Driver activated	11%	14%	1%	3%
	Mandatory	9%	11%	0%	n.a.
Inter-urban	Informative	2%	5%	0%	7%
	Driver activated	3%	8%	9%	17%
	Mandatory	2%	8%	8%	6%
Motorway	Informative	3%	7%	n.a.	4%
	Driver activated	6%	13%	5%	16%
	Mandatory	5%	13%	4%	16%

3.7 UK

3.7.1 External Vehicle Speed Control (EVSC)

A comprehensive assessment of ISA, the External Vehicle Speed Control (EVSC) study, was conducted in the UK by the University of Leeds (Carsten & Fowkes, 2000). Starting in 1997, this three-year project reviewed a broad range of factors with respect to the possible introduction of an automatic system for limiting the top speed of road vehicles. The project provided information on driver behaviour while using the system, on the likely costs and benefits associated with a range of speed-limiting systems, on the network side effects of limiting maximum speed and on possible implementation scenarios. This study involved on-road and driving simulator trials.

3.7.2 EVSC field trial

The on-road EVSC trials were conducted in 1998 along a 67km route that included urban and rural roads and a stretch of motorway. Twenty-four drivers participated in the trial and drove a single test car on three occasions. This car was fitted with a *Mandatory*, 'dead' throttle system rather than a 'haptic' throttle mechanism i.e. rather than providing force feedback via the accelerator pedal, the system modified the fuel supply to the engine, thus preventing speeding. Two types of ISA were fitted: A *Voluntary* system that drivers were free to switch on or off and a *Mandatory* system that was switched on all the time. The results showed that the *Mandatory* system was successful in reducing speeding and also resulted in improved following and braking behaviour.

Some problems were observed in the trials. Although use of the driver select system was high, drivers were prone to disengage the system in areas where speeding was the norm. Drivers sometimes found themselves being left behind by other traffic and were overtaken more frequently by other vehicles when they were using the ISA system. This lead to frustration and low satisfaction ratings. In one instance, it was decided that the posted temporary speed limit of 30mph could not be implemented due to the fact that other traffic, including HGVs were travelling at 50-60mph through this zone. For this reason, Carsten and Tate (2000) concluded that it may be unwise to implement *Mandatory* ISA until a significant number of vehicles are equipped with this technology.

3.7.2.1 EVSC Data modelling

The EVSC team also used simulation models to derive 'best estimates' for crash reduction at three levels of accident severity, for a variety of ISA systems, which were broadly defined as *Advisory, Driver Select (Supportive)* and *Mandatory*. Each system had speed limits in fixed, variable or dynamic forms. The estimates were derived using Nilsson's Power Model (2004), which was described earlier in this document. The results suggested that the wholesale deployment of ISA would impact substantially on the percentage of injuries and fatalities sustained as a result of RTCs. Depending on the power and versatility of the ISA system used, it was estimated that injury crashes could be reduced by between 10% to 36%, and Fatal and Serious crashes and Fatal crashes could be reduced by 14% to 59% (Table 7).

Table 7 Best estimates of accident savings by EVSC type and by crash severity (Source: Carsten and Tate (2000))

System Type	Speed Limit Type	Best Reduction Estimates		
		Injury Accident	Fatal & Serious Accident	Fatal Accident
Advisory	Fixed	10%	14%	18%
	Variable	10%	14%	19%
	Dynamic	13%	18%	24%
Driver Select	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%

3.7.3 ISA-UK

The ISA-UK study aimed to build on and expand the findings of the Swedish large-scale trials. The on-road trials in this project were conducted from 2004 to 2006 and involved cars, trucks and motorcycles. This review reports the results of the car trial only, however full details of all the trials can be found in Carsten, Fowkes, et al. (2008). The car trial was conducted in three phases, (pre-activation, activation and post-activation) over six months and involved 79 participants. The sample embodied a wide variety of driver characteristics in terms of gender, age, private and fleet motorists, intentions to speed or not to speed. The test vehicles were equipped with *Supportive* (active accelerator) ISA technology.

The results of this study showed that whereas the ISA system had virtually no effect on drivers' speed choice when they were travelling below the speed limit, it had a marked impact on top-end speeds. Although drivers were able to override the ISA system at will, driving with ISA available reduced the 85th percentile speed on 30mph (48km/h) urban roads by approximately 2.5mph, and the proportion of distance travelled when exceeding the speed limit declined from 40% to 35%. On 70mph (112km/h) roads, the 85th percentile speed fell by over 4mph (6km/h) and the proportion of distance travelled when driving over the speed limit declined from 31% to 25%. The researchers pointed out that although these reductions may not seem dramatic, ISA was very effective in preventing large excesses in speed. Generally, the amount of speeding decreased in the active phase, except in 60 mph zones, where there was little speeding in the first place. Speeding increased to the final phase but did not reach pre-activation levels.

The use of a *Voluntary* ISA system also allowed the researchers to examine individual differences in driver willingness to either accept or override speed control. Figure 5 details the extent of overriding of the ISA system on 30 mph roads which are typical of urban areas and on 70 mph roads which are generally inter-city dual carriageways (often motorways). The patterns for age and gender are very similar for both types of roads. Intending and non-intending speeders behaved similarly on urban roads. However, there was a notable difference in behaviour between private and fleet drivers: Private drivers overrode the system more frequently than fleet drivers on urban roads, whereas fleet drivers overrode more frequently on 70mph roads. The researchers concluded that this might indicate that the compliance with speed limits in urban areas was more important to fleet drivers than compliance on inter-city roads and motorways. These results also showed clearly that those who might benefit most from ISA (males, young, speed intenders) tended to use it least.

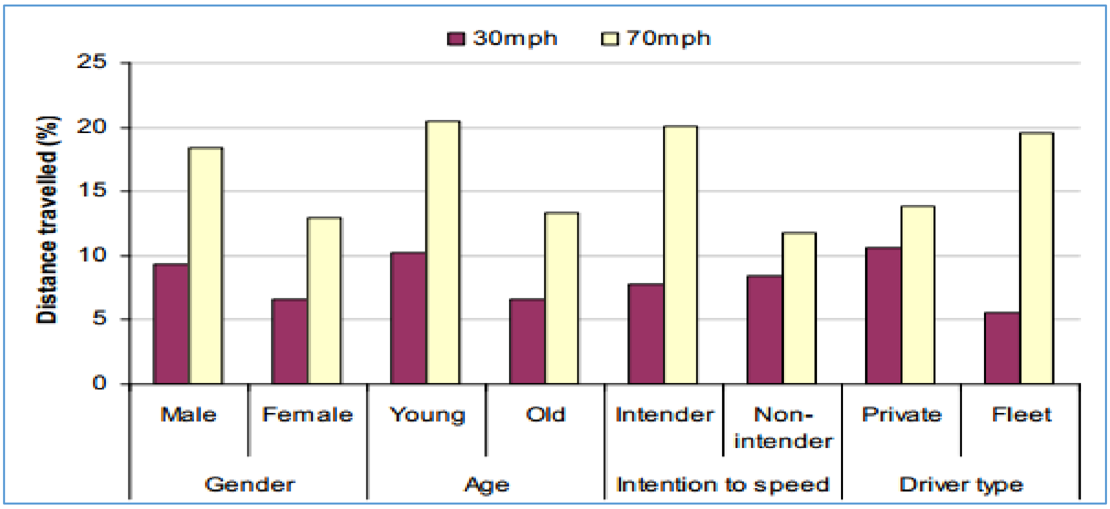

Figure 5. Comparison of overriding behaviour by user group in 30 and 70mph zone (Source: Carsten, Fowkes, et al. (2008)).

3.7.4 Lancashire ISA project[3]

The Lancashire project tested a low-cost, non-over-ridable *Informative* ISA system which provided drivers with visual and auditory alerts when they exceeded the speed limit and when they were approaching crash black spots. The system was installed in 430 vehicles for a period of 9 months, from April 2010 to March 2011 and over 2.8 million miles of driving data was recorded. A wide range of drivers participated, including novices and experienced drivers, generic drivers, and also taxi, bus and fleet drivers. The ISA was delivered by means of a nomadic device (i.e. mobile phones), so drivers could decide whether or not to use the system before they started each journey. The effectiveness of the system was examined by defining the data in two different ways; 'ISA available" (ISA in use intermittently) and 'ISA in use' (drivers choose to receive the speed information). The results showed that *Informative* ISA had a small positive effect on speed across the majority of speed limit zones. The greatest reduction was the 85th percentile speeds on 70mph roads. However, there was a large reduction in the proportion of speeding; reductions of 30% on 30mph roads and 56% on 70mph roads were recorded. Even when the system was only used intermittently, it was still effective in reducing the percentage of time spent speeding, with reductions of 18% in 30 mph roads and 31% on 70mph roads registered (Table 8).

Table 8 Reduction in speeds and speeding from 'No ISA' to 'ISA available' and 'ISA in use' (Adapted from Waibl et al. (2013))

Speed limit zone	ISA available			ISA in use		
	Mean	85th	% speeding	Mean	85th	% speeding
20	-1%	0%	-6%	-1%	-3%	-7%
30	-3%	-2%	-18%	-2%	-5%	-30%

[3] The review of this project is derived from a secondary source, i.e. (Waibl et al., 2013).

40	-2%	-2%	-23%	-3%	-4%	-40%
50	-2%	-1%	-25%	-2%	-3%	-44%
60	-1%	-1%	-16%	-1%	-2%	-21%
70	-2%	-2%	-31%	-4%	-6%	-56%

Note: The underlined results were statistically significant at the level $p<0.05$.

Some demographic factors that appeared to influence the effectiveness of the *Informative* ISA system were also identified. The system was found to be less effective generally with drivers over 60-years-old, mainly because baseline speeds were lower in this group than in any of the other age categories. Nevertheless, the system was still effective at reducing speeding in drivers within the older age group. Conversely, drivers aged 25 and younger were more resistant to remaining below the speed limit. Driving experience was also a notable factor. *Informative* ISA was effective in reducing higher speeds in novices (i.e. the 85th percentile speeds), but this group were more resistant generally to keeping their speed under the speed limit. Higher-mileage drivers were also more resistant to keeping their speed under the speed limit on in all but 30mph speed zones. No gender effects were found in the influence of ISA across the speed limit zones (as reported in Waibl et al., 2013).

3.7.5 London Bus ISA

Transport for London tested an after-market ISA system on 47 busses in June 2015. The system was fitted on two bus routes; No 19 (from Battersea to Finsbury Park) and No 486 (from North Greenwich to Bexleyheath). The trial used a *Mandatory* ISA system, using GPS data matched against an on-board map and speed-limit database. This prevented the busses from exceeding the local speed limit, by controlling the amount of acceleration that was possible. Drivers were not able to override the system, except in case of an emergency. The system’s effectiveness was assessed by comparing pre-trial and trial data. The results showed that the system was effective with reducing speeds, particularly with preventing speeding in 20mph zones. Busses fitted with ISA remained within the speed limit 97-99% of the time: the only exception was on hills due to the effect of gravity. The percentage of time spent travelling above the speed limit reduced from a range of 15-19% to 1-3% in 20mph zones and 0.5-3% to 0-1% in 30mph zones (+/-50km/h) (TRL (2016) as cited in; ETSC, 2018).

No adverse effects on driving behaviour were recorded, despite an expected increase in riskier overtaking by surrounding traffic. Some increase in platooning from vehicles behind the busses was noted which resulted in a reduction in average speeds in 20mph zones and a marginal journey time increase was recorded. Modelling based on the trial predicted a safety improvement following the introduction of ISA. Given the short duration of the trial, it was not possible to examine actual casualty data. Although there was no significant difference in fuel usage, there was some evidence of improved emissions in some of the 20mph zones. Feedback from the drivers showed that they rated their experience as negative in the early part of the trial due to problems with system installation and calibration. However, once these had been rectified, far fewer issues were noted. Some concerns were raised by the drivers that other road users would become frustrated with the busses complying with the speed limit. Bus passengers were unaware of the effects of ISA on their journeys, but once it was explained, they reacted positively (ETSC, 2018).

Following the success of the trial, the Mayor of London announced in late 2017 that TfL would require all new buses to be fitted with ISA. It is expected that by the end of 2018, over 500 buses will have the technology fitted. Following this, ISA will be introduced onto new buses at the point of manufacture. As TfL buys around 900 buses a year, it is expected that by 2028 the whole London fleet of 9000 buses will be renewed.

3.8 EU-funded research

The European Union has also funded research projects that investigated ISA, most notably MASTER (Várhelyi & Mäkinen, 1998) and PROSPER (Cunningham & Sundberg, 2006).

3.8.1 MASTER

Field tests were conducted as part of the Managing Speed of Traffic on European Roads (MASTER) project using a *Mandatory* speed limiting ISA system in Sweden, the Netherlands and Spain (Varhelyi, 1998). Twenty to 24 drivers in each country drove twice along a test route; once with the limiter switched off and once again when it was switched on. The results showed that when the system was in use mean speeds were reduced significantly in all three countries in 30, 40, 50, 60, 70 and 90km/h zones in urban and rural areas under normal and free (unobstructed) driving conditions. Reductions in mean driving speeds ranging from -2% to -16.1% were recorded in urban areas. Mean speeds decreased in rural areas, except in 80km/h zones where increases of 2.4% and 1.4% were recorded in normal and free-flowing traffic respectively (Table 9). Overall, the use of ISA in this trial resulted in reductions of -3.5% and -7.4% in mean speed in normal and free driving conditions respectively. Variations in speed were also reduced except for an increase of 4% in normal traffic on 90km/h limit roads and a marginal increase of 1% in speed variation was also recorded on 40km/h roads in free-flowing traffic. Safer car following distances were also observed at speeds under 50km/h, although decreased headway was observed in the 70-90km/h zones. Speeds were recorded approaching roundabouts, intersections and curves. Travel times increased by between 2.5% to 8.9% across the three countries and when combined these increases were statistically significant.

