Update on the road safety benefits of intelligent vehicle technologies—Research in 2008-2009

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Abstract

Previously, a comprehensive range of 34 safety-related Intelligent Vehicle Technologies (IVTs) has been evaluated for effectiveness in Australia, based on a business case model developed by the Transport Accident Commission (TAC) in Victoria. This paper reviews new literature from 2008-2009 regarding IVTs. An annotated bibliography of more than 150 documents, reports and published articles was constructed. No major new IVT was identified that could be added to the current list. While revised estimates of effectiveness could be undertaken, these would refine rather than cause major changes to rankings. There is little, if any, improved confidence in the estimates of effectiveness. Several European projects have attempted to develop methodologies for prioritizing IVT, however they are considered to rely too much on uncertain estimates of the potential benefits of the technology. The TAC methodology that uses a business-case approach is still regarded as the most robust approach in view of this uncertainty. Emerging issues identified included: the possibility of behavioural adaptation to IVTs by drivers; a trend by vehicle manufacturers to combine IVTs (either as a package of safety-related IVTs, or safety-related IVTs in combination with other communication, entertainment or information IVTs); an increased focus on conducting robust field operational testing of IVTs; and issues associated with original equipment manufacturer (OEM) fitment and retrofitment of IVTs. It is recommended that IVT developments should continue to be generally monitored on a very regular basis, but it may be appropriate in future to also conduct specific studies to review particular vehicle types (e.g., cars, trucks, motorcycles) or individual IVTs.

Keywords

Technology, Vehicles, Intelligent transport systems, Intelligent vehicle technologies

Introduction

In a preceding report completed in early 2008, a comprehensive range of safety-related Intelligent Vehicle Technologies (IVT) were evaluated [1, 2]. In this paper, we review new literature that has emerged in 2008-2009 regarding IVTs. The literature is expanding rapidly, with relevant research studies regularly appearing at weekly or fortnightly intervals. This project identified more than 150 documents, reports and published articles, comprising both academic and grey literature.

In recent years, there has been an explosion of new technologies for incorporation within vehicles that are currently on the market or under development by suppliers to the automotive industry. Intelligent Transport System (ITS) technologies are now recognised and accepted as offering the potential to effect radical improvements in the efficiency and comfort of operation and in the safety of operation of the road transport system.

Many ITS technologies now appearing in motor vehicles relate to the support of information, communication and entertainment functions: Digital read-outs and virtual instruments are beginning to replace the traditional analogue instruments in the vehicle cockpit; voice recognition technology is being introduced to enable drivers to access and operate secondary vehicle controls (e.g., environmental controls), communications and entertainment systems without taking their hands from the steering wheel or their eyes from the road environment; GPS-enabled navigation systems provide routing information, enable the driver to access real-time traffic reports and alert drivers to changes in speed limits and approaches to locations such as schools, railway level crossings and camera-based enforcement; and entertainment screens and USB ports – even internet access – are being provided. As well, many ITS technologies for motor vehicles relate to fuel and power trains, reflecting increasing concerns with energy and motive power for motor vehicles within the road transport system. Road-based ITS technologies are also being increasingly used, including advanced traveller information systems and route information for drivers, as well as demand management measures such as road tolls, road pricing and access control to the road transport network [3].

Safety-related ITS technologies for motor vehicles typically involve engineering systems built into the vehicle and/or the road that intervene when users suffer lapses of concentration, make unsafe decisions, or fail to detect a developing unsafe situation. A number of these technologies are aimed at improving safety either by reducing the risk of a crash occurring or by improving the protection offered by a vehicle in the event of a crash. But which technologies are worth backing? Which technologies provide a strong business case to government and to the industry itself for active development, incorporation and marketing to the Australian consumer?

In preceding reports, a comprehensive range of safety-related IVTs were evaluated [1, 4,5] using a business case approach weighted towards opportunity for safety benefits from government intervention through regulation or promotion (see Johnston, Ferreira & Bunker [6] for a recent alternative economic risk management approach to prioritise ITS). A range of current and emerging in-vehicle safety technologies were assessed in accordance with a set of criteria including safety impact, cost, level of community acceptability, need for legislative or infrastructure support and the model for market penetration. Key technologies were highlighted that scored highly across these criteria as a basis for agreeing a core of technologies for subsequent support and promotion (see Table 1). The work was presented at the November 2008 Australasian Road Safety Research, Policing and Education Conference [1], and subsequently described and discussed by Paine in a number of Australian New Car Assessment Program (ANCAP) presentations during 2009 and at the 21st International Technical Conference on the Enhanced Safety of Vehicles conference [7], and briefly discussed by Faulks in a presentation on the Safe System approach to road safety delivered to the Occupant Protection Committee of the US Transportation Research Board in January 2009 [8]. Across these diverse audiences, the work has not been subject to any criticism regarding the approach or analysis.

In September 2009, the TAC requested Vehicle Design and Research, and Safety and Policy Analysis International, to review and provide an update on the research and commentary that had been published in 2008-2009 that was relevant to the implementation of road safety-related intelligent transport systems in Australia. The key task was to review the latest research to identify:

a) new technologies;
b) revised estimates of cost effectiveness for existing IVT; and
c) new or updated methodologies for "picking winners" (cost effectiveness and related measures).