Table 9 Effects of mandatory ISA on mean speed and speed variation in normal and free-flowing traffic conditions in the MASTER project (Adapted from (Varhelyi, 1998)

Speed Limit (km/h)	Average Effect on Mean Speed		Effect on speed variation	
	Normal	Free	Normal	Free
Urban Roads				
30	-2.0%	-1.5%	-1.4%	-1.5%
40	-16.1%	-27.4%	-7.2%	+1.0%
50	-3.0%	-4.3%	-1.8%	-0.3%

60	-6.9%	-12.5%	-6.4%	-5.1%
Rural Roads				
70	-4.3%	-4.4%	-3.9%	-4.1%
80	+2.4%	+1.4%	-1.3%	-1.6%
90	-1.9%	-4.5%	+4%	-6.1%
Motorways				
110-120	+0.5%	-3.7%	-2.1%	-0.4%
Overall	-3.5%	-7.4%	-2.9%	-1.5%

Although no negative behavioural adaptation was observed in terms of interactions with other road users, drivers reported increased frustration, stress and impatience. User attitudes towards *Mandatory* ISA improved during the trials where 30% thought that speed limiters should be *Mandatory* in all cars, 59% were in favour of self-operated ISA, while just 10% were completely against the use of ISA to limit speed. Half of the test drivers said that they would install a speed limiter on their car if it was provided free of charge. Some national differences in attitudes were also found, for instance;

- The majority of drivers in Sweden (62%) said that they would install speed limiters in their cars, this fell to 50% in the Netherlands and 30% in Spain
- Dutch drivers reported more frustration with the system
- A larger proportion of Dutch drivers (23%) opposed mandatory speed limiting, although 59% agreed that limiting speed in poor visibility was a good idea
- The overwhelming majority of Spanish drivers (80%) were in favour of mandatory compulsory speed limiting in darkness, whereas drivers in the other two countries were doubtful or disagreed entirely with this suggestion

3.8.2 PROSPER

The Project for Research on Speed Adaptation Policies on European Roads (PROSPER) tested the impact of ISA using simulator and field studies in Hungary and Spain (Cunningham & Sundberg, 2006). 64 drivers used vehicles that were fitted with *Advisory* (auditory warning) or *Supportive* (active accelerator) ISA systems. The results showed that both ISA systems lowered mean and 85th percentile speed[4] and also speed variance. The largest effects were found for higher speeds, as evidenced by changes in the 85th percentile speeds. The *Supportive* system was more effective than the *Advisory* system. The authors of this study noted that this result is in line with the findings of the large-scale Swedish trials, where both systems were also tested. Taken together, the findings of both of these studies provide strong evidence that *Supportive* (active accelerator) ISA is more effective in reducing speed that *Advisory* (warning beep) systems. In the PROSPER study, both the Spanish and Hungarian

[4] The 85th percentile speed represents the speed below which 85% of drivers are travelling.

participants expressed positive attitudes towards ISA. However, after using the systems for one month, attitudes became more differentiated and also less positive. Hungarian drivers experienced the same level of speed reduction regardless of the speed limit, whereas the Spanish drivers experienced larger decreases at lower speed limits. The Hungarians experienced an increase in time pressure whereas the Spanish reported a decrease. Both sets of drivers perceived that their driving performance was affected negatively. Nevertheless, both systems were seen as useful. Simulator trials were also conducted to see how the Human Machine Interface design of ISA systems might affect driver behaviour and acceptance. However, a review of ISA HMI was deemed as out-of-scope for the current review.

3.9 Australia

3.9.1 Victoria – TAC SafeCar

The TAC SafeCar project was conducted in collaboration between the Australian Transport Accident Commission, the Ford group and Monash University Accident Research Centre, in order to evaluate the effects of ITC on driver performance and gauge driver acceptability (Regan, 2005). Twenty-three drivers drove the SafeCar vehicles that were equipped with *Supportive* (active accelerator) ISA for a total distance of 16,500kms.

The results showed that the system reduced mean, maximum and 85th percentile speeds and reduced speed variability in most speed zones. ISA also reduced the percentage of time drivers spent travelling in excess of the speed limit while not impacting negatively on travel times. Mean speeds were reduced significantly by up to 1.4 km/h in the 60 km/h and 100 k/m/h zones. However mean speeds rose significantly in the 70 and 80 km/h zones (by up to 1.5 km/h) after the ISA was deactivated. Overall however, no significant difference in mean speeds was found between the pre- and post-ISA installation conditions. This suggests that there were no real long-term benefits of ISA. Moreover, the data suggested an upward trend for mean speed to increase during the ISA activation period. The researchers considered that this might have been an indication that drivers were becoming habituated to the speed warnings and ignoring or tolerating them for longer periods of time. Alternatively, they speculated that drivers may have started to use the upward pressure on the accelerator as a kind of cruise control system (Regan, 2006). Nevertheless, based on the data gathered, it was estimated that the ISA system could reduce the incidence of fatal and serious injury crashes up to 8% and 6% respectively.

Participants from both the active and control group in this study rated the ISA system significantly less useful to them at the end of the study, compared to their assessment at the beginning of the study. Reasons proffered for this relative dissatisfaction included that other cars around them were speeding, drivers should be responsible for adopting appropriate speed, and others cited inaccuracies with GPS. Over 80% of participants believed that the ISA system would decrease speed effectively in 50, 60, 80 and 100 km/h zones and in residential zones. The majority also believed that ISA would reduce speeds on freeways (68%), rural roads (62%), in low-volume traffic (65%) and when road conditions are poor (60%). Most participants judged that the ISA system was likely to reduce the incidence and severity of RTC. However, belief in crash-related safety benefits of the system decreased significantly after use (from 100% to 73%).

This study also examined the effects of other driver support technologies. Interestingly, it seemed that the ISA system was most effective in reducing speeding when it was combined with a forward driver warning system. It appears that receiving guidance from two separate systems produced this cumulative effect.

3.9.2 New South Sales (RTA-NSW)

The New South Wales ISA trial (RTA-NSW) was the largest test of intelligent road safety technology ever conducted by a road safety agency in Australia, involving over 110 private and non-government fleet vehicles (Wall, 2010). The objectives of the research were to assess the potential safety benefits, economic effects (fuel consumption and travel times) and to gauge the acceptability of *Advisory* ISA systems to drivers and fleet managers.

Over 110 light vehicles including private and company fleets were equipped with an *Advisory* ISA device. More than seven million vehicle speed records were analysed to measure changes in speed compliance. The *Advisory* system reduced speeding in 89% of the vehicles and the median probability of speeding was also reduced by almost 30% when the system was active. Following the removal of the *Advisory* ISA system, incidences of exceeding the speed limit increased in 85% of the vehicles. The researchers on this project concluded that ISA technology could potentially realise substantial road safety benefits by increasing compliance with speed limits.

3.10 North America

Three trials conducted in North America were considered in this review; Michigan (Regan, 2012) and also the Speed Choice and SafeMiles projects in Canada which were reported in Waibl et al. (2013).

3.10.1 Kalamazoo, Michigan

An ISA field trial was conducted in Kalamazoo, Michigan in 2011 (Regan, 2012). This involved 50 participants, 40 of whom who drove eight vehicles equipped with *Informative* ISA systems that issued auditory and visual signals when speed exceeded the posted limit by 5 mph or more. Half of the active group were also provided with a monetary incentive for some of the trial period. They were issued with a €25 bonus credit, which declined by 3 cents for every six-second period that the driver remained 5-8 mph. above the speed limit. The penalty increased to six cents if the driver went 9 mph. or more above the limit. A visual display provided updated bonus amounts when the ignition was turned on or off. The results showed that the incentive system produced significant reductions in excessive speed and the feedback system led to modest reductions in speeding. When incentives were in operation, drivers consistently increased the percentage of time driving at or under the speed limit and also reduced their average speeds in several speed zones.

3.10.2 Speed Choice and Modelling the Impacts of Speed on Safety and the Environment (Canada)[5]

The Speed Choice and Modelling the Impacts of Speed on Safety and the Environment study (Taylor, 2006 as cited in: Waibl et al., 2013) evaluated two ISA systems on 10 private and 10 commercial vehicles, involving 70 datasets. The IMITA SA system, similar to the one used in the Lund study, provided information (audio-visual), and support (haptic accelerator pedal) feedback. The OttoMate system provided information only. Private motorists using the IMITA SA visual feedback system, which emitted repetitive warnings when the speed limit was exceed, recorded decreases in speed violations of 12% (8% in 80 km/h zones and 15% in 100 km/h zones). No significant additional reductions were recorded when haptic support was added subsequently. Drivers of commercial vehicles also benefitted from the audio-visual and the haptic feedback, with the haptic feedback achieving larger reductions. The impact of the haptic support was largest in 100 km/h zones, where violations decreased from 23% to 14%. Private motorists using the OttoMate system, which sounded a warning only as the speed limit was broken, recorded increased speed violations (up by 4%), particularly in the 100 km/h zone (up by 14%). This may be evidence of behavioural adaptation: It seems that some drivers were annoyed with repeated warnings and intentionally drove over the speed limit to avoid having to listen to these frequently.

3.10.3 SafeMiles

The SafeMiles project commenced in 2006 and involved a replication of an earlier Dutch Belonitor study which rewarded participants for complying with speed limits and maintaining safe headway. The rewards consisted of points which could be redeemed for goods and services. During the active phase, participants were provided with feedback on their driving habits, providing them with the opportunity to improve their driving skills. The total reward points that were accumulated during each trip were displayed during and at the end of each trip. Participants drove for 234,480kms using the system and speed compliance rates improved significantly in all speed limit zones and compliance remained high during a 2-week post trial period. The highest compliance rates during the feedback phase occurred in the 100km/h zones and the lowest compliance rates were in the 50km/h zones. Some age and gender differences in compliance were also observed. Drivers aged between 30-39-years exhibited the largest change in compliance during the active phase and males aged between 20-29-years lost all the rewards they earned during the active phase during the post-trial period. Participants reported high acceptance of this system and believed that it should be applied more widely (Transport Canada (2007), as cited in: Waibl et al., 2013)).

3.10.4 Limiting the speed of HGVs

The EU requires that speed limitation devices are installed on large Heavy Goods Vehicles (Directive 92/6/EEC) and buses and also Heavy Commercial Vehicles (Directive 2002/85/EC). It was assumed that speed limiters and ISA can contribute to key policy objectives set out in the 2011 White paper on Transport, in particular advancing towards zero fatalities in road transportation in 2050 and reducing 1990 GHG emission levels by 60% in 2050. Subsequent research indicated that these directives had a positive effect on traffic safety, with an

[5] Details of the Canadian ISA trials were derived from secondary sources.

estimated reduction of 9% in fatal crashes on motorways and a 4% reduction in serious injuries and a 3% reduction in injury crashes. It was further estimated that there was a reduction of approximately 50 fatalities annually following the introduction of the Speed Limitation directives. It was further estimated that the introduction of speed limiters resulted in a reduction of the total CO_2, NO_X and PM emissions of HCVs of around 1% (EU Commission, 2013).

4 ISA IMPACT

The expected impact of ISA technologies is summarised in this chapter in terms of road safety and driver behaviour, acceptance and environmental factors. The potential for negative impacts is also considered.

4.1 Effect on road safety and driver behaviour

The safety effects of ISA technologies depend on the type of ISA system, the type of road environment (urban, rural, motorways etc.) and the penetration level of ISA equipment in the vehicle fleet (OECD/ECTM, 2006). Some individual differences in driver reactions to ISA systems were also observed in terms of their willingness to use the systems correctly (Barnes et al., 2010).

4.1.1 Crash reduction

ISA has been evaluated in numerous trials in Europe, North America and Australia, a representative selection of which have been described in this review. However, none of these trials have been large enough to capture empirical information about actual crash involvement. For instance, as part of the Swedish large-scale ISA trial, researchers in Lund tried to assess the system effect of having 284 ISA-equipped vehicles circulating in the city however they could not find any effect of ISA on crash trends (Swedish National Road Administration (Vägverket), 2002). This is not surprising, given that road traffic crashes occur relatively rarely, and this trial was relatively small. In fact, the true effects of ISA are only likely to emerge when a larger percentage of vehicles have been equipped with the technology.

4.1.1.1 Impact of injuries and fatalities

As an alternative to using actual crash data, data models which map the relationship between speed and crash risk are often used to assess the effectiveness of ISA on road safety. Specifically, the observed (or estimated) changes in speed choice are used to predict changes in crash or injury risk (Lai, Carsten, & Tate, 2012). One of the most famous examples of this approach was demonstrated in the U.K. ESVC study. The results, shown in Table 10, predict reductions of between 18-59% in fatalities and reductions ranging from 14-48% in serious injuries following the wholesale introduction of ISA (Carsten & Tate, 2000). The largest reductions would be achieved using *Mandatory* systems, however substantial reductions were also predicted for *Advisory* and *Supportive* systems. A similar pattern of reductions was reported in the French LAVIA project although the effects estimated were considerably smaller than those derived in the ESVC study.

There are several reasons for the apparent differences in safety benefits between these two studies. First, the study design and calculation methods varied between the studies. The ESVC values were based on results derived from a simulator study and also a field test which involved just one vehicle equipped with the ISA system, whereas the LAVIA field test was conducted on a larger scale, with 22 equipped vehicles over a one-year trial period. Second, the ESVC results were obtained using statistical formulae linking average speed to the fatality and injury rate. However, the LAVIA study relied mainly on real-world, in-depth crash data (distribution of travel speed before crash and distribution of magnitude of impact, injury risk curves) and on travel speed distributions in traffic that were collected as part of the trial. Third, the LAVIA study was based on distributions rather than means, which are regarded as more accurate (Driscoll et al., 2007). Fourth, whereas the values computed by ESVC were for all crashes, those examined in LAVIA related to front and side impact crashes only.

Table 10 Comparison of estimated safety benefits

ISA Type	Injury Severity		Study			
		ESVC	LAVIA	ISA-UK	TAC SafeCar	Doecke & Wooley
Advisory	Fatal	18-24%	4-7%			11%
	Serious	14-18%	0-3%			8.3%
Supportive	Fatal	19-32%	3-17%	21%	9%	18.4%
	Serious	15-25%	1-11%		7%	15.6%
Mandatory	Fatal	37-59%	8-16%	46%		28.3%
	Serious	29-48%	0-9%			26.5%

Further analysis conducted by Oliver Carsten and his colleagues as part of the ISA-UK study suggested that ISA could reduce RTCs on all roads by 28.9% (33% on urban roads; 18.1% on motorways. *Supportive* ISA could reduce fatalities by 21% and *Mandatory* ISA could reduce this to 46% (Carsten, Fowkes, et al., 2008; Carsten & Tate, 2005).

Expected crash savings were also reported in two Australian studies. Here again, the results differed substantially. The analysis conducted in Australia by the Centre for Automotive Safety (Doecke & Woolley, 2010) suggested that the use of ISA across the road network could reduce the risk of fatal crashes by 11% (*Advisory*), 18.4% (*Supportive*) and 28.3% (*Mandatory*). Reductions of 8.3%, 15.6% and 26.5% were predicted for serious crashes for *Advisory, Supportive* and *Mandatory* systems respectively. However, the estimated crash savings for *Supportive* ISA that were reported in the TAC SafeCar study (Regan et al 2006) were more than 50% lower than those calculated by Doecke and Wooley; a 9% reduction in fatalities and a 7% reduction in serious crashes.

Overall, there seems little dispute that the introduction of ISA will result in a reduction in fatal and serious injury crashes. However, because different methods were used to derive the crash reduction estimates presented in Table 10 it is hard to predict with any certainty what the magnitude of these savings would be following the introduction of *Advisory, Supportive* or *Mandatory* ISA.

4.1.1.2 Impact by speed zone

Doecke and Woolley (2010) also estimated the potential reduction in the risk of injury crashes in Australia in terms of speed zones. The results, summarised in Table 11 show clearly that the *Mandatory* system was most effective in reducing the risk of speeding across all speed zones. In general, the higher the level of intervention, the more the potential for risk reduction. However, *Advisory* systems were judged as more effective than the *Supporting* system in 80 km/h zones.

Table 11 Percentage reduction in the risk of injury crashes in Australia (SOURCE: DOECKE AND WOOLLEY, 2010)

Speed Limit (km/H)	Advisory	Supportive	Mandatory/Limiting
50	6.5%	19.6%	42.4%
60	2.1%	9.4%	15.8%
80	14.4%	12.3%	23.3%
100	17.3%	28.8%	35.9%
110	4.6%	12.4%	21.7%

The estimates shown in Table 11 were also used to calculate the potential annual savings that could be realised through the full implementation of these three types of ISA. The results showed that savings of $1.2, $2.2 and $3.7 billion Australian dollars could be expected following the introduction of *Advisory, Supportive* or *Mandatory* ISA systems respectively.

4.1.1.3 Impact for different implementation scenarios

Realistically though, ISA cannot be introduced overnight, so the impact on crashes in the future depends on the number of vehicles fitted with each type of ISA at any given time. According to the OECD, where just a few vehicles are equipped with ISA, there may be an increase in overtaking manoeuvres, leading to increased risk. However, when critical mass is achieved, the ISA-equipped vehicles will effectively reduce the speed of the rest of the vehicles in the traffic stream (OECD/ECTM, 2006). Simulation modelling has been used effectively to estimate the likely impact of ISA for different implementation scenarios. For instance, researchers in the Institute of Transport Studies at Leeds University, used a mathematical model to estimate the proportions of injury crashes that would be prevented on the entire U.K. road network with increasing penetration of ISA. The estimates, shown in

Table 12, indicate that both the *Supportive/Voluntary* and *Mandatory* variants of ISA would be considerably more effective than *Advisory* ISA and that effectiveness increases with penetration level: At 100% penetration reductions of 12% were predicted for *Supportive/Voluntary* ISA, reductions of 28.9% were estimated for *Mandatory* ISA, whereas reductions of just 2.7% can be expected for *Advisory* ISA (Carsten, Lai, et al., 2008).

Table 12 Percentage of injury crashes on all U.K. roads that would be prevented with ISA fitment

Penetration	*ISA Variant*		
	Advisory	*Voluntary (Supportive)*	*Mandatory*
20%	0.5%	2.4%	5.8%
40%	1.1%	4.8%	11.6%
60%	1.6%	7.2%	17.3%
80%	2.2%	9.6%	23.1%
100%	2.7%	12.0%	28.9%

The crash reduction potential of *Mandatory* ISA was also examined as part of the ISA-UK study in terms of two implementation strategies; Market Driven and Authority Driven (Carsten, Fowkes, et al., 2008). The results, shown in Table 13, demonstrate clearly that savings associated with the Authority-Driven implementation scenario far outstrip those to be made under Market-Driven conditions

Table 13 Crashes saved from 2010 to 2070

Crash type	Market-Driven	Authority-Driven
Slight (Minor)	4%	15%
Serious	8%	25%
Fatal	13%	30%

4.1.2 Impact on driver behaviour

4.1.2.1 Impact on Speed-related behaviour

A high-level summary of the impacts of the various ISA systems on drivers' speed–related choices from the 24 key studies that featured in this review is shown in Table 14. This shows that the ISA systems used in all but the Ghent trial had the effect of reducing speed and speeding.

Table 14 Summary influence of ISA on driving speed choice reported in 24 key studies

Date	Study Location	Driver/Vehicles	Advisory	Supportive	Mandatory	Recording	Average	Variation	Maximum	Speeding	% spent	85th Percentile
		Nos.	ISA System				Speed Choice					
	Sweden											
1993	Lund	75	√		√		↓					
1996	Eslöv	25	√		√		↓			↓		
2000-2001	"Right Speed" - Borlänge	400	√				↓	↓			↓	
2000-2001	"Lund ISA"	290		√			↓	↓				
2000-2001	“SmartSpeed” -Umeå	4000	√				↓					
2000-2001	Lidköping – Spearheading the way to vision zero”	280	√	√			↓		↓			
2004	"ISA for Stockholm"	130	√				↓			↓		
2002-2003	Gothenberg	16 busses		√						↓		
	Netherlands				√							
1998	Groningen	24	√				↓	↓				
1999	Tilburg	479			√		↓	↓		↓		
2011	ISA for serious offenders	51			√	√		↓				
2001	**Finland**	24			√	√	↓			↓	↓	
	Denmark											
2001	Alborg INFATI	24	√				↓					↓
2007-2009	Alborg - "Pay-as-you-Speed"	146	√			√				↓		
2002	**Belgium** - Ghent	37 vehicles		√			↔					
2001	**France** - LAVIA	100	√		√		↓					
	UK											
1997-2000	EVSC	24			√				↓			
2001-2005	ISA UK	79		√					↓		↓	↓
2010-2011	Lancashire	402	√				↓				↓	↓
2015	London Bus				√		↓				↓	
	EU											
-1998	Master	60			√	√	↓	↓				
-2006	PROSPER	64	√	√			↓	↓				↓
	Australia											
2002-2004	"TAC Safe Car"	23		√			↓	↓	↓	↓	↓	↓
2010	New South Wales "RTA-NSW"	110	√				↓				↓	↓
	North America											
2011	USA - Kalamazoo, Michigan	50	√			√	↓			↓	↓	
-2006	**Speed Choice, Canada**	**79**	√	√								
2006	Safe Miles, Canada					√				↓		

Key: Tick marks indicate ISA system used in each test. Downward arrows indicate decreases in speed. Horizontal arrows indicate no change in speed.

Since mean and excessive speeds are critical factors in road safety many studies that feature in this review examined these parameters. Arguably the strongest evidence showing the speed reduction potential of ISA was collected as part of the Swedish large-scale trials, which were conducted between 1999 and 2002, and involved up to 5,000 vehicles, and more than 10,000 drivers. Irrespective of which type of ISA that was used (*Advisory, Supportive, Mandatory*) mean speeds were reduced by 1-2km/h in all speed zones, and overall decreases in speeding violations were also recorded (Swedish National Road Administration (Vägverket), 2002). Interestingly, findings from the Ghent trial showed increases in average speed for drivers who exceeded the speed limit less frequently. It appears the information provided by the ISA system acted as cue to drive 'up' to the speed limit.

Table 155 summarises the findings from key studies that feature in this review in terms of the impact of *Advisory, Supportive* and *Mandatory* ISA on mean speed and speeding.

Table 15 Impact of Advisory, Supportive and Mandatory ISA on mean speed and speeding

I[st] Author/Study	Location	Study Year	Vehicles/ Drivers	Speed Zones (Km/h)	Mean speed change (km/h)	Speeding reduction
Advisory/Informative ISA trials						
SNRA/ Borlänge	Sweden	2000	/400	30-70	-0.6 to -2.8	10-77%
Lahrmann/INFATI	Denmark	2001	20/24	Undefined	-	5-6%
Päätalo	Finland	2001	24	40-80	-2.8	39%
Driscoll/LAVIA	France	2001	10	Undefined	-0.8	-
Brookhuis/Groningen	Netherlands	1998	/24	50-120		-4%
Taylor/Ottawa	Canada	2006	20	14-100	-	13-22%
/Lancashire	UK	2011		30-70mph	- 1 to – 3	30-70%
Advisory/recording ISA involving incentives						
Lahrmann/PAYS	Denmark	2008	/146	50-130	-3.6 to -8.5	-77%*
Supportive ISA trials						
MASTER	Netherlands Spain & Sweden	1997	64-68	30-120	+2.4 to -16.1	-
SNRA/Lund	Sweden	2001	/290	30-70	-0.8 to -2.0	20-53%
Driscoll/LAVIA	France	2001	10	30-120	-1.4 to -2.0	-
Vlassenroot/Ghent	Belgium	2002	37	30-90	+0.7 to -1.1	-
Regan/Melbourne	Australia	2003	15	60-100	-1.4	57%

I[st] Author/Study	Location	Study Year	Vehicles/ Drivers	Speed Zones (Km/h)	Mean speed change (km/h)	Speeding reduction
Lai/ISA-UK	UK	2007	80	32-113	-0.4-3.1	2-22%
Transek/Stockholm	Sweden	2005	20/120		-	30%
Taylor/IMITA	Canada	2006	10	40-100	-	2-19%
Carsten/ISA-UK	UK	2006	79	30-100mph	n.a.**	n.a.**
Mandatory/Limiting ISA trials						
Besseling/Tilburg	Netherlands	2000	21/140	30-80	-3 to -8.3	-
Päätalo	Finland	2001	24	40-80	-3.4	74%
Carsten/EVSC	UK	1998	1/24	30-100mph	n.a.**	n.a.**

*Percentage of speeding by more than 5km/h
**No definitive figures were reported by the authors of these reports

This table demonstrates a clear trend regarding the safety potential of the various ISA systems in terms of reducing mean speed and speeding. *Advisory/recording ISA involving driver incentives* and *Mandatory* ISA were the most effective systems. *Supportive* ISA was more effective than *Advisory* ISA.

4.1.3 Individual differences in behavioural effects of ISA

Some individual differences in the behavioural effects of ISA have been noted in the field trials. For instance, researchers working on the NSW trials reported that younger drivers (under 25-year-olds) were less likely than older drivers to reduce the proportion of time spent speeding using an *Advisory* ISA system and this group were also more likely to turn the device off at times (Barnes et al., 2010). In the Swedish large-scale trials, young male drivers expressed more negative attitudes towards ISA than young females. Older females were more positive than older males, and drivers who did not want to keep the ISA system at the end of the trial drove significantly faster both before and during the ISA trials than did drivers who wanted to keep the system (Hjälmdahl & Várhelyi, 2004; Hjälmdahl, Várhelyi, Hydén, Risser, & Draskoczy, 2002).

4.2 Impact on the environment

Safety concerns are not the only reason why speed management is necessary. Speed management strategies are also consistent with other important EU and domestic policy goals such as reducing fuel consumption, CO_2 emissions, air pollution, and congestion. In addition to safety targets, the EU has set a target of reducing transport-related greenhouse gas (GHG) emissions by 60% by 2030, when compared to 1990. Irrespective of EU targets, research shows that in 2015 the transport sector (excluding international aviation and maritime emissions) contributed 21% of total EU-28 greenhouse gas emissions, with road transport up by 19% from 1990 levels. Furthermore, road transport was responsible for almost 73% of total greenhouse gas emissions from transport in 2015, with passenger cars contributing 44.5%, and heavy-duty vehicles contributing 18.8% (European Environment Agency, 2017)

Here in Ireland, the most recent emissions figures compiled by the Irish Environmental Protection Agency (EPA) show that the share of CO_2 in total greenhouse gas emissions has increased to 64.9% in 2016 compared to 59.2% in 1990. Between 1990 and 2016, transport showed the greatest overall increase (139.3%), with road transport increasing by 145.4%. These data also show that transport was the third largest contributor to greenhouse gas emissions (20%), after agriculture (32%) and industry (20.5%) (Environmental Protection Agency, 2018).

Since fuel consumption and carbon dioxide emissions depend on a vehicle's travelling speed… lower and better enforced speed limits are '...one of the most certain, equitable, cost-effective and potential popular routes to a lower carbon economy" (Anable et al., 2006: as cited in ETSC, 2008, p. 9).

4.3 Environmental factors

A number of the key studies in this review examined the environmental impact of ISA and these are summarised at a high-level in the table below.

Table 16 Impact of ISA on environmental factors

Study Location	Drivers/Vehicles	Journey time	Fuel Consumption	NO_x Emissions	CO_2 Emissions
	Numbers	**Environment**			
Sweden					
Lund	75	↑	↔	↓	↓
Eslöv	25	↑	↑	↓	↑
"Right Speed" - Borlänge	400	↔	↓		
"Lund ISA"	290	↔	↓	↓	↓
"SmartSpeed" -Umeå	4000	↔			
Lidköping – Spearheading the way to vision zero"	280	↔			
Gothenberg	16 busses	↔			
Netherlands					
Tilburg	479		↓		
Alborg - "Pay-as-you-Speed"	146	↔			
UK					
EVSC	24	↑	↓		

Study Location	Driver/Vehicles	Journey time	Fuel Consumption	NO_x Emissions	CO_2 Emissions
	Numbers	Environment			
EU					
Master (Sweden, Spain, Netherlands) (3X20 subjects)	60	↑			
Australia					
"TAC Safe Car"	23	↔	↓		↓

Key: Tick marks indicate ISA system used in each test. Downward arrows indicate decreases. Upward arrows indicate increases. Horizontal arrows indicate no change.

4.3.1 Fuel Savings

Emissions are linked to fuel consumption and the most frequently cited research findings regarding possible reductions in fuel consumption when using ISA systems were the conclusions reached in the EVSC project (Carsten & Fowkes, 2000), where simulation models were used to estimate potential savings. The results showed that savings of 1%, 3% and 8% respectively could be expected from the introduction of *Mandatory* speed limiting devices on motorways, and in non-built up and built up areas on other road types in the UK. A similar study conducted as part of the Tilburg trial estimated fuel savings of 11%, based on full implementation of *Mandatory* ISA (Dutch Ministry of Transport, 2001, as cited in; Oei & Polak, 2002).

4.3.2 Travel time and congestion

Travel time impacts on fuel usage and traffic congestion. Studies that investigated the effects of ISA on travel times have reported mixed findings. Some have revealed increases in travel times with the use of ISA particularly limiting systems, while others have found no change, or even a decrease in travel times, on some road types. For instance, expected increases in travel time were calculated by the U.K. EVSC research team, who showed that there would be an increase of 2.6% in rush hour travel time, rising to 6.4% outside of rush hour if drivers were forced to comply with speed limits. The mean increase across the whole day would be 4.4%. There would be a 4.3 % increase in built-up areas, a 0.4% increase in non-built up areas and no increase in travel times on motorways (Carsten & Tate, 2000; Liu & Tate, 2004). Although most studies that investigated the impact of ISA on travel times predicted that travel times would increase due to the overall reduction in travelling speeds, some also found that traffic flow improved which should reduce average travel times and also traffic congestion.

4.3.3 Emissions

A number of studies have indicated that fitting cars with ISA systems would contribute greatly to reducing CO_2 emissions. For instance, Anable et al. (2006) developed a model to calculate the emission savings in the U.K. between 2006 and 2010 in relation to two scenarios;

enforcing the 70mph (112km/h) speed limit and reducing this limit to 60 mph (96 km/h). The results showed that;

- A properly enforced 70mph (112km/h) speed limit would cut carbon emissions by nearly 1 million tonnes per annum.
- A new 60mph (96km/h) speed limit would nearly double this reduction, reducing emissions by an average of 1.88 million tonnes per annum.

Similar research conducted in France, for the French Environment Ministry, estimated that the potential impact of full compliance with speed limits would reduce carbon emissions by 2.1 tonnes of CO2 for private cars, 0.4 million tonnes for HGVs and 0.5 million tonnes for utility vehicles, resulting in a total reduction of 3 million tonnes of CO2 emissions annually (ETSC, 2008). The results from the Swedish Lund trial showed average reductions of 11% and 8% for NOx and Hydrocarbons respectively when using *Supportive* (active accelerator) ISA (Várhelyi, Hjälmdahl, Hydén, & Almqvist, 2000; Várhelyi, Hjälmdahl, Hydén, & Draskóczy, 2004). The Australian SafeCar trial reported a 4% reduction in fuel consumption and CO2 emissions when ISA was used with following distance warnings in 80km/h zones (Regan et al., 2006). A micro simulation model was used to predict the network effects of the EVSC *Mandatory* ISA system in the UK (Carsten & Tate, 2000). The key results, summarised in Table 177, suggest that the use of *Mandatory* ISA would result in increases in travel time, decreases in fuel consumption, but would have very little impact on emissions. However, the authors noted that the Mandatory ISA EVSC system was likely to reduce variability in travel time by making traffic flow more smoothly, which in turn would make journey times more predictable.