The findings of the review

There are a wide range of safety features and products available for motor vehicles that can assist in avoiding accidents (active safety) or reducing the risk of serious injury (passive safety). Some of these features are only available on luxury vehicles and these vehicles tend to do well in crashworthiness ratings based on real world crashes. The Swedish insurance organisation Folksam has estimated that at least 30% of fatal and serious injuries could be avoided if the average crashworthiness of the fleet was raised to that of the best vehicles currently available. Further benefits would be available from crash avoidance technologies and it has been estimated that there is the potential to save more than 50% of serious and fatal injuries through improved active and passive safety in vehicles.

Table 1. Brief description of the in-vehicle technologies (IVTs) examined

CRASH AVOIDANCE	
ABS BRAKES	Prevents individual wheels from lock up during heavy braking (or on slippery surfaces) and subsequently assists driver to maintain control.
ABS WITH ELECTRONIC BRAKE DISTRIBUTION	As with ABS but distribution of braking forces is optimised to maximise the available friction (similar to brake proportioning valves).
ADAPTIVE CRUISE CONTROL	Detects distance and speed of preceding vehicle and maintains appropriate headway.
ADAPTIVE HEADLIGHTS	Motorized headlamps linked to sensors that measure the vehicle's angle, pitch, steering direction and orientation; as such, they can adjust their direction and intensity to provide additional illumination on curves, turns, and hills.
ALCOHOL /DRUG IGNITION INTERLOCK	Require driver to perform and pass a breath alcohol test before the vehicle can be driven, and includes rolling re-test capability during driving.
BRAKE ASSIST	Detects fast brake application. Provides emergency braking assistance.
CRASH RECORDER	Continuously records vehicle speed and other parameters and stores this in the event of a collision ('black box' recorder).
DAYTME RUNNING LIGHTS (INTELLIGENT)	Dedicated daytime running lights with a sensor that automatically switches to low beam headlights at dusk.
ELECTRONIC STABILITY CONTROL (ESC)	Detects if vehicle if nearing the limits of traction during cornering and braking and adjusts braking to individual wheels and engine torque to improve stability.
FATIGUE WARNING SYSTEM	Detects whether the driver is exhibiting signs of fatigue (doze alert).
FOLLOWING DISTANCE WARNING	Detects distance to preceding vehicle and alerts driver if the gap is less than recommended headway for the current speed.
FORWARD COLLISION AVOIDANCE WITH BRAKING	Detects distance and closing speed of objects in path of vehicle and automatically decelerates if driver does not heed warning.
INTELLIGENT SPEED ADAPTATION	Determines current speed limit (mainly from digital map) and alerts driver if the limit is being exceeded (passive ISA) or limits the speed of the vehicle (active ISA).
INTERSECTION COLLISION WARNING	Detects vehicles approaching from the side at intersections. Alerts driver if a collision is possible.
LANE DEPARTURE WARNING	Recognises lane markings and alerts driver if the lane boundary is crossed.
NIGHT VISION ENHANCEMENT	Generally uses non-visible light frequencies to enhance driver vision.
REVERSING COLLISION AVOIDANCE	Sensors detect objects in the path of a reversing vehicle plus visual aids (cameras) to improve the rearward field of view.
ROLLOVER WARNING	Alert drivers when the lateral forces or vehicle dynamics indicate a risk of rollover (this is mainly a heavy truck application).
SEAT BELT INTERLOCK/ REMINDER	Require driver to put on seat belt before the vehicle can be driven (interlock), or provide alert to driver that seated occupants do not have seat belts connected.
SIDE BLIND SPOT/ LANE CHANGE WARNING	Detects distance and closing speed of objects in adjacent lanes and alerts driver if a collision is imminent.

SMART LICENCE	Vehicle will not operate without an appropriate electronic licence. This might have speed or time-of-day restrictions.
SPEED ALARM (MANUAL)	Alert drivers when the vehicle speed exceeds a pre-set limit (driver selects a speed for an audible alert).
TOP SPEED LIMITER	Vehicle is rendered incapable of traveling above a set speed.
TRACTION CONTROL	System detects potential wheel spin due to excessive driving torque and limits this torque.
TYRE PRESSURE MONITORING	Detects when a tyre drops below 75% of recommended pressure and alerts driver.
VEHICLE-TO-VEHICLE (V2V) and VEHICLE -TO-INFRASTRUCTURE (V2I) or INFRASTRUCTURE-TO-VEHICLE (I2V) COMMUNICATIONS	Standards for exchange of information between vehicles, and between vehicles and roadways.
WORKLOAD MANAGER	Filters and prioritises the information made available to the driver. Postpones or cancels certain distractions, such as non-urgent vehicle warnings or integrated mobile telephone calls.

INJURY PREVENTION AND POST-CRASH RESCUE	
ACTIVE HEAD RESTRAINTS	Seat design responds to rearward collision by moving head restraint forward and other actions that reduce the risk of whiplash type injuries.
BONNET FOR PEDESTRIAN PROTECTION	Detects collision with pedestrian and either deploys external airbag or raises bonnet to lessen impact.
PRE-EMPTIVE COLLISION PREPARATION	Detects imminent collision. Deploys safety devices such as seat belt pretensioners.
SIDE AIRBAGS WITH HEAD PROTECTION	Side airbag or curtain deploys in side impact and protects the head.
MAYDAY DISTRESS CALL IN SEVERE CRASH	Alerts emergency services (or a contractor) if a severe collision occurs
NAVIGATION SYSTEMS (GPS)	In-Vehicle Information Systems (IVISs) such as a route navigation system using visual route displays, and/or voice instructions for route following, as alternatives to driver distraction arising from consulting a map or other document while driving