Table 17 Impact of Mandatory EVSC ISA system on different road networks

Network	Saturation Penetration	Travel Time	Fuel Consumption	Emissions*
Urban Peak	100%	+2.6%	-8.0%	No impact
Urban Off-Peak	100%	+6.4%	-8.5%	No impact
Rural	60%	+0.4%	-3.0%	+1%
Motorway	0%**	0%#	0%#	No impact

*The emissions predictions were for current vehicles.
**The motorway modelled was so congested that the EVSC ISA system had negligible effect.

More detailed estimates of vehicle CO_2 emissions were calculated using comprehensive data collected for the UK ISA project and these indicated that ISA would have a stronger impact on CO_2 emissions on high speed roads. For instance, on 70mph (112km/h) speed zones, the use of *Voluntary* and *Mandatory* ISA would reduce CO_2 emissions by 3.4% and 5.8% respectively.

However, the change in emissions in other speed zones remained variable and small (Carsten, Fowkes, et al., 2008).

Controlling the speed of commercial vehicles can also have a significant impact on CO_2 emissions. Trials conducted in the Netherlands showed that fitting vans and light trucks with devices that limited speed to 110km/h yielded fuel savings of 5%, which reduced emissions. According to the European Transport Safety Council (ETSC), the effectiveness of such measures is likely to increase over time because the increasing use of motorways and also the increasing power capabilities of vehicles generally means that speeds of above 110km/h will be reached more easily (ETSC, 2008).

The findings summarised here suggest that the introduction of ISA will result in reductions in fuel consumption and emissions. The European Transport Safety Council also noted that vehicle manufacturers are likely to respond to the widespread adoption of ISA by optimising engine performance to suit these new 'typical' driving conditions, rather than the marketed top speed capability of a vehicle and this should ultimately result in reduced emissions (ETSC, 2006).

4.4 ISA User Acceptance and psychological factors

When it comes to the introduction of different in-car systems, public acceptance is hugely important. Without popular support, ISA will not be adopted widely, and it is highly unlikely that any government would decide to require ISA without strong such support. Attitudinal research has featured prominently in many ISA research studies. In general, the findings indicate that driver acceptance tends to vary according to the type of ISA system, the type of road environment and the type of driver.

4.4.1 ISA type

Results of the SARTRE 3 (2004) and SARTRE 4 surveys (2011) showed that around one quarter of European drivers believed that having a device in the car that would restrain them from exceeding the speed limit would be useful. The results from field trials showed that acceptance levels were highest for *Advisory/Informative* ISA systems but tended to decrease as the level of intrusion and control increased and invariably, the most effective form of ISA, *Mandatory* speed limiting, proved least popular with users.

A nation-wide survey was used to gauge the attitudes of 1,000 Swedish driver towards various forms of ISA technologies (Várhelyi et al., 2000). The results showed that the majority of respondents had a positive attitude towards a device which automatically lowers the maximum possible speed of cars in slippery conditions and poor visibility and also towards a device which warns the driver or reduces speed automatically if the car is about to collide with another road user. However, just one-third of drivers were in favour of *Mandatory* limiting i.e. systems which prevent drivers from exceeding the prevailing speed limit (

Table 18).

Table 18 Driver acceptance of different systems for influencing speed behaviour

Acceptance	Mandatory Speed Limiter			Collision Risk	
	Generally	On Slippery roads	In poor Visibility	Warning	Intervention
In Favour	34%	59%	59%	80%	65%
Opposed	48%	23%	23%	7%	19%
Neither	16%	16%	16%	11%	14%

Attitudinal research conducted in Belgium and the UK among people without any experience with ISA found that the majority of respondents were in favour of ISA, even the *Mandatory* version: 88% of respondents were in favour of *Voluntary* ISA systems and 59% supported the introduction of *Mandatory* systems (De Mol et al., 2001; as cited in Katteler, 2005). Carsten (2002) also reported that 53% of UK drivers favoured the installation of *Mandatory* ISA.

Early trials in Lund (Persson et al., 1993) and in Eslöv (Almqvist & Nygård, 1997) found that drivers were more positive about ISA after they had used the system. Drivers in Eslöv indicated a strong preference for the feedback from the haptic throttle (*Supportive* ISA) over warnings given by buzzers or lights (*Advisory* ISA).

In the large-scale Swedish trials, user acceptance grew initially, but tended to decrease slightly over time. However, most drivers wanted to keep the system, particularly those who tested the informative versions (Figure 6). Half of the participants in the MASTER study (Varhelyi, 1998) and many of those in the Ghent trials (Vlassenroot et al., 2004) were also willing to keep the system at the end of the trials.

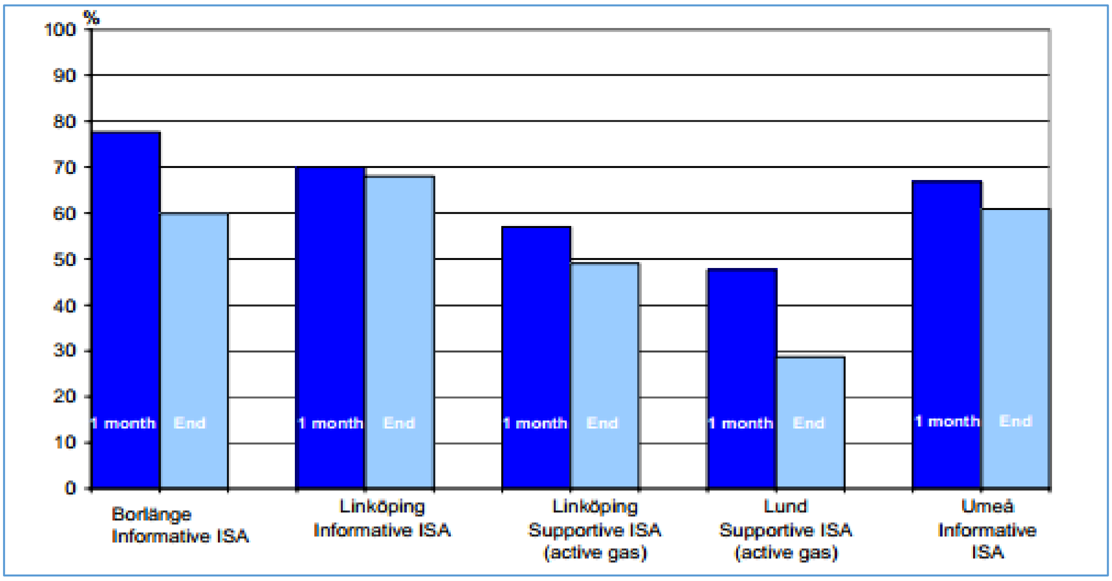

Figure 6. Share of test drivers who wanted to keep the ISA equipment in the Swedish trials. (Source: Bidding and Lind (2002).

An acceptability scale was used in the U.K. EVSC project, which allowed drivers to express opinions about two types of ISA: *Voluntary* and *Mandatory*. The results showed that drivers were much more positive about the *Voluntary* as opposed to the *Mandatory* system. A comparison of pre and post-test attitudes showed that drivers' evaluation of the usefulness of the *Mandatory* system improved during the course of the trial. However, satisfaction levels for the *Mandatory* system remained low (Carsten & Tate, 2000). Conversely, findings from the Dutch, Tilburg trial showed that the majority of test drivers (64%) had a positive attitude towards the *Mandatory* ISA system used. The general public also reported positive attitudes towards ISA and this support increased with greater exposure to the system (Duynstee & Martens, 2001). Some negative aspects of Mandatory ISA were also reported. For instance, drivers in the LAVIA (Cunningham & Sundberg, 2006) and Tilburg (Duynstee & Martens, 2001) trials reported feeling pressure from other drivers and perceptions of increased danger from other traffic was also noted in the EVSC project (Carsten & Tate, 2000).

Overall, the results from field trials show that the majority of drivers were in favour of ISA and that support was inversely related to the amount of control that the system exerted over driving speed choice; the more controlling the system, the less the drivers favoured it. In general, drivers who participated in ISA field trials were more positive about these technologies than the average driver.

4.4.2 Type of road environment

Acceptance of ISA differed for different road types, the associated speed limits and driving speeds. As shown in the earlier detailed review and also illustrated in the summary table in Appendix B, greater acceptance was seen for urban roads with 30km/h and 50km/h speed limits.

4.4.3 Type of driver

The research findings also suggested that drivers who would most benefit from ISA, are least willing to use it. For instance, in the Safe Miles study, males aged from 20 – 29 years lost all the rewards they gained very quickly after the trial ended and the *Advisory* system used in the Lancashire study was less effective affecting speed choice among drivers aged 25 years and under (Waibl et al., 2013). The results of the Australian SafeCar study showed that inexperienced drivers were less accepting of ISA than more experienced drivers after they had actually used this technology. This suggests that there is a danger of self-selection bias if ISA is introduced on a voluntary basis.

When assessing the effectiveness of measures for controlling speed, it can be useful to identify different groups of speeding drivers. Paine (1996) estimated the proportion of speeders and the related risk of crashing in terms of four speeder types: Recidivist, intentional, inadvertent and reluctant (

Table 19). This shows clearly that about two-thirds of drivers (i.e. the inadvertent and reluctant speeders) might be assisted by an *Advisory* system that informed them when they exceeded the speed limit. "Reluctant" speeders would be further supported if other drivers knew that an ISA system was in operation. For instance, the ESVC ISA trial in Leeds used a car sticker for this purpose.

Table 19 Estimated proportion of speeding drivers and contribution to speed-related crashes (Source: Paine, 1996)

Category of speeding driver	Estimates for drivers and crashes
Recidivist **–** Grossly excessive speed. Risk taker	3% of drivers: 10% of crashes
Intentional **–** Feels "safe" at 10-15 km/h above the speed limit. Thinks that the risk of penalties is low	30% of drivers: 35% of crashes
Inadvertent **–** Drivers a powerful/smooth car, which is too easy to drive at over the speed limit, or misses speed signs, or forgets current speed zoning	35% of drivers; 30% of crashes
Reluctant **–** Under pressure, drives at the speed of the traffic stream, which is exceeding the speed limit. Does not want to impede traffic. Is intimidated by tailgaters	30% of drivers; 25% of crashes

Sometimes, however, drivers exceed the speed limit unintentionally. For instance, 87% of drivers who took part in the TAC SafeCar ISA speed alerting trial reported that they sometimes exceed the speed limit inadvertently (M. A. Regan et al., 2005). Participants in that study also tended to agree that ISA systems should be compulsory for all drivers and to disagree that ISA systems should only be compulsory for habitual speeders. Nevertheless, findings from other studies show that when serious offenders face a choice of losing their license or installing the system, their acceptance could increase considerably (van der Pas et al., 2014).

4.5 Negative impact on driver behaviour

Negative aspects of the various ISA technologies were reported in many of the studies in this review and some have also been hypothesised (OECD/ECTM, 2006). These include direct effects such as driver distraction, and indirect effects such as behavioural adaptation.

4.5.1 Driver distraction

Any activity that distracts the driver, or competes for his/her attention while driving, can potentially degrade driving performance and thus have serious consequences for road safety (K L Young & Regan, 2007). The deployment of ISA could potentially add to the increased levels of driver distraction within the vehicle and careful consideration is needed regarding the location and nature of any in-vehicle warnings and displays. For instance, results from the EU HASTE project showed that visual distraction and cognitive distraction due to using in-vehicle systems impact differently on the primary driving task. Visual distraction resulted in poor steering behaviour and degradation of lateral control, whereas cognitive distraction dis-improved longitudinal control, particularly in relation to car following. The HASTE studies also showed that some elderly drivers experienced problems particularly in situations where secondary task demand was high (Carsten et al., 2005). Although a detailed review of the opportunities and challenges that arise in developing automotive HMI is beyond the scope of this document several EU-funded projects have explored this issue, notably the Adaptive Integrated Driver-vehicle interface (AIDE) project (http://www.aide-eu.org/).

4.5.2 Behavioural adaptation

Aside from safety benefits, ISA use is likely to impact on driver behaviour in a number of other ways. Indeed, it is widely accepted that drivers tend to prioritise mobility over safety and as a result, tend to adapt their behaviour in response to the introduction of new safety-enhancing features (anti-lock braking systems etc.) (Sagberg, Fosser, & Saetermo, 1997). This phenomenon, known as 'behavioural adaptation' refers to "those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change" (OECD, 1990, p.23). This phenomenon has been examined extensively in road safety research and there is general agreement that while behavioural adaptation does not occur consistently, when it does occur, it tends to reduce the size of the expected effects of an intervention, rather than eliminate them altogether. In road safety research the primary concerns are negative behavioural adaptations related to frustration, risk compensation, diffusion of responsibility and habituation. Some negative behavioural adaptations were reported in studies that feature in this review including;

- Frustration, leading to unsafe actions and/or less safe interactions with other road users
- Driving faster on road segments where ISA is not active
- Using shorter headway and gaps when driving in traffic (risk compensation)
- Overreliance on the system to the extent that drivers neglect to monitor and/or adjust driving speeds appropriately (diffusion)
- Tendency for non-ISA users to intimidate ISA users
- Decreased effects of voluntary ISA systems on driving speed over time (habituation)

Increased frustration when using ISA was reported in many studies (Carsten & Fowkes, 2000; M. A. Regan et al., 2005; Swedish National Road Administration (Vägverket), 2002; Varhelyi, 1998). Some studies also indicated that long-term use leads to more frustration (Lai, Hjälmdahl, Chorlton, & Wiklund, 2010). Persson et al. (1993) reported that drivers in the early Lund study tended to compensate for having to drive slower in the area covered by the ISA system that was used by driving faster where the system was not active. Participants in the EVSC trial tended to disengage the system in areas where speeding was the norm (Carsten & Fowkes, 2000).

A certain degree of frustration regarding the auditory alerts that featured in some types of *Advisory* ISA systems was also noted. For instance, drivers in the Swedish trials often attempted to override the system because they felt annoyed by the alerts (Swedish National Road Administration (Vägverket), 2002). Canadian drivers in the Speed Choice project were observed to intentionally drive over the speed limit to avoid having to listen to the alerts frequently (as cited in; Waibl et al., 2013).

In some trials participants tended to adopt shorter headways in car following (Carsten & Fowkes, 2000; Varhelyi, 1998; Várhelyi et al., 2004). Riskier gap acceptance when interacting with other vehicles at junctions was also observed (Carsten & Tate, 2000; Persson et al., 1993.

Another adaptation effect that emerged in many field trials was that drivers without ISA tended to 'crowd' (follow too closely) the ISA-equipped cars (Duynstee & Martens, 2001; Persson et al., 1993; Saint Pierre & Erlich, 2008). Drivers in the Lund trial sometimes forgot to monitor their speed outside of the test area, suggesting overreliance on ISA in speed choice decision making (Swedish National Road Administration (Vägverket), 2002; Varhelyi, 1998). Overreliance on the haptic feedback provided by some ISA systems was reported in several studies. In the Swedish and Belgian trials evidence was shown that the information provided by haptic feedback ISA systems sometimes resulted in increases in average speed in drivers who previously drove slower without the ISA support (Hjälmdahl, Almqvist, & Várhely, 2002). A tendency towards 'driving up' to the speed limit, was noted in the Ghent study, in causing average speeds to increase (Vlassenroot, 2011). Participants in the Australian TAC SafeCar study agreed that they would lose trust in ISA systems if it was unreliable, i.e. if it issued false warnings (87%) or failed to issue warnings when it should (84%) (M. A. Regan et al., 2006).

In contrast, a number of improved safety-related behaviours were also reported such as reductions in the number of traffic conflicts (Almqvist & Nygård, 1997). Drivers in the Tilburg trial reported less overtaking and maintaining larger following distances when using ISA (Duynstee & Martens, 2001). However, it is hard to say for certain whether or not these effects would persist with long-term acclimatisation to ISA. Jamson, Carsten, Chorlton, and Fowkes (2006) suggested that frustration associated with ISA use may subside as drivers become more accustomed to using the system and come to appreciate the nature of the trade-off between safety and mobility that results from ISA use. However, some studies indicate that ISA may become less effective over time. For instance, findings from large-scale studies in the UK and Sweden indicated that the longer drivers had the ISA system, the more they overrode it or drove a large proportion of their journey with it overridden (Lai et al., 2010).

5 ISA IMPLEMENTATION

The use of ISA as part of an overall speed management strategy has widespread support among network and safety institutes, government bodies and those who have a stake in this issue in the EU, North America, and Australia and further afield. For instance, research conducted as part of the EU-funded PROSPER project showed that stakeholders (politicians, governmental institutes, research institutes, pressure groups and commercial groups) in the eight countries involved in the project regarded ISA as an effective safety measure. An introduction among all driver groups, on all road types and on a *Mandatory* basis was preferred. A half-open, *Supportive* (active accelerator) system, was considered as the best option at that time: Stakeholders believed that that this scenario would produce the best results in terms of safety, environment and congestion (Cunningham & Sundberg, 2006). A survey conducted by the OECD also indicated that almost all of its member countries support the installation and use of *Informative* ISA (OECD/ECTM, 2006). Although ISA technology has been available for some time, and reducing crash risk has been high on the political agenda in Europe, little progress has been made with implementing ISA. Whereas initial estimates suggest that the date when *Mandatory* ISA is fitted and used in the whole of the European fleet would be around 2035, clearly such targets cannot be met in the absence of strong political backing for ISA (RoSPA, 2016).

5.1 Implementation scenarios

Two general scenarios are envisaged for implementing ISA; Authority Driven and Market Driven and these are summarised as follows by the Royal Society for the Prevention of Accidents (see RoSPA, 2016).

5.1.1 Authority driven implementation

In an authority driven scenario, adoption of ISA would be encouraged initially and eventually required. In this scenario bodies that could enable quicker up-take of ISA would play a more proactive role, mainly through financial encouragement or legal punishment. For instance,

- Government bodies could lead by example by equipping their vehicle fleets with ISA technologies
- Compulsory fitting of ISA devices could be specified as a licencing requirement for public services vehicles such as busses and taxis
- Lower insurance premiums could be offered, based on *Mandatory* speed limiting and to a lesser extent for vehicles equipped with *Advisory* or *Supportive* ISA systems
- ISA could be used to help prevent crashes and injuries among high-risk groups of road users including; younger and older aged drivers and those who have a known propensity for speeding

5.1.2 Market driven Implementation

In a market driven scenario, users choose to have ISA because they want it. This scenario emphasises the role of car manufacturers and the subsequent consumer choices made by fleet managers and private car buyers in the proliferation of ISA equipped vehicles on the roads.

5.1.2.1 Euro NCAP

The Euro NCAP protocol began awarding points for safety assist technologies as part of their Safety Assist score in 2009. This score is determined from tests to the most important driver assist technologies that support safe driving to avoid crashes and mitigate injuries. The recognition of ISA technologies constitutes an important step in promoting the large-scale deployment of ISA in the future: Cars will almost certainly need to have a speed assistance system fitted as standard in order to qualify for the coveted 5-star rating. The current Euro NCAP protocol (Euro NCAP, 2017) actively promotes the installation of speed assistance systems that;

- Inform the driver on the present speed limit;
- Warn the driver when the car's speed is about the set speed threshold;
- Actively prevent the car from exceeding or maintaining the set speed

The Euro NCAP tests also take account of the functionality of the system to ensure that it can be used without undue distraction to the driver. For systems that actively control speed, tests are carried out to ensure that the system does this accurately (Euro NCAP, 2018).

5.1.2.2 Stimulating demand

A number of financial and non-financial incentives have been proposed to encourage drivers to install and use ISA technology. Financial incentives can be provided either by reducing installation costs or through continuous discounting. The former will encourage drivers to purchase the system, whereas the latter would be more effective in encouraging drivers to use the system once it has been installed. A number of variants of these approaches were discussed by Chorlton, Hess, Jamson, and Wardman (2012). In addition to financial rewards, the non-fiscal incentives discussed included; increasing the number of penalty points for speeding and also the length of time these points remain on a driver's record. Bundling safety features with more attractive features (e.g. entertainment packages) at the point of sale were also considered. Two variants of post-installation discounting were also discussed; fuel rebates or cash back on a driver's insurance premium provided they use the system for a certain proportion of their driving.

Some of the studies reviewed in this report examined schemes designed to drive market demand for ISA systems. For instance, the participants in the Danish Pay-as-You-Speed study were awarded bonus points, linked to a discount on their insurance for driving below the speed limit. Whereas this scheme was very successful in reducing speed and speeding, researchers in the study found that the offer of a 30% discount on insurance premiums was not sufficient to encourage younger drivers (under 24-year olds) to participate in the research (Lahrmann, Agerholm, Tradisauskas, Berthelsen, & Harms, 2012).

5.1.2.3 Willingness to pay

Private motorists would have to bear some (or perhaps all) of the costs involved in equipping their vehicles with ISA so many studies have attempted to determine how much drivers would be willing to pay to have ISA installed. In the early Lund trial, Almqvist and Nygard (1997) established that 58% of drivers could envisage paying to have ISA installed, but 42% would not pay the average estimated cost (approximately £66.57). It seems that willingness to pay is also influenced by the nature of the ISA systems. For instance, Bidding and Lind (2002, as cited in; Jamson, Carsten, Chorlton, & Fowkes, 2006) reported that 50% of drivers using an *Informative* ISA system, 34% using an *Advisory* (warning) system and between 20-40% of those who used *Supportive* (active accelerator) systems were willing to pay to keep it after the end of the trial, suggesting that willingness to pay may be contingent on the degree of interventional support that the system provides.

5.1.3 Market penetration

Market penetration of ISA under these different deployment scenarios for the 60-year period between 2010 and 2070 was modelled by U.K. researchers (see Lai, Carsten, & Tate, 2012) and the results are shown in Figure 7. This indicates that *Advisory* ISA would predominate if a market driven approach is taken to the deployment of ISA technologies. In contrast, in an authority driven scenario, *non- Mandatory* systems would eventually be superseded by *Mandatory* systems by around 2045.

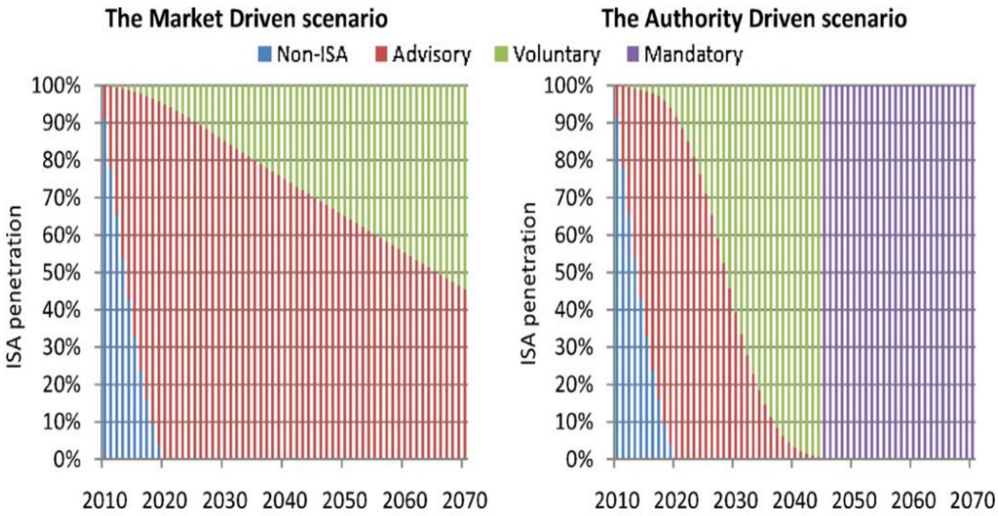

Figure 7. Penetration of ISA under different deployment scenarios (Source: Lai et al., 2012).

Crash outcomes were also predicted based on these two scenarios. The estimates suggested that ISA would deliver substantially greater safety benefits in an Authority Driven rather than in a Market Driven scenario. It was predicted that the Authority Driven scenario would reduce fatal crashes by 30% and serious crashes by 25% whereas the Market Driven scenario would reduce fatal crashes by 13% and serious crashes by 8%. Overall, 16% of crashes would be prevented in an Authority Driven scenario and 5% of crashes would be prevented under a Market Driven scenario (Lai et al., 2012).

5.2 Costs and benefits analyses

Implementation of speed control using ISA technologies will require a substantial investment, so it is prudent to consider whether or not this initiative would be worthwhile from a financial perspective. Benefit-to-cost ratios (B/CRs) are used to compare the net present values of the overall benefits of an intervention to the overall costs. As a rule of thumb, for an intervention to be implemented, benefits should outweigh the overall costs substantially. For safety schemes, a B/C ≥ 3 is generally regarded as a threshold for justifying investment. Comprehensive cost benefit analyses have been undertaken as part of some of the ISA studies discussed in this review, including the EU-funded PROSPER study, the ESVC and ISA-UK projects. The results of a cost benefit analysis that was conducted in Australia are also summarised in this review.

5.2.1 PROSPER

A cost benefit analysis was conducted as part of the EU-funded PROSPER project (Cunningham & Sundberg, 2006). The results, shown in Table 200 detail the B/CRs for Market Driven and Authority Driven scenarios, under *Mandatory* ISA conditions. This shows that in all countries and for both implementation scenarios the benefits of *Mandatory* ISA outweighed the costs by a margin of at least 2 to 1. The Authority Driven scenario outperformed the Market Driven scenario substantially and also exceeded the justification threshold (i.e. B/CR ≥ 3) in all countries except Spain. It is interesting that the B/CR for Spain was lowest, given that speeding was more problematic there than in some of the other countries in this study. However, the researchers suggested that since the Spanish vehicle fleet was large for the volume of travel undertaken, the cost of equipping such a large fleet is relatively high, compare to these other countries.

Table 20 Benefit-to-cost ratio of ISA scenarios calculated in PROSPER (Adapted from Cunningham and Sundberg (2006))

Country	Market-Driven Scenario	Authority-Driven Scenario
Belgium	3.5	4.5
Britain	3.1	4.0
France	2.4	3.3
Netherlands	2.6	3.8
Spain	2.0	2.5
Sweden	2.5	3.4

5.2.2 EVSC

A cost benefit analysis was also carried out as part of the UK EVSC project (Carsten & Tate, 2005). The results are summarised in Table 211 in terms of *Advisory, Driver Select* (drivers could enable or disable control of maximum speed) and *Mandatory* ISA (vehicle speed was limited at all times). Speed limits were classified as 'fixed' (posted limit), variable (additional information about slower sections on the network) and dynamic (additional lower limits to account for current conditions e.g. weather, traffic, incidents etc.).

Table 21 Benefit-to-cost ratios for ISA variants estimated in the UK EVSC project (Adapted from Carsten & Tate, (2005))

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 in increase by 2.9% per annum.

All of the B/CRs that were estimated exceeded the 3.0 threshold. The lowest B/CRs were calculated for the *Driver Select* system, and this was followed by the *Advisory* system. The largest B/CRs were estimated for the *Mandatory Dynamic* system: 12.2 for the low GDP growth scenario and 16.7 in the high GDP growth scenario. The B/CRs for Compulsory usage of *Mandatory* ISA (i.e. all vehicles would be required to use *Mandatory* speed limiting ISA) were in a range from 7.4 to 16.7, i.e. the payback would be between 7 and 16 times the cost of implementing the scheme. This study also estimated some 'one-off' costs for implementing ISA in the UK in 2010 including; establishing the ISA mapping system (£8 million for a 'fixed' speed limit system', £12 million for a 'variable' speed limit system and £43 million for a 'dynamic' speed limit system. Additional, annual costs were estimated as £2.25 million and £1 per vehicle for a fixed or variable system and £4.5 million plus £5 per vehicle for a dynamic system (Carsten & Tate, 2005).

5.2.3 ISA-UK

A cost benefit analysis was also performed as part of the ISA-UK project (Carsten et al., 2008). Lowest and highest estimates from this analysis are shown in Table 222 in terms of one Market-Driven and three Authority-Driven scenarios (depending on the date of full implementation). The overall B/CRs were also calculated and these amounted to 3.4 for the Market Driven scenario and 7.4 for the Authority Driven scenario. These estimates are broadly in line with those produced in the PROSPER project and further confirm the superior potential of the Authority Driven approach in terms of providing value for money.

Table 22 Lowest and best estimated BCRs for Market-Driven and Authority-Driven implementation of Mandatory ISA in the UK (Adapted from Carsten et al., (2008))

Implementation Scenario	Lowest estimated BCR	Highest estimated BCR
Market-Driven	1.6	3.1
Authority Driven (2045)	2.8	5.5
Authority-Driven (2040)	3.0	5.7
Authority-Driven (2035)	3.1	5.7

5.2.4 Australia

A comprehensive analysis of the potential of ISA was also conducted in Australia by Doecke and Woolley (2010). The results of their economic analysis for two commercial ISA systems Speed Alert and Speedshield are shown in Table 233 in terms of B/CRs and Payback Period at 0-8% discount rates if all vehicles were fitted with ISA over the 20 year duration of the scenario that was used. The discount rates were included to reflect the return on investment that could be gained elsewhere, and these have the effect of devaluing benefits (and costs where warranted).

Table 23 Economic analysis results if ISA was implemented in all vehicles in Australia (Source: Doecke & Woolley, (2010))

ISA device	BCR			Payback Period (years)		
	0%	4%	8%	0%	4%	8%
Advisory-Speed Alert	2.89	2.36	1.92	3.7	4.0	4.3
Advisory Speedshield	2.29	1.89	1.58	6.1	6.7	7.5
Supportive-Speedshield	2.42	2.09	1.79	5.7	6.2	6.9
Limiting - Speedshield	4.03	3.48	2.98	3.0	3.2	3.5

These results show that the *Limiting* ISA system would produce the greatest return on investment: The B/CRs were consistently highest for *Limiting* (*Mandatory)* ISA where discounted values were very close to or exceeded the threshold of 3. The payback periods ranged from three years for the *Limiting* system up to 7.5 years for other forms of ISA.