In recent years, the most promising developments in vehicle safety have been in the field of electronics and computing, through ITS technologies. Within a vehicle, ITS can improve safety in several ways through IVTs:

a) Prevent access to the road system by unsuitable vehicles or drivers (e.g., alcohol interlocks);
b) Provide warning or guidance to drivers (e.g., headway warnings, blind spot warnings, lane departure warning, speed limit alarm);
c) Provide corrective action in the event of the vehicle exceeding performance/legal limits (e.g., ABS brakes with electronic brake distribution, electronic stability control, intelligent speed adaptation/limiting);

d) Improve the performance of injury mitigation systems (e.g., smart airbags, "preview" crash detection to prime seat belt tensioning systems, pop-up bonnet to reduce risk to pedestrians);
e) Reduce the risks from post-crash trauma (e.g., "Mayday" rescue systems).

Despite the promise of these IVTs in improving road safety and reducing road trauma, there are impediments to the implementation of IVTs, including:

- Unproven technology - particularly "fail safe" issues;
- Lack of infrastructure provision to support an IVT technology;
- Cost;
- Availability for a wide range of vehicles;
- User acceptance;
- Lack of understanding of potential road safety benefits by consumers and decision makers;
- Legal issues such as radio spectrum allocation; and
- Tax and insurance disincentives

Safety is but one of many major factors to be considered in the design, manufacturer and operation of motor vehicles. Indeed, much of the demand for IVTs is related to factors other than safety, such as energy sustainability and vehicle occupant comfort and amenity (e.g., climate controls, entertainment, and communications). A particular feature of many current vehicle technology programs is a focus on fuels and the power train. For example, the US Department of Energy Vehicle Technologies Program [9] is examining ways and means to deploy clean and efficient vehicle technologies and renewable fuels. The question of sustainable management in vehicle design is being addressed by vehicle manufacturers. In Europe, for example, the Ford Motor Company has implemented a Product Sustainability Index as a management tool for use by automotive engineers that documents eight indicators reflecting environmental (life-cycle Global Warming Potential (GWP), life-cycle air quality potential, sustainable materials, restricted substances, and drive by exterior noise), social (mobility capability, and safety) and economic (life-cycle cost of ownership) vehicle attributes [10]. The Ford Galaxy and S-MAX are the first vehicles where this tool has been applied from the beginning of their development, and an evaluation of the Product Sustainability Index showed significant improvements compared to the predecessor management tools.

There is also a concern that the introduction of an in-vehicle technology itself may have a safety disbenefit. Lee and Strayer [11] outlined the concerns that have arisen regarding IVTs, and their comments remain apposite today:

> “Beginning with the introduction of the car radio, there have been concerns regarding how in-vehicle technology might undermine driving safety. Those concerns are particularly apparent today as many worry about the safety consequences of introducing vastly more complex technologies into the car, most prominently regarding the use of cell phones while driving. Developments in the areas of wireless communication, computing, and GPS technology make an increasing variety of navigation, E-mail, and Internet systems available to the driver. This availability, coupled with increased commute times, productivity pressures, and the diffusion of work beyond the office, makes it likely that drivers will use these devices while driving. . . . The increasingly common use of existing technology and the rapidly emerging new technology make it imperative to understand how in-vehicle technology affects driving safety. Properly designed, the new technologies may enhance driving enjoyment and safety; poorly designed, they can be deadly.
>
> The true safety impact of these [cell telephone] devices in terms of crashes and fatalities may be underestimated. Compared with alcohol-related crashes, for which there is a clear marker of a causal agent, crashes related to cell phones do not leave a telltale trace. Even in the portion of cases for which cell phone records are available, it is often difficult to precisely time-stamp the crash and relate it to the distraction. Many telematic devices leave an even weaker trace.” /(p.583)

Similarly, comments on the impact of ITS by Newman-Askins, Ferreira and Bunker [12] are pertinent to consideration of safety-related IVTs:

> "The nature and extent of impacts of ITS projects is fundamentally different from those of conventional road projects. Evaluation of ITS projects is complicated by the presence of the unique variables affecting the outcomes of projects, which include driver behavioural response and market penetration issues. . . . . It is important that the costs and benefits of both ITS and conventional projects are evaluated comprehensively in order to ensure efficient and cost-effective project selection and prioritisation. There is little historical data available to quantify most ITS impacts and some ITS impacts, such as increased comfort or travel time reliability, are qualitative or difficult to measure or value. There is presently little understanding of the causal relationships between ITS projects and their impacts and often it may not be appropriate to transfer results in space and time." (p.1)

Despite the continuing changes in digital and materials technologies, these comments remain as relevant today for ITS, and IVTs specifically, as they were five or more years ago (see also Marschke, Ferreira and Bunker [13].

Behavioural adaptation, offsetting behaviours, and behavioural compensation

An important issue that has arisen in discussion about IVTs is that of ''behavioural adaptation'' (also known as "offsetting behaviour", or "behavioural compensation"). As noted by Cacciabue and Saad [14], behavioural adaptation relates to unexpected or unanticipated behavioural changes that may appear in response to the introduction of a change in the road transport system and which may (more or less) jeopardise its expected safety benefits. Behavioural adaptation, when it does occur, may be an immediate response to the change introduced in the road transport system but it may also only appear after a longer period [15]. Generally, behavioural adaptation does not eliminate the safety gains from IVT measures, but mitigates (or tends to reduce) the size of the expected safety effects. Concern over behavioural adaptation can be dated, in particular, to the work of Peltzman [16] concerning the effects of automobile safety regulation on road trauma following the US National Traffic and Motor Vehicle Safety Act 1966. Peltzman reviewed the contribution of a number of technological changes to the expected reduction in vehicle occupant fatalities in the United States: lap seat belt; energy-absorbing steering column; shoulder seat belt; High Penetration Resistant windscreen; padded instrument panel; and dual braking system; arguing that there was little effect arising from these measures and proposing that people had changed, or offset, their behaviour in response to the perceived safer technologies.