Further economic analyses were reported in this Australian study for a number of different implementation scenarios e.g. market-driven, new vehicles only, fleet vehicles only, heavy vehicles only, for young drivers only and for systems using Navaid devices. Due to the complexity of these analyses it is not possible to represent them adequately within the scope of this review. Interested readers should consult Doecke and Woolley (2010) for full details. However, the overall findings are summarised as follows;

- The B/CR and payback period were heavily influenced by the unit price
- B/CRs range from 0.29 to 4.03 over 20 years for ISA implementation
- Payback periods range from 3 to 100+ years for ISA implementation
- Break even prices increased as the level of ISA intervention increased
- The B/CR was greatest in the 'all vehicles' and the 'new vehicles' implementation scenarios
- Even if Navaid ISA devices are seldom used and are less effective than dedicated ISA devices they may still prove a cost-effective option
- If the increased risk for young drivers could be taken into account, implementation of ISA on vehicles used by young drivers may present a cost-effective option
- Limiting ISA generally produced the greatest B/CR for a given scenario
- Installing the strongest possible ISA device on young drivers' vehicles and in new vehicles may represent the most cost-effective method of implementation

The researchers also cautioned that care should be taken when deciding on an ISA implementation path that older, less safe vehicles are not made more attractive to drivers who are more likely to be responsible for a speeding crash, such as young drivers.

In all of the cost benefit analyses reported in this review, almost all of the costs were attributable to the in-vehicle equipment. The consistency with which the critical threshold B/CR (≥ 3) was exceeded suggests the implementation of ISA on a large-scale is entirely justifiable from a social investment perspective. These analyses also demonstrate that the more forceful Authority Driven scenario represents the best option in financial terms. However, the benefits also depend on the form of ISA used and the rate with which they are adopted. Studies conducted in the late 1990s and early 2000s suggest that between 20-58% of drivers who tested various ISA systems expressed willingness to purchase these systems, and such willingness was dependent on the level of support offered by the system. More recently, Vlassenroot (2011) assessed willingness to pay for four different types of ISA systems (Informative, Warning, Supportive and Restrictive) in a sample of almost 6,000 Belgian and Dutch drivers. The results showed that although free placement was preferred for every system, most respondents expressed willingness to pay for less controlling systems i.e. Informative (30%) or Warning (24%). Supportive ISA was resisted more strongly (36%), but incentives such as smaller insurance charges (15%) and other subsidies (14%) would help to convince drivers to install this. Support for Restrictive ISA was lowest: over half of those surveyed indicated that they would never buy this ISA.

5.3 Barriers to implementation

Some barriers to ISA implementation have been identified and these have hindered progress in implementing ISA on a wider scale. Researchers from the EU-funder PROSPER project, which was conducted in Belgium, France, the UK, Sweden, Spain, the Netherlands, Germany and Hungary (Cunningham & Sundberg, 2006) tested stakeholder opinion regarding barriers to ISA. Five stakeholder groups were consulted; political, government and governmental institutions; scientists and research centres; pressure groups and mobility actors; and commercial companies. Nine main issues were identified, and these are presented in order of importance;

- Technical functioning (reliability, accuracy etc.)
- Applicability to the road network
- Observed benefit to the customer
- Price of ISA
- Liability problems in case of accidents/violations/malfunctioning
- Customer's privacy
- Needed time for renewal of the vehicle fleet
- Image of the car industry
- Need for extra driving education

More recently, van der Pas, Marchau, Walker, van Wee, and Vlassenroot (2012) compiled a systematic and representative inventory of 'uncertainties' surrounding ISA implementation and asked experts in this field to assess the extent to which these uncertainties represented real barriers to implementation. A summary of the most important barriers identified in this study is shown in Table 24.

Table 24 Uncertainties that represent the most important barriers to ISA implementation by ISA type (Adapted from van der Pas et al., (2012))

Uncertainty Description	Ranking*		
	Advisory/ Informative	Supportive	Mandatory
Technical characteristics and updating of the speed limit database	1	5	7
Liability allocation in case the ISA system malfunctions	2	1	1
Factors that contribute to driver acceptance of ISA and the degree to which these factors influence acceptance	3	7	5
Willingness of drivers to use ISA	4	2	2
Identity and relative importance of stakeholders involved with implementation	5	4	3
Effects of different implementation strategies (i.e. choice of ISA types)	6	3	4

*Item ranking from highest (1) to lowest (7) uncertainty.

These findings suggest that both the long-term effects and the effects of large-scale implementation of ISA remain uncertain and that these are the most important barriers to the implementation of the most effective types of ISA. Van der Pas and his colleagues suggested that one way to deal with these uncertainties would be to commence with small-scale implementation and then expand penetration gradually in order to see how ISA influences the transport system over time.

Concerns regarding technical functioning, liability issues, and applicability to the whole road network as well as driver acceptance of and willingness to use ISA also constitute significant barriers to implementation of ISA technologies. The ETCS position paper on ISA "Intelligent Speed Assistance – Myths and Reality" shed further light on some of these barriers and how these might be addressed (ETSC, 2006). Regarding technical functioning, they state that accumulated evidence from field trials confirm the accuracy, efficiency and robustness of ISA technologies. ISA technologies are technically much simpler than other automatic devices e.g. collision avoidance systems. The next step involves integrating ISA technology into the original system architecture of cars and this should be done in such a way as to ensure compatibility. The ETSC see the liability issue as a 'red herring' because industry has already implemented other ITS systems (e.g. advanced cruise control etc.) that intervene in controlling a vehicle to assist the driver without significant concern for liability. Regarding public/driver support, the ETSC cites the results of the SARTRE 3 survey and field trials (which were described in this review) which showed that a majority of drivers are in favour of ISA systems and support increased as they gained experience with using the technology. They also believe that the choice of implementation strategy (Market Driven or Authority Driven) will affect the speed at which ISA proliferates in the road traffic system and this is the domain of policy makers in general and legislators in particular.

5.4 Official support for ISA

Whereas the findings from surveys and field trials indicate that there is considerable public support for ISA, an implementation strategy is needed to speed up the process of implementation of ISA in vehicles and this requires inputs from policy makers in general and legislators in particular. Stakeholder views about the legal obstacles to ISA deployment were elicited in PROSPER (Cunningham & Sundberg, 2006) and these are presented in order of importance;

- Development of EU-directives for use of ISA in different vehicle types
- Legislation about liability issues (accidents/violations/malfunctioning
- International harmonisation of standards and test procedures
- Translation of EU-directives into national legislation
- Homologation of vehicles with an ISA system

In 2008 the EU Commission acknowledged that it has "a clear role to play in creating the right framework conditions for accelerated and coordinated deployment of ITS" (EU Commission, 2008 p.4). Thereafter, the EU Commission published Directive 2010/40 which addresses standards, rules on liability and the intention to set up a group to advise on ITS.

Some progress was made subsequently on a number of these issues. For instance, work is being carried out on developing and planning the maintenance of accurate, up-to-date digital speed maps. The Transport Network ITS Spatial Data Deployment Platform (TN-ITS), (which evolved from work performed in several EU-funded projects), was established in an inaugural General Assembly in Dublin in June 2013. Supported by the EU Commission, the TN-ITS platform serves to facilitate and foster the exchange of ITS-related spatial data between public road authorities as data providers and map makers and other parties as data users. TN-ITS focuses on the exchange of information on changes in static road attributes e.g. speed limits. Current members include transport authorities in Norway, Sweden, Finland, Estonia, Lithuania, Slovenia, Hungary, Belgium, The Netherlands, France, Spain, Portugal, Greece, Ireland and the UK, along with the map makers TomTom and Nokia Here and key stakeholders such as the ETSC and ERTICO (TN-ITS, 2018). The EU Commission also supported the harmonisation of speed limits throughout the EC as a basis for the introduction of legally enforceable speed limits in the region (EU Commission, n.d.).

Whereas much progress has been made in overcoming the technical, legal, commercial and attitudinal barriers to ISA implementation, until recently, the pace of this progress has been somewhat slow, indicating that more needed to be done at EU and national level to support the widespread introduction of ISA technologies within the EU as a whole.

5.4.1 Recent developments within the EU

On 17 May 2018, the EU Commission published a large package of transport policy proposals termed "The Third Mobility Package" involving key measures to improve road safety in the EU. This included revision of the "General Safety Regulation" which incorporates a set of new vehicle safety measures, including mandatory installation of new driver assistance technologies which are expected to come into force from 2020 onwards. The Commission stated that;

"Intelligent speed assistance, lane-keeping systems, driver drowsiness and attention monitoring and distraction detection and reversing detection systems have a high potential to reduce casualty numbers considerably. In addition, those systems are based on technologies which will be used for the deployment of connected and automated vehicles too. Therefore, harmonised rules and test procedures for the type approval of vehicles as regards those systems and for the type-approval of those systems as separate technical units should be established at Union level" (EU Commission, 2018, p.14).

The ETSC supports the proposed measures, especially those with the most potential for reducing death and injury such as overridable ISA and Automated Emergency Braking (AEB), both of which are already widely available on the market. However, the ETSC also believes regulation is needed to make sure that the benefits are extended to all new vehicles as standard (ETSC, 2018). Euro NCAP also promotes installation of Intelligent Transport Systems (ITS) to help drivers to control their speed. It assesses the three ITS functions that have been the central focus of this review i.e. *Voluntary, Advisory* and *Mandatory* ISA taking into consideration system accuracy and potential for driver distraction (Euro NCAP, 2018).

5.5 ISA in the context of Connected and Automated Vehicles

The automation of any system usually follows a well-defined developmental trajectory (Endsley, 2018) and the five levels of vehicle automation that were outlined by the Society of Automotive Engineers (2018) are set out in Figure 9. This illustrates that driver assistance technologies such as ISA represent the first level of automation.

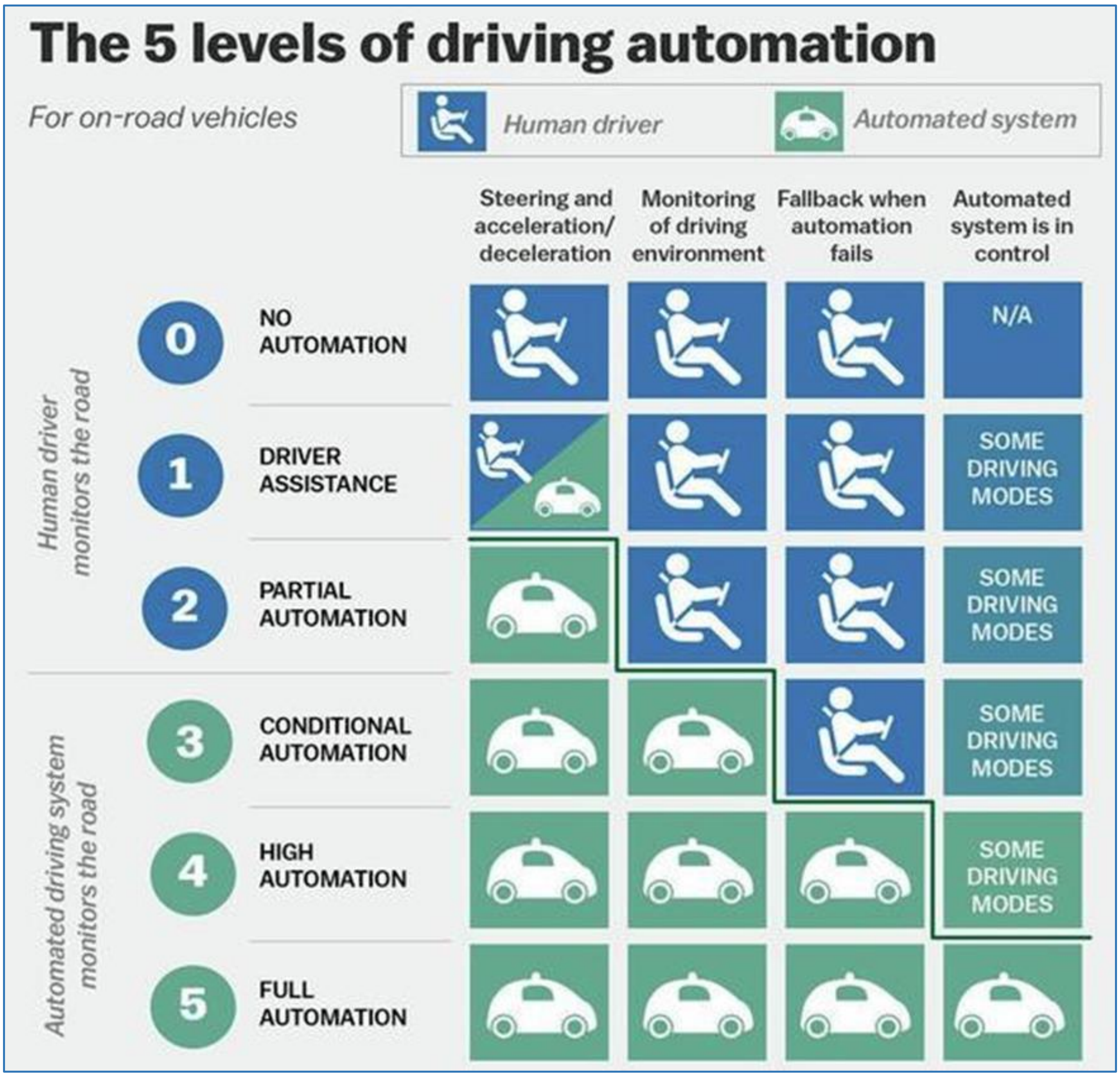

Figure 8: The 5 levels of driving automation. (Source: SAE https://www.sae.org/standards/content/j3016_201806/)

It is widely acknowledged that systems such as Driver Assistance employ technologies that will also be used as part of the development of connected and autonomous vehicles (EU, 2018).

Currently much of the focus in relation to vehicle automation concerns so-called ‘self-driving' cars i.e. vehicles that drive themselves for a large part of the time (level 3) or cars that can drive themselves all the time within designated areas (level 4). Some vehicle manufacturers such as Ford reportedly plan to skip over level 3 and go straight to level 4. Their CEO Mark Fields claims that they will have cars with no gas pedal and no steering wheel deployed in certain cities in 2021. Toyota also plan deployment of level 4 autonomous vehicles for use by ride-sharing companies. Daimler expects large scale commercial production of level 4 and 5 vehicles to take off between 2020 and 2025 (Emerj, 2018). Analysis conducted by McKinsey

& Company (2016) suggests that subject to progress on technical, infrastructure and regulatory challenges, up to 15% of all new vehicles could be fully autonomous by 2030, rising to 80% by 2040.

Clearly, however there is still quite a way to go before fully autonomous vehicles designed for commercial and domestic use can be developed, tested, approved, marketed and ultimately proliferate on our roads. For instance, Euro NCAP has not included Automated Driving systems yet in the safety star ratings because they are still learning how these systems are currently designed, what their physical limitations are, and what safety benefits can be expected. Instead, Euro NCAP focuses on providing information about the current state-of-the art and comments on the design strategy taken by the car manufacturer, within the context of what is legally allowed according to European regulation and this includes ISA technologies (Euro NCAP, 2018)

The evidence presented in this review shows that ISA technologies which are available currently are effective at reducing crash risk and thus can help to reduce crash-related injury and death significantly in the short to medium term.