Staubach [17] has stated recently:

> "Despite the many views on offering vehicle assistance for the driver which can be derived from accidents, further studies are still necessary in order to predict possible changes in behaviour (behavioural compensation) which are determined through regular use of driver assistance systems. Such behavioural changes have previously been associated with ADAS like antilock brakes. The extent of changes in behaviour is dependent on the conspicuity of safety measures and considering ADAS particularly on the design of the human–machine interface. Broad testing of such systems is necessary in a driving simulator and on real journeys so that the safety potential of ADAS is not offset by driver behaviour. Standards (ISO 17287) and guidelines are already in place, such as the Code of Practice for the Design and Evaluation of ADAS (2006) compiled in Project Response. The same applies to the effects of habituation on driver assistance systems and high familiarisation with the functionality of systems. For example, a warning about cyclists when turning right could lead to catastrophic results if the act of looking over your shoulder was simply 'unlearnt' as a result and consequently forgotten even in vehicles not fitted with this kind of warning. This has to be avoided by means of ergonomic design principles and measures of driving education which emphasise the driver's individual responsibility." (p. 1032)

Safety effects from combinations of IVT

A number of IVTs can often be included as original fitment (OEM) within a particular make or model by a vehicle manufacturer. As noted in the recent report of the Road Safety Committee of the Parliament of Victoria into vehicle safety [18], this can make assessment of the efficacy of any particular measure problematic.

Elvik [19] has discussed this issue in a recent study, noting that estimating the combined effects of several road safety measures is a problem encountered by any policy maker who has developed a road safety program consisting of more than one road safety measure. Little research has been done to identify the best method for estimating the combined effect of several road safety measures. A common method, termed the method of common residuals, is a simple method assuming that the effects of several road safety measures combine multiplicatively and remain unchanged, in percentage terms, when several road safety measures are combined. Elvik suggests that the method of common residuals may be too simple and may overestimate the combined effect of a set of road safety measures. A modified version of the method, termed the dominant common residuals method, has been proposed. In this method the common residuals are raised to the power of the residual for the most effective measure included in the set. For example, if the effect of three road safety measures individually result in 70%, 60% and 50% crash reductions, the common residuals method would predict a combined effect of 79% ($1-[(0.7\times0.6\times 0.5)] = 1-0.21 = 0.79$). In contrast, the dominant common residuals estimate = $1-[(0.7\times0.6\times 0.5)0.5] = 1-0.46 = 0.54$, that is, 54%. Thus, the dominant common residuals method is more conservative than the common residuals method. Elvik notes that while there is no theoretical justification for the dominant common residuals method, it can be argued that it is a plausible approach as it is often the case that several road safety measures influence more or less the same risk factors, and that exposure to several risk factors is correlated. For example, Nilsson [20], in a study of driver compliance with speed limits, seat belt use and alcohol use, showed that those who drink and drive are more likely to speed and not wear seat belts than those who do not drink and drive. Thus if seat belt ignition interlocks were mandatory, the risk associated with drinking and driving would be reduced and any measure designed to curb it would therefore be less effective than if introduced as an individual countermeasure alone.

The Mercedes-Benz E-Class is a instructive example of the trend towards combining many different IVTs. The new Mercedes-Benz E-Class has a multitude of safety systems. Together, they are intended to allow the car to 'think' – one that can see and sense danger, and then act autonomously. These systems have been tested in a virtual crash test world more than 17,500 times before actual crash testing was undertaken. The IVTs included are:

- Lane Keeping Assist: Many cars now have lane keeping assistance, but Mercedes-Benz has developed the system further. A camera keeps a constant eye on the line taken by the car and the driver's control inputs, allowing it to detect when the car leaves its lane unintentionally and if there is a risk of an accident. It can then either counter steer or make the steering wheel vibrate. By measuring all factors including steering angle, the extra intelligence can work out whether the car has left its lane intentionally, so there would be no warning if, for example, the driver accelerates before overtaking or joining a motorway, brakes heavily or steers into a bend.
- Speed Limit Assist: A camera on the windscreen of the E-Class can detect speed-limit signs and then indicate the speed limit on the display in the speedometer. Alongside the camera, data in the satellite navigation system is used to double-check the limit. It makes no difference where the speed limit is displayed, as long as it is on a circular sign.
- Night View Assist: First introduced on the current S-Class, the second-generation Night View Assist has a special pedestrian detection function. By throwing an invisible cloak of infra-red light over the road ahead, and using sensors to detect human movement, the driver is warned on the screen of pedestrians that are out of range of the headlights.
- High Beam Assist: Tests have shown that drivers using Mercedes-Benz's Adaptive High Beam Assist are safer in the dark because they see pedestrians, cyclists or obstacles on the road up to 150 metres earlier than is the case with conventional low beam. The firm also claims it is less stressful.