6 CONCLUSIONS AND RECOMMENDATIONS

The evidence presented in this review demonstrates that ISA technologies are effective in supporting drivers with managing speed. Experts in this field agree that by restricting the vehicle to the posted speed limit, ISA provides one of the most effective strategies for reducing inappropriate speeds, thereby improving road safety (ETSC, 2015). Furthermore, due to rapid advances in the development of low-cost technologies (e.g. GPS and nomadic devices) it is clear that the widespread deployment of ISA to support speed management is entirely feasible. Indeed, from a technical point of view, large-scale implementation of ISA is possible in the short-term. In this regard, the ETSC reported recently that a major new study conducted by TRL for the EU commission identified ISA among a number of technologies that are suitable for mandatory fitting as part a review of EU vehicle safety legislation because it is technologically feasible, currently on the market and provides a positive B/CR (ETSC, 2018).

All of the ISA systems that were examined as part of the review were effective in reducing speed at some level, during a specific timeframe. A substantial accumulation of research evidence demonstrates comprehensively and conclusively that there is a clear relationship between speed and crash risk. Evidence cited in this report also shows that the introduction of ISA would undoubtedly improve road safety to the extent that, when used correctly, these systems are very effective in reducing driving speeds, and speeding is a major risk increasing factor in terms of crashes, injury and death. However, some of the studies in this report also indicated that the anticipated safety benefits of ISA may be offset to some extent as a result of negative behavioural adaptation and/or driver distraction. Moreover, successful implementation of ISA depends heavily on driver acceptance of the principle of in-vehicle control generally and on their willingness to install these systems and to use them correctly. Different types of ISA technologies impact differently on driver behaviour and on traffic safety: The more controlling the system, the more effective it is in reducing speed and road safety generally, but the less acceptable it will be to drivers. Research shows that the greatest benefits will be derived through the use of *Mandatory* ISA. However, this form of speed control was least acceptable to drivers who participated in field trials.

The pace of the uptake of ISA technologies will be dictated by the implementation strategy that is used. The proliferation of ISA would proceed faster in an *Authority Driven* scenario than it would in a *Market Driven* scenario. However, the evidence in this report suggests that this approach would be less acceptable to the general public. In addition, a *Market Driven* approach to implementation will likely favour the fitment of ISA systems that *Advise* or *Support* drivers, which have been shown to be less effective in reducing speeding and consequently in reducing the frequency and severity of road traffic crashes.

More public engagement is required in Ireland to gauge acceptance of various forms of ISA and to identify the most effective ways to encourage voluntary uptake of ISA, by individuals or fleets. For instance, a communication plan should be developed which uses evidence from ISA research trials to explain the benefits of ISA to fleet managers and to the general public. In addition, a survey should be conducted to gauge public opinion generally and qualitative research (e.g. interviews, focus groups) should also be conducted to elicit the viewpoints of key stakeholders so that these can be taken into account when formulating an implementation strategy. Interestingly, research conducted by the RSA into Irish peoples' perceptions and attitudes towards next generation technologies such as Connected and Autonomous Vehicles (CAVs) showed that while 42% of those surveyed believed that self-driving cars will improve road safety, just 26% expressed a strong interest in owning such a vehicle (RSA, 2018). Given that ISA would be much easier and cheaper to implement, this suggests that the promotion of ISA should be undertaken the short to medium term. Also, since driver willingness to relinquish control over some and eventually all aspects of vehicle functioning will be key to the deployment of Connected and Automated Vehicles (CAVs), and since this review shows that many drivers appear reluctant to relinquish control of speed choice, it seems that more research is needed to identify the instrumental and psychological needs that are fulfilled by driving in general, and speeding in particular for some drivers, and to find ways to address such needs in a safer context.

The costs and benefits related to different types of ISA devices will have to be taken into account. Elaborate systems such as *Voluntary* ISA are likely to be too expensive for many drivers. However, ISA can be delivered much more cheaply using *Advisory* ISA systems via GPS and nomadic devices such as mobile phones.

In any event, the roll-out of ISA in Ireland will be contingent on the development and testing of digital speed maps. In his address to the RSA International Road Safety Conference in 2016, John McCarthy, a Senior Advisor in the Department for Transport, Tourism and Sport (DTTAS), outlined this process which entails a full review and update of speed limits on national, regional and local roads, possible legislative and regulatory changes, and benchmarking against engineering guidelines and standards, and reported that DTTAS has been tasked with a number of actions supporting this process. DTTAS, in collaboration with the Local Government Management Agency (LGMA), are working currently to progress a digital speed database for Ireland as set out in Action 13 in their Speed Limit Review (Department for Transport, Tourism & Sport, 2013).

The evidence presented in this review shows clearly that ISA technologies that are available currently represent an efficient and effective way of controlling speeding and thus improving road safety **immediately.** Furthermore, these systems are relatively cheap and easy to fit and retrofit. For these reasons, it is recommended that more effort should be focused on promoting and supporting the use of ISA technologies in the short to medium term while in preparation for the widespread proliferation of Connected and Autonomous Vehicles (CAVs).

6.1 ISA in the context of a Safe System approach

Traffic safety depends on creating safe roads, safe vehicles and safe drivers. As illustrated by Cunningham and Sundberg (2006), ISA forms part of an ICT solution which straddles the interface between Safe vehicles and Safe drivers (see Figure 9). The speed of motorised vehicles is a central issue because it affects both crash causation and severity and influences the effectiveness of a range of measures. This understanding is central to the Safe System approach (EU Commission, 2018c). The evidence presented in this review shows that ISA technology can play an important role in preventing speeding.

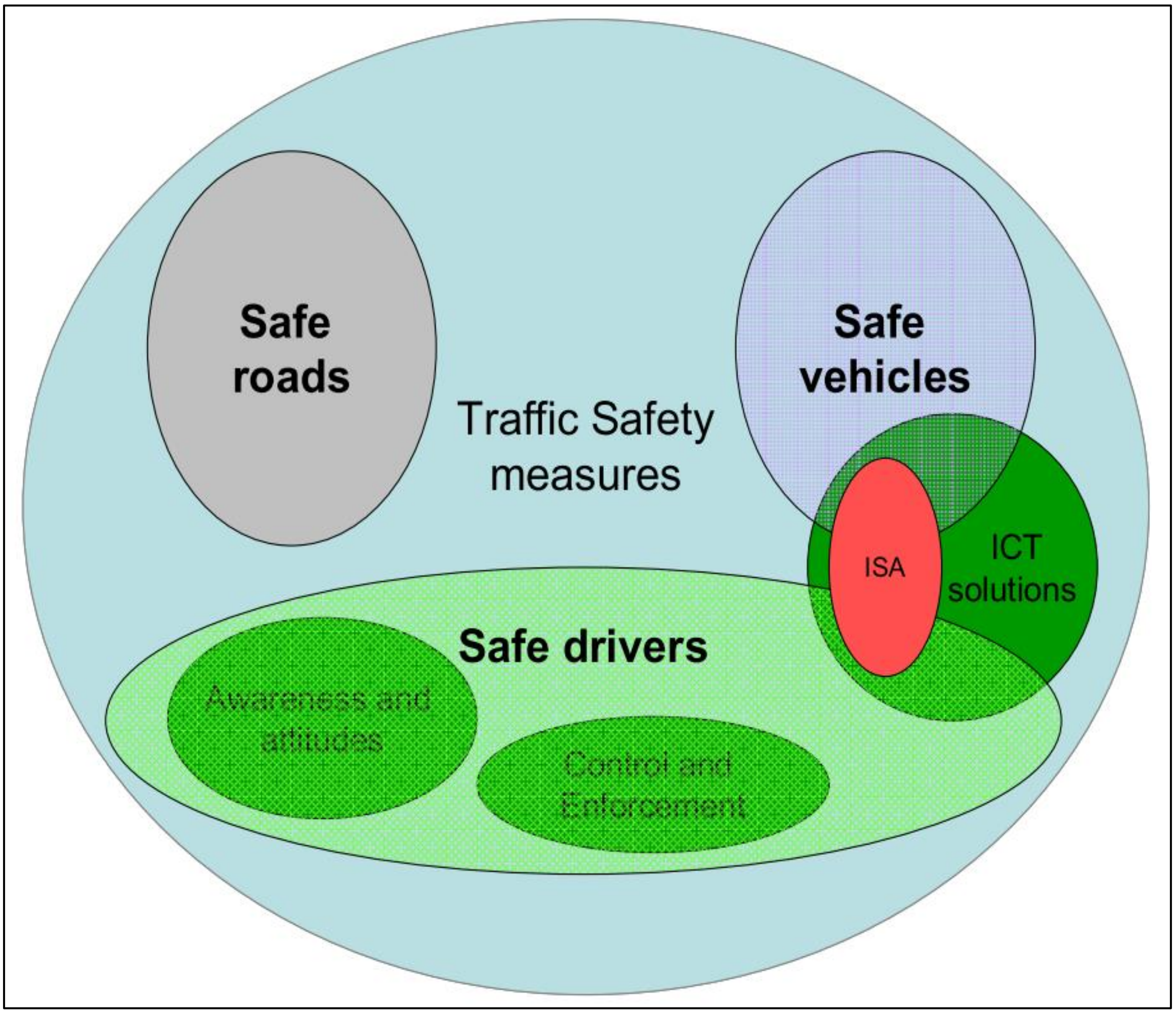

Figure 9. ISA in the context of traffic safety measures (Source: Cunningham and Sundberg (2006)).

As demonstrated clearly in this document, this approach, when coordinated with existing measures, will undoubtedly help to reach the targets set out in the Government Road Safety Strategy (2013 – 2020) in terms of reducing collisions, deaths and injuries on Irish roads.

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APPENDIX A INFORMATION SOURCES

Table 25 List of websites and electronic databases used as sources for literature on ISA

Source	Host	Date[6]
FOT-NET DATA	http://wiki.fot-net.eu/index.php?title=Intelligent_Speed_Adaptation_trials	16/09/2018
Google	www.google.ie	01/09/2018
Europa	http://europa.eu/pol/trans/index_en.htm	17/09/2018
European Transport Safety Council (ETSC)	http://etsc.eu/	20/09/2018
Eurostat	http://ec.europa.eu/eurostat	20/09/2018
Institute for Transport Studies (ITS) University of Leeds	http://www.its.leeds.ac.uk/projects/isa/publications.htm	01/04/2018
International Road Traffic and Accident Database (IRTAD)	http://internationaltransportforum.org/irtadpublic/index.html	15/03/2018
Organization for Economic Co-operation and Development	http://www.oecd-ilibrary.org/	04/03/2018
SWOV	http://www.swov.nl/index_uk.htm	17/08/2018
Royal Society for the Prevention of Accidents (RoSPA)	http://www.rospa.com/	24/08/2018
RSA	http://rsa.ie/	01/09/2018
Science Direct	www.sciencedirect.com	01/09/2018
Transport Research Innovation Portal (TRIP)	http://www.transport-research.info/	25/08/2018
Transportation Research Information Database (TRID)	http://trid.trb.org/	14/08/2018
Web of Science	apps.webofknowledge.com	31/08/2018

[6] Date when the most recent comprehensive search was conducted

Table 26 Individuals and organisations contacted for information on ISA

Country/Region	Organisation	Individual
EU	EU/Europa	Rudolf Koronthály
	ERTICO	Maxime Flament
		Kees Wevers
	ETSC	Ellen Townsend
	Euro NCAP	Michiel Van Ratingen
UK	ITS, Leeds University	Professor Oliver Carsten
Ireland	Road Safety Authority	Sharon Heffernan
Sweden	Trafikverket Swedish Transport Agency	Anders Lie
Finland	VTT, Finnish Transport Agency	Harri Peltola
Belgium	Flemish Transport Ministry	Nele Dedene
Netherlands	Dutch Ministry of Transport	Marcel Otto

APPENDIX B SUMMARY TABLE OF ON-ROAD ISA TRIALS[7]

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
Europe										
France	Saad & Malaterre, 1982	ONSER	Urban	1 drive of 200km	12 drivers/ 1 vehicle	Mandatory Limiting - Driver-set maximum speed	Observations & Interviews		Speeds tended to be set above limit	
Sweden	(Persson et al., 1993)	Lund	Urban	1 hour	75 drivers/ 1 Volvo 750	Advisory- Speed limit display; Limiting - Speed limiter (active throttle with no override). Limit set to 50 km/h	Speed; Travel time; Red running; Car following interactions; Conflicts; Emissions; Attitudes	General speed reduction; Less red light running; Less conflicts	Increased speed on approaches and in turnings; Deteriorated behaviour in interactions	Improved after testing the system
Sweden	(Almqvist & Nygård, 1997)	Eslöv	Urban	2 months	25 drivers/ Drivers own vehicles	Advisory - Speed limit display Limiting - Speed limiter (active throttle with no override possibility)	Speed; Travel time; Interactions; Conflicts; Emissions; Opinions	General speed reduction; Improved behaviour in interactions	Travel time increased by 5%	Improved after testing the system

[7] Adapted from Young and Regan (2002)

[8] This describes the amount of exposure each driver had to ISA or the total distances driven in the trial. In some instances, only an approximate duration or distances are known.