Light is thrown on to the opposite side of the road on full beam then, using a camera which picks up oncoming traffic, the beam's range is adapted as the car nears. What this means is that the low-beam range can be increased from 65 metres to up to 300 metres without dazzling other motorists. At the heart of the system is a camera located on the inside of the windscreen, which sends new data every 40 milliseconds so that the range of the variable-control bi-xenon headlamps can be adjusted. Testing the system, you can clearly see the pool of light sitting in front of the approaching car, mirroring its movement. It means that the maximum possible stretch of road is illuminated at all times.

- Attention Assist: Highly sensitive sensors monitor the driver's behaviour, driving style and current driving situation and more than 70 other parameters including longitudinal acceleration, the use of the indicators and pedals as well as certain control inputs and external influences such as side winds or road unevenness, for example. By doing this, the system is able to understand when the driving situation has changed into a pattern it recognises as not having full control of the car and issue a series of beeps and a flashing image on the display. Rather than use cameras looking at the driver's face, favoured by other manufacturers pioneering these types of system, Mercedes-Benz believes its approach is best because drivers wearing glasses don't confuse it, and it is cheap enough to be able to be fitted as standard to all E-Classes.
- PRE-Safe: As standard, all E-Class models will be fitted with PRE-Safe using, for the first time, short range radar to identify situations that might turn into accidents. It can instinctively activate preventive occupant-protection measures, allowing the seat belts and airbags to deploy with maximum effect in the event of an impact. Using the information provided by the radar to trigger the seat belt tensioners at the very last moment before an unavoidable collision, the forces exerted on the driver and front passenger can be greatly reduced. The car will also go into maximum emergency braking automatically if a crash is inevitable and the driver has failed to react to the warnings given by Brake Assist PLUS. At around 1.6_seconds before the impact, the system initiates autonomous partial braking and decelerates the car with around 40% of the maximum braking power. At 0.6 seconds, it brakes fully creating an electronic 'crumple zone' before the impact. Engineers claim that braking fully any earlier would make the system unsafe – it has to be absolutely certain of collision before slamming on the brakes.
- Pedestrian protection: Standard equipment for the new E-Class includes an active bonnet, which reduces the risk of injury to pedestrians from body parts hitting the engine through the bonnet. In the event of an accident, a system of springs, fired by sensors at leg height in the bumper, raises the rear section of the bonnet by 50 millimetres, ensuring a deformation zone which offers crucial space between the pedestrian and the engine. Drivers can reset the Mercedes-Benz active bonnet themselves without having to visit a workshop – particularly handy as an animal strike near the sensors would 'pop' the bonnet.

A related issue is the merging of safety-related IVTs with other in-vehicle technologies associated with informing, entertaining or communicating with a driver. In just one example, the AIDA project (Affective, Intelligent Driving Agent) is a collaboration between Volkswagen of America and the Massachusetts Institute of Technology (SENSEable City Lab and Personal Robots Group of Media Lab) that is seeking to foster the communication of relevant safety and trip information from on-board technologies to the driver. AIDA is a platform comprising of a personal robot and an intelligent navigation system that aims to mimic what might be termed "the friendly expertise" of a driving companion who is familiar with both the driver and the city. AIDA is presented as a robotic head mounted on the dashboard of the car. A laser projector is mounted inside the robotic head and projects colour graphics to create expressions on its "face" and allow the robot to make a wide range of human-like gestures that can send subtle signals to the driver. A downturned face with pleading eyes, for example, indicates that AIDA is "worried" because the driver has failed to buckle the seat belt. The hope is that with AIDA a driver will buckle up to avoid making the car "feel bad". But AIDA is intended to do more than provide seatbelt reminders. It uses sensors inside and outside the car to pick up clues about the driver's state of mind: grip strength and skin-conductivity sensors in the steering wheel, for example, tell the robot when the driver is tense. The focus is on navigation, so a mandatory task for AIDA is to predict the destination of the driver as well as the most likely route that the driver will follow. Instead of focusing solely on determining routes to a specified waypoint, the AIDA system uses an analysis of driver behaviour in order to identify the set of goals the driver would like to achieve, incorporating information such as business and shopping districts, tourist and residential areas, as well as real-time event information and environmental conditions. This information about driver preferences is intended to help AIDA to behave more intelligently. This will in turn allow for useful reactions from AIDA such as proposing route alternatives when something unexpected happens in the predicted route, or providing the right information at the right time (e.g. a fuel warning before passing by a petrol station) [21].

The development of robotic agents to advise and assist drivers is associated with research programs that are investigating how the use of in-vehicle technologies is changing the way drivers approach the driving task, plan their trips, and even think about the use of motor vehicles as a form of transport. For example, Leshed, Velden, Rieger, Kot and Sengers [22] reported that although in-car GPS navigation technology is proliferating, it is not well understood how its use alters the ways people interpret their environment and navigate through it. Navigation using GPS technology is based on abstract representations of spaces and places ("Turn right in 500 metres"), which can be contrasted with how people have traditionally defined and used navigation by location and functional interrelationships (e.g., "Turn right at the next street after you pass the shops") rather than just signage alone. With use of the in-car GPS navigation technology, people become immersed more in the virtual-technological environment and this affects their interaction with the physical (road) environment. This contrasts with ordinary experiences of navigating through spaces and attending to places without use of GPS technology.

Increasing the knowledge base

There are now many, many conferences, seminars and workshops associated with ITS, IVTs and safety, including such regular events as the International Technical Conferences on the Enhanced Safety of Vehicles (the ESV conferences) and the ITS World Congress, as well customary sessions within annual conferences such as the Australian Road Safety Policing and Education Conferences, and new events such as the 2009 Conference on Driver Distraction and Inattention or single events such as the 2009 International Conference on Intelligent Speed Adaptation.

As well, many new ITS projects are being conducted. Just some of the recent work includes:

- AIDE - Adaptive Integrated Driver-vehicle InterfacE, including an examination of safety benefits from advanced driver assistance systems;
- UK-ISA – Intelligent Speed Adaptation project in the United Kingdom, examining how intelligent speed limiting of vehicles can impact on safety;
- WATCH-OVER - Vehicle-to-Vulnerable roAd user cooperaTive communication and sensing teCHnologies to imprOVE transpoRt safety, examining systems for the prevention of crashes involving vulnerable road users in urban areas, based on short range communication and vision sensors;
- iTETRIS – Integration of wireless communications and road traffic simulation platforms to facilitate vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technologies can improve traffic management through real-time exchange of traffic information;
- PRAISE - Preventing Road Accidents and Injuries for the Safety of Employees, which includes an examination of how IVT safety equipment can improve and manage work-related road safety;
- EASY – Effects of Automated Systems on SafetY, again looking at the safety benefits from advanced driver assistance systems;
- HASTE - Human Machine Interface And the Safety of Traffic in Europe, examining the change in risk of crashing due to operating an IVIS;
- PROSPER – Project for Research On Speed adaptation Policies on European Roads, looking at user reactions to different types of road speed management methods and implementation strategies, and technical, legal and policy aspects relating to Intelligent Speed Adaptation;
- eCall – an in-car automatic emergency call system across Europe;

- eMOTION – a Europe-wide multimodal on-trip travel information service project, examining the provision of rela-time information about multi-modal travel for both road users and public transport users;
- 2DECIDE - Toolkit for sustainable decision-making for ITS deployment, providing a management methodology for access to knowledge on the benefits and costs of an ITS to support decision making;
- SAFERIDER- Advanced telematics for enhancing the SAFEty and comfort of motorcycle RIDERs, examining advanced driver assistance systems and the provision of information to motorcyclists;
- SAFESPOT, developing cooperative networks where the vehicles and the road infrastructure communicate to share information gathered on board and at the roadside to enhance the drivers' perception of the vehicle surroundings;
- COOPERS - Co-operative Systems for Intelligent Road Safety, providing vehicles and drivers with real time safety-related information that is individual or local situation /precinct based, via dedicated I2V, V2I and V2V communications; and
- NextGenITS, a national project developed by Belgium to demonstrate ITS services: e-call, traffic information, intelligent speed adaptation, road charging, and cooperative vehicle systems.

Some of these projects are discussed, by way of examples that have explicit safety benefits, in the following paragraphs.

AIDE - Adaptive Integrated Driver-vehicle InterfacE

Concluding in 2008, the AIDE project investigated the knowledge, the methodologies and the human-machine interface technologies required for safe and efficient integration of advanced driver assistance systems (ADAS), in-vehicle information systems (IVIS) and nomad devices into the driving environment. The objectives of the AIDE project were:

- to maximise the efficiency, and hence the safety benefits, of advanced driver assistance systems,
- to minimise the level of workload and distraction imposed by in-vehicle information systems and nomad devices and
- to enable the realisation of the potential benefits of new in-vehicle technologies and nomad devices in terms of mobility and comfort.

The project yielded several dozens of documents, papers and reports. A final workshop was held in Gothenburg, Sweden, 15-16 April 2008.

PRAISE - Preventing Road Accidents and Injuries for the Safety of Employees

PRAISE is a new project run by the European Transport Safety Council on Preventing Road Accidents and Injuries for the Safety of Employees. The project aims to advance work-related road safety management and provide the know-how to employers who have to take on that challenge. A first thematic report has been released that aims to present how in-vehicle safety equipment can improve and manage work related road safety. The report addresses all employers managing all types of vehicle from public authorities, vehicle leasing suppliers, small two car delivery companies to large international companies and also vehicle manufacturers. Vehicle safety features can reduce the incidence and severity of crashes and the vehicle supply industry developed many technology-based interventions for fleet operators to consider in vehicle specification and purchase decisions. Particular technologies of interest in the PRAISE project include:

- Seat Belts and Reminders
- Speed Management Technologies
- Adaptive Cruise Control
- Alcohol and Alcohol Interlocks
- Electronic Stability Control
- Event Data Recorders

- Following Distance Warning
- Emergency braking
- Route Planning; and
- Fatigue and Drowsiness Detectors

The European Transport Safety Council concludes that IVTs can make a life saving contribution to improving road safety at work. Crucial to their effectiveness however is that they are integrated into management structures that address the greatest risks. Employers should make every effort to apply IVTs to their working environment, but also train staff in the use of IVTs and monitor their implementation into the workplace. At a European level the deployment of life saving technologies should be prioritised in the upcoming ITS Action Plan and Directive. Their use within the context of improving road safety at work should also be included in the new 4th Road Safety Action Programme. They should be prioritised by all according to their greatest life saving potential. As part of the PRAISE project, the European Transport Safety Council [23] has launched a call for entries in a competition on work related road safety. As the project aims to increase road safety in the work context and "praise" best practices in order to help employers secure high road safety standards for their employees, the PRAISE competition targets companies who can demonstrate what they have achieved through their efforts to reduce collisions at work and/or while commuting to and from work. A 'PRAISE Award' will be presented annually to an employer identified for taking on the road safety challenge responsibly.