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
Sweden	Vägverket, 1999, 2002; 2003a; Lind, 2000; Wallen, Warner & Aberg, 2008	"Right Speed" - Borlänge	On-road		400 private and commercial drivers & vehicles	Advisory (Informative) ISA system for Quality Insurance	Mean, maximum speed; % time spent speeding; Travel time; Fuel consumption	Mean speed reductions of 3 to 4 km/h observed; Greatest effect 50 km/h speed zones; Reduced amount of time above speed limit; Reduced speed variance; Lower approach speeds at intersections; Financial incentive increased driver motivation to reduce speed; Reductions in fuel consumption; No increase in travel times	Decreasing effect over time (on speed)	Easier to adhere to speed limits; Commercial drivers not as positive as private drivers; Auditory warning annoying
Sweden	Adell, 2007; Adell & Várhelyi 2008; Hjälmdahl et al., 2002; (90) Hjälmdahl, 2002;	"Lund ISA"	On-road	3-11 mths.	290 vehicles 50% private 50% commercial	Supportive (Active Accelerator Pedal-AAP)	Speed; Following behaviour; Interaction with road users; Travel time; Emissions;	Sig. reduction in average speed and speed variation; AAP improved interactions with pedestrians & headway; Better car following behaviour; Decreased fuel consumption & emissions	Drivers forgot to change speed outside test area, suggesting delegation of responsibility; Decreasing effect over time (on speed); Drivers with negative	Driver acceptance high within built-up areas; Younger male drivers more negative: Older female drivers more positive; Drivers found the system useful but not satisfactory;

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
	Hjälmdahl, 2003						Acceptance		attitude more likely to use kick-down function to exceed speed limit	Perceived decrease in risk of getting fined; Attitudes towards the system tended not to change after use
Sweden	Sunberg, 1999; Vägverket, 2002; 2003d	"Smart Speed" - Umeå	On-road		Private and public transpor t drivers/ 4,000 vehicles	Advisory (Informative) Light and auditory signal presented when limit was exceeded	Speed: Acceptance	Mean speed reductions of up to 0.9 km./h on 30-50 km/h roads; No decrease in speed in 70 km/h zones (measured at the roadside)	Driving pleasure decreased; Frustration increased; Perceived longer travel times	Greater awareness of speed limits and vulnerable road users; Easier to adhere to speed limits; Over two-thirds of drivers wanted to keep ISA at end of trial
Sweden	Vägverket, 1999, 2002; 2003b	"Lidköping – Spearhead -ing the way to vision zero"	On-road		Private, company and municipal authority drivers/ 150 vehicles (Informat ive); 130 vehicles (Active	Advisory (Informative) Supportive (AAP)	Speed; Acceptance	Reduction in average and maximum speeds; Calmer traffic flow (fewer stops and braking); No evidence of increased travel times		Drivers reported highly positive attitudes towards the ISA systems; Systems (especially AAP) made it easier to comply with speed limits and improved road safety; Perceptions of 'holding up' the

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
					Accelerator)					other traffic with AAP
Sweden Stockholm	Transek & SWECO VBB, 2005	ISA for Stockholm	On-road	6 mths.	20 vehicles; 130 drivers	Supportive (AAP); (3 mths.) Vibrating accelerator (3 mths.)	Speed; Acceptance	Decrease in perceived speeding violations (less often and less serious); Mean speed decreased especially on higher speed- limited roads		75% of drivers wanted to keep the system Two-thirds of drivers found the system impairs driving pleasure. Many found it effortful and frustrating (esp. the active system). Perceptions of 'holding up' traffic. Perceived longer travel times.
Sweden Gothenburg	Transek, 2003		On-road (2002 – 2003)	6 mths.	16 busses	Supportive (Active accelerator)	Speed; Acceptance	Decrease in speeding violations; No perceived increase in travel times		Bus drivers had negative attitude to ISA
Nether-lands Groningen	(Brookhuis & de Waard, 1999)		On-road	1 drive with ISA active	24 drivers	Advisory – Audio/visual feedback	Speed; Mental workload; Acceptance	Reductions in mean speed, speeding and speed variability	No sig. effect on workload	Continuous feedback most acceptable; Found system reduced speed variability

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
Nether-lands Tilburg	(Duynstee & Martens, 2001) Van Loon & Duynstee	AVV Tilburg trial	On-road	12 months	20 cars – 479 drivers; 1 bus – 20 drivers	Limiting - Mandatory speed enforcement	Speed; Acceptance	Average speed lower; Less violation of other traffic laws	Mixture of ISA and non-ISA cars causes some irritations between the two groups.	Negative response in low speed areas (e.g. 18 km/h): Acceptance increases as speed limit increases 52% agreed ISA increased pedestrian and cyclist safety. 3% agreed ISA was safer for driver. Up to 65% of test drivers supported ISA. 30% other reference groups opposed it. Appreciation highest for 80 KM/H roads. Information and communication has a large effect on acceptance.

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
Nether-lands	Van der Pas et al., 2014	ISA for speed offenders	On-road	650,000 kms	51 speed offenders	Speedmonitor (recording ISA) Speedlock (Mandatory Limiting)	Crash likelihood; Speed variation	Reductions in crash likelihood Reduced speed variation, Smoother manoeuvring Improved interactions	Negative reactions from other drivers (tailgating and increased overtaking)	
Finland	Päätalo et al., (2002)		On-road		24 drivers	Advisory - Informing; Limiting - Compulsory; Recording	Speed acceptance; Travel time	All systems reduced percentage of time spent speeding; Limiting system was most effective No significant difference in driving times across systems	Mental demand highest for mandatory system. Effort, frustration and insecurity levels greatest for mandatory system	Poor acceptance of Compulsory system; Recording system most popular
Belgium, Ghent	Broekx et al. (2005) Valssenroot, 2008	PROSPER	On-road		34 cars; 3 buses	Supportive (Active Accelerator Pedal)	Speed; Acceptance; Voluntary use of the system	Small effect on speed; Not effected in 30 to 70 km/h zones; Decrease in 85 percentile in all speed zones; Effect larger in higher speed zones	Speed increases for some drivers; Average driving speed increases for infrequent speeders; Drivers more likely to drive at speed limit than under- causes increase in average speed Fast acceleration	30% of drivers voluntarily used system outside test period; Good acceptance and belief that the system is useful

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
									towards speed limit	
Denmark, Aalborg	Lahrmann, Madsen & Boroch, 2001; Nielsen & Lahrmann, 2005	INFATI	On-road	4 weeks	24 drivers	Advisory	85th percentile speed; Speed violations; Acceptance; Workload	Speeds reduced; Speeding violations reduced; Greater awareness of speed and of speed violations; Reduced mental strain monitoring speed limits		Lower acceptance in lower speed zones than in higher speed zones
Denmark. Aalborg	Agerholm et al., 2008; Lahrmann et al., 2007	Pay-as-you-speed (PAYS)	On-road Urban & Rural		146 drivers	Advisory-visual/audible warning i.e. Penalty points to reduced insurance costs	Speed	Most education in speed on rural roads with 80 km/h limit. Less on 110 km/h motorways and on urban 50 km/h roads; Most effective when incentive and information are provided	None	
France	Ehrlich et al, 2003; Driscoll et al, 2007	LAVIA	On-road	130,000 kms (approx.)	100 drivers/ 20 vehicles	Advisory; Voluntary: Mandatory	Speed; Acceptance; Driver behaviour	Mean speed reduced; Greater reductions for voluntary system	Increased pressure from other drivers	Mandatory system deemed less acceptable than voluntary system and even considered dangerous
Spain	Jiménez et al., 2008		On-road		8 drivers	Dynamic advisory	Speed; Acceptance	No change in mean and maximum speed; Percentage of travel distance spent speeding reduced;		Suggested safe speed deemed to be reasonable

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
								Speeding on bends reduced		
UK	Comte, 1996		Simulator		30 drivers	Limiting	Speed; Gap Acceptance; Following behaviour (headway); Red light violations	Reduced speeds; Longer headways; Reduced red light violations;	Increased frustration and time pressure; Risky gap acceptance behaviour	Less physical effort required to drive
UK	Carsten & Fowkes, 2000; Carsten et al., 2000	External Vehicle Control (EVSC) Project	On-road; Micro-simu-lation	1 X 67km route	24 drivers	Limiting - Mandatory; Driver Select (voluntary) limiting	Speed; Braking; Following behaviour; Acceptance; Workload	Excessive speeds reduced, especially with Mandatory ISA and in urban areas; Voluntary (driver select) system half as effective as Mandatory; Improved following behaviour; Less abrupt braking; Micro-simulation: Improved fuel consumption; Predicted decrease in injury; Full cost-benefit will be realised when fleet penetration is 60% or more	Time pressure and frustration increased; Driver select disengaged in high speed areas	The voluntary, Driver Select was considered “more useful” as a safety feature than the Mandatory system

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
UK	Lai et al., 2007a; Lai et al., 2007b; (also Carsten et al., 2008)	ISA UK Car & Truck Trial	On-road		79 car drivers (20 private & 20 fleet); 1 truck driver	Car & truck; Limiting	Speed; Workload; Attitudes and acceptance; Self-reported behaviour	Car: ISA reduced 85th percentile speeds & amount of time spent over the speed limit; Less effect in 20mph & 60mph zones: ISA reduced speed variability in low speed zones and incidents of severe braking; Physical demand reduced when driving with ISA; Non-significant reduction in mental demand and effort; Increased time pressure; Truck: Tolerance allowed for uphill meant not precise limit, but shifted speed distribution down & very rarely>5mph over limit; Speed variation reduced; Driver used override 0.2% of time on 30mph roads, slightly less on 50kph roads	Car: Drivers did not feel less vigilant with ISA; Reported more aware of speed limit, more likely to check speedometer, more likely to anticipate conflicts and more likely to attend other road users when driving with ISA Truck: Less speeding in 30mph zones but more in 40, 50mph zones in post period than baseline	Car: More likely to override system in 70mph (highest) speed zones, and if male, young, and/or prior intention to speed; Private drivers more overrides in urban, fleet drivers on motorways; Experience with ISA reduced intentions to speed and belief that speeding leads to shorter journey time; After trial, 54% willing to install on own car. 62% approved fitting to new vehicles, 56%approved fitting to all vehicles. Truck: Perceived usefulness & satisfaction low to start with &declined following experience with system Trust declined after using ISA Would not be willing to install

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
UK	Jamson et al., 2007; (also Carsten et al., 2008	ISA UK Simulator Trial	Simulator		32 drivers	Mandatory	Overtaking attempts and success rate; Time to collision; Maximum speed; Following behaviour; Workload; Acceptability	Little difference between 50% and 100% penetration scenarios; Using ISA, fewer attempts to overtake and more of those attempts abandoned; No difference in number of hatch encroachments, but ISA lengthened time in hatch area; No difference in minimum headway at start of manoeuvre but ISA shortened headway distance at end (drivers cut back in closer); Without ISA, drivers exceeded speed limits during overtaking; No change in headway during car following sections		No difference in workload & acceptability between 50% equipped and 100% equipped conditions

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
UK	Simpkins et al., 2007	ISA UK Motorcycle Trial	Test track		33 riders	Advisory; Informative; Assisting	Acceptance; Limited data on speed behaviour	Advisory/Informative system had little effect on speed; Assisting system reduced speed violations		Advisory system most useful; Informative not as good as expected (ratings lower post ride than pre-ride); Negative satisfaction for Assisting - least willing to install this; Majority of riders would consider installing Advisory or Informative systems; All systems thought to decrease crash risk; No concerns with stability
UK		Lancashire	On-road	9 months Over 4.5 million kms	402 regular, novice, fleet, taxi and bus drivers	Advisory (Visual & Auditory Warning) using nomadic devices		Small reduction on speed Larger reduction in proportion of speeding in 30 and 70 mph zones Significant reductions even when the system was used intermittently	Less effective with older drivers, whose baseline speeds tended to be lower Younger drivers more resistant to reducing speed	

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
UK	TRL	London Bus	On-road			Mandatory (controlled accelerator)	Speed Attitudes & Acceptance Emissions	Speed reduced Percentage time spent travelling over the speed limits reduced from a range of 15-19% to 1-3% in 20mph zones and 0.5-3% to 0-1% in 30mph zones (+/- 50km/h)	Some vehicle platooning. Some drivers concerned that other road users would become frustrated.	No significant difference in fuel usage. Reduced emissions. Some calibration problems initially but after these were sorted, driver acceptance increased.
EU Trans-national										
Sweden, NL Spain		MASTER	Urban; Rural; Motorway	2 Test drives	20 – 24 drivers in each country	Advisory – Speed limit display; Limiting – Active throttle with no override facility	Speed; Travel Time; Time-gap in car following Behaviour interactions; Workload; Opinions	General speed reduction; Smoother speed on approaches; Car following improved on 30 – 50 Km/h roads	Travel time increased by 7% Car-following deteriorated on 70-90 km/h roads Reported increases in frustration and decreases in performance	The majority accepted the advisory system. Half of the drivers would accept the limiting system in their cars voluntarily.
UK	Várhelyi et al., 1998	MASTER	Simulator		60 drivers	Advisory; Fixed & dynamic speed limiting	Speed; Following behaviour; Overtaking manoeuvres; Traffic violations; Collisions	Large speed reductions; Reduced speed variance; Better speed adaptation	Less safe following distances; Negative behavioural adaptation in fog, due to loss of vigilance	Increased frustration

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
Netherlands	Rook & Hogema, 2005; Rook, Hogema & van der Horst, 2004	PROSPER	Simulator		64 drivers	Supporting - Haptic gas pedal – low force; Haptic gas pedal – high-force; Tactile pedal – vibrates as indicator; Limiting - Dead throttle-restricts speed	Speed; Workload; Acceptance	ISA reduced mean speed; Tactile pedal less effective than dead throttle in reducing speed; Low-force haptic reduced speed less than the high-force haptic	Mean speed in curves not affected	Low-force Haptic and tactile increases workload slightly; Other systems did not increase work load; Acceptance generally good; Satisfaction low; Low-force haptic perceived as most satisfying & useful; 44% would like tactile pe haptic pedal in own car; 25% would like dead throttle; 23%would like high-force haptic pedal
Hungary & Spain	(Cunningham & Sundberg, 2006)	PROSPER	On-road		64 drivers	Advisory (BEEP) Supportive - Active Accelerator Pedal (AAP);	Speed (mean and percentile)	Reductions in mean and 85^{th} percentile speed; AAP most effective	None	50% of drivers willing to use system; Higher willingness for beep system
		North America								
Canada	Taylor, 2006	Speed Choice	On-road		10 vehicles; 79 datasets (drivers)	Advisory (OTTOMate) Information only Supportive (IMITA-SA) auditory and haptic support	Speed; Travel time; Acceptance; Fuel consumption	Decrease in time spent speeding in all speed zones for Limit Advisor system; Fuel consumption reduced during ISA usage	Increase in over-speed percentage with OttoMate system	ISA and speed management not liked; Limit Advisor preferred system

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
Canada		SafeMiles		3 mths approx. 234,480 km		Recording ISA Compliance with speed limited rewarded		Compliance improved significantly especially in 30-39 age group. Compliance highest in 100km/h and lowest in 50km/h zones		High overall acceptance Users wanted to see the system used more widely
USA Michigan (2,24)	Regan et al., 2012; Regan & Bliss, 2013	Kalamazoo trial	On-road		8 vehicles/ 50 drivers	Advisory - (auditory and visual signals) Cash Incentive	Speed; Perceived mental workload; Trust and Acceptance	Advisory ISA: Modest reduction in speeding; Incentive system: Significant reduction in speeding; Combined ISA and Incentive system: Reductions in speeding similar to incentive only condition		
Asia-Pacific										
Australia - Melbourne	(M. A. Regan et al., 2006)	TAC SafeCar	On-road 2002 – 2004)	16,500kms	23 drivers 15 Ford Falcons	Supportive (Actively Supporting)	Speed; Following distance; Travel times; Fuel consumption and emissions; Crash estimates; Acceptance; Workload	Reductions in mean, maximum, 85th percentile and speed variability; No significant change in travel times	No compensatory behaviour observed; Drivers experienced increased frustration due to speed limit inconsistencies in the ISA digital map	High – ISA deemed useful, effective and socially acceptable

Context						Intervention	Mechanism	Outcomes		
								Key Results		
Region/ Location/	Author(s)/ Date/ Endnote	Study Name	Study type	Study Duration[8]	Drivers/ Vehicles	ISA Functionality	Measures Investigated	Safety Benefits	Negative Aspects	Acceptability
Australia – NSW	(Barnes et al., 2010; Wall, 2010)	RTA-NSW	On-road		110 vehicles	Advisory		Reduction in amount of time spent speeding.	Technology was “unforgiving”. Did not allow driver to travel a few km/h over the limit without beeping. Drivers under 25-yrs were less likely to time spent speeding and more likely to turn devices off	Raised awareness of speed zones and speeding violation. Reduced worry re speeding. 65% found it very useful. 21% wanted to keep it.
Australia	(Fitzharris et al., 2012)	ISA-Heavy Vehicles	On-road	12 weeks 4 weeks pre and 8 weeks with ISA	6 vehicles	Advisory Auditory & Visual warnings	Pre and post questionnaire, logged trip data & Operator Trip Logs	Reduction in speed violations. Biggest effect in zones =>80 Km/h (25%). Little benefit in zones <= 70 km/h.		Divergence of opinion re acceptability