EASY – Effects of Automated Systems on SafetY

Another current project is EASY, being conducted by the Institute of Transport Studies at the University of Leeds by Professor Oliver Carsten. This project is scheduled to run from January 2007 - April 2010, with reporting after that time. The project is examining how some of the new advanced driver assistance systems (ADAS) that are envisaged by the car manufacturers will affect safety. Currently, the most advanced assistance system on the market is Adaptive Cruise Control (ACC) which automates the task of car following. ACC is particularly designed for motorways, but can also be used on rural and even urban roads. It has deliberate limitations, in that it cannot deal with situations requiring severe braking and that the ACC radar cannot detect stationary objects. The car manufacturers plan to extend the capability of ACC so that it can handle most forward situations. They also plan to provide lane keeping systems which will automate lateral control of a vehicle (i.e., steering), once again particularly for motorway driving. The combination of longitudinal and lateral control will provide a situation in which a large part of the driving task is automated. As a consequence, there is a risk that drivers will no longer feel a need to pay attention to the road and traffic environment, and therefore may not be aware of impending risk. They may also lose track of when manual control has been resumed, for example, on exiting from the motorway, and therefore be slower in responding when required to brake or steer. This project is conducting a systematic evaluation of driver's performance and safety awareness as they experience increasingly greater automation of the driving task. The major tool for this work is the new driving simulator at the University of Leeds, which has a complex motion base to provide gravitational feel to the drivers. The initial set of experiments will be designed to identify any safety related problems that result from driving in a semi-automated vehicle. A wide range of drivers will be used, with the major factors in their selection being age, gender and trust in automation. Having identified the problems, a second set of experiments will focus on solutions, that is, on ways in which driver alertness and awareness can be enhanced. The results are intended to provide guidance to those governmental organizations that are planning to use new driver assistance systems to increase road capacity and safety, and to lead to better design of new products by the vehicle manufacturers.

eCall

eCall automatically dials 112, Europe's single emergency number, when a car has a serious accident and sends its location to the nearest emergency service [24]. The October 2009 issue of the Safety Monitor newsletter by the European Transport Safety Council noted that on 9 September 2009 representatives of Europe's mobile phone industry Association signed the EU's Memorandum of Understanding to implement the in-car automatic emergency call system, eCall, across Europe. eCall is estimated to save up to 2,500 lives each year in the EU when fully deployed, and to reduce the severity of injuries by 10 to 15%. So far the system is not operational in any EU country. In a policy document adopted on 21 August 2009, the European Commission made a last call to all EU countries to speed up voluntary implementation of eCall before the end of 2009, otherwise it could propose regulatory measures to make this technology available all over Europe as soon as possible.

eMOTION - Europe wide multimodal on-trip travel information

In the eMOTION project, public authorities, transport and telecommunication operators, IT suppliers and transport consultancies specified multi-modal, on-trip traffic information services for road and public transport users. The eMOTION project is an attempt to provide an answer to the situation in traffic information and mobility domains where information technologies support traveller information services but where there is no common ground, and the creation of new and innovative services does not seem to be feasible. Information is made available via on-trip-devices like PDA/Smart Phones or in-car-systems. The project addressed both organisational and technical issues. The technical specifications developed in the eMOTION project provide for an open architecture, which enables the step-by-step integration of existing information services, if they follow the eMOTION technical standard specification. In the most general view, the eMOTION architecture can be seen to enable the development and operation of end user applications accessing distributed data and content sources that was otherwise only available from different and heterogeneous providers. The project was completed in 2008.

2DECIDE - Toolkit for sustainable decision-making for ITS deployment

The lack of easy and efficient access to knowledge on benefits and costs of ITS is recognised as a key factor for slow investment. A single entry approach for a new ITS toolkit for better decision making is the main objective of the project, which will develop a web-based decision-support toolkit. The 2DECIDE project is planned for 2009-2011, and was launched on 9 October 2009 in Brussels, Belgium. Pfliegl [25] indicated that the 2DEDCIDE (ITS Toolkit) was intended:

- to support decision making processes;
- to enable easy accessibility to existing knowledge;
- to support EU ITS policy goals as well as national ITS deployments strategies;
- to gain the utmost benefit of ITS deployment and the related investments for a sustainable road and public transportation system

(see also Smyth & Bradley [26]).

SAFERIDER - Advanced telematics for enhancing the SAFEty and comfort of motorcycle RIDERs

The European project SAFERIDER [27], funded within the 7th Framework-Programme of the DG Information Society & Media, aims to study the potential of advanced driver assistance systems and in-vehicle information systems (ADAS, IVIS) to be integrated and provided through an efficient and rider-friendly interface to motorcyclists. The first stage was to identify existing products and prototypes of information and communication systems for motorcycles (referred to as powered two-wheelers, PTW). This process resulted in the production of a benchmarking database for the identified systems. The second step was to conduct the ergonomic inspection of selected existing products, in order to identify which IVIS functions would be more usable and safe for the riders. The evaluation of positive and negative aspects of available IVIS functions was based upon static evaluation of the products by experts. At the final stage, experts had the opportunity to test these IVIS functions in dynamic condition, that is to say, while the system is implemented on a moving motorbike.

Field operational testing

Increasingly, attention is being given to field operational testing of in-vehicle technologies. Field operational testing is widely recognised as an effective instrument to test new transport technologies in the real world. The TAC Safe Car project is a good example of field operational testing, as are the current ISA trials being conducted in New South Wales and in Western Australia. Such field trials can raise awareness, collect real data, and enhance the take-up of in-vehicle technologies.

In Europe, the Field Operational Test Support Action (FESTA) project funded by the European Commission developed a handbook of good practice to support such operational testing of technologies. The European approach to field operational testing was developed in 2008 through the FESTA project, in the form of a handbook of good practice. The handbook provides practical guidance for researchers to allow the development of projects involving a range of in-vehicle technology systems within an overall integrated and coordinated program of research. The FESTA handbook covers issues concerning all aspects of the time-line and administration of a field operational test, such that advice will be provided regarding aspects from needs analysis at the commencement of an FESTA handbook all the way through to the integration of the acquired data and estimation.

A large-scale field operational test of eight new high-tech intelligent in-vehicle safety and efficiency technologies will be carried out throughout 2010 across multiple brands in Europe. In the context of a European-wide research project euroFOT, 28 organisations, including car manuacturers, universities, research centres, will scientifically test and assess the impact of the advanced features on drivers' safety and behaviour [28]. Beginning in 2010, at least 1,000 vehicles from various European vehicle brands equipped with various intelligent in-vehicle systems, including lateral (for side-end collisions) and longitudinal (for front-end ones) controls, Curve Speed Warning, Fuel Efficiency Adviser and others, will drive around Europe for approximately one year. The collected data should deliver answers with regards to the impacts that these systems have on safety, efficiency and driver comfort. The research project is supported by European funds from the DG Information Society and Media.

Not all field trials for IVT are funded or coordinated by government. In Australia, a recent field operational trial was the Vehicle Safety and Speed Monitoring System (VSSMS) developed by Dampier Bunbury Pipeline and its asset manager, Alinta Asset Management, using a Global Positioning System (GPS) to continually monitor and track the speed and location of all vehicles working on the almost 1,600 km length of the pipeline [29, 30]. The VSSMS project arose as a combination of speeding, unsealed roads and poor driving conditions across vast distances had led to a number of vehicle incidents, including one fatality in 2006. Despite attempts to improve driver behaviour through training and awareness campaigns, vehicle incidents continued to occur, with inappropriate speed almost always being found to be a main contributing factor. Under VSSMS, vehicle data is transmitted to a central control room at 30-minute intervals, where the location, date, time and speed data can be viewed in table format and graphically superimposed on Google Earth Pro. Personnel working on Dampier Bunbury Pipeline activities over the entire state of Western Australia are now monitored 24 hours of every day. The system monitors all access roads and tracks that connect the work sites with the public road network. The graphical representation of the vehicles changes colour depending on their status. Vehicles are displayed in red in an emergency, amber if travelling above the speed limit, and green if travelling within speed limits with no signs of an emergency. For emergencies or serious speed breaches the system automatically generates SMS and email alerts to key personnel. Additionally, drivers are provided with two panic alarm buttons for emergencies, one on the vehicle's dashboard and the other on the vehicle's key. When pressed for three seconds the vehicle's location is instantaneously sent to key personnel, who can trigger an appropriate emergency response plan to the Mayday alert. The control room is operated 24 hours a day with staff constantly monitoring the VSSMS screen.

Integration of safety-related in-vehicle technologies into larger vehicle-based projects

As noted earlier, the demand for IVTs can be related to factors other than safety. This means that safety-related IVTs are often incorporated into larger vehicle technology projects, and marketed as systems rather than stand-alone technologies.

In Europe, the Intelligent Car Initiative of the European Commission [31] is intended to help resolve road transport system problems such as congestion of road networks and urban areas, harmful effects on the environment and public health, waste of energy and, above all, injuries, material damage and fatal crashes. The use of information and communication technologies in building intelligent cars can contribute towards:

- increasing road safety;
- making transport systems more efficient;
- using fuel more efficiently;
- helping drivers to prevent or avoid accidents;
- providing drivers with real-time information about the road network in order to avoid congestion; and
- enabling drivers to optimise journeys.

Despite their potential, most intelligent systems that can be used in vehicles are not widely available. Motor vehicles equipped with safety-related IVT systems are mainly top-of-the-range cars representing only a small percentage of the market. The large-scale deployment of active safety systems (ABS, adaptive cruise control, etc.), has sometimes faced numerous obstacles, including legal barriers, the high cost of intelligent systems and the lack of public information. Moreover, the extremely competitive situation in the automotive sector creates conditions which are unfavourable to the development of these systems. Through the Intelligent Car Initiative it is intended that there will be a comprehensive approach at the European Union level that will enable harmonised solutions to be found (including removing obstacles to market deployment, stimulating product demand, and building consensus among key players, as well as addressing pollution, road safety and congestion problems common to all the Member States) (see the first report of the Intelligent Car Initiative [32]).

In the UK, in another recent example, the Foot LITE project at Brunel University will examine issues in safe, ecological and efficient driving [33], aiming to encourage sustained changes to driving styles and behaviours which are safer, reduce congestion, enhance sustainability, help reduce traffic pollution emissions, and reduce other social and environmental impacts. Using existing technologies, the project is intended to utilise a 'smart' driving advisor to obtain and display information about vehicle journeys and driving style through user-friendly smart phone applications. With internet access, drivers will be able to obtain post-journey feedback that includes a comprehensive review of driving behaviour, and also to share data and benchmark within an on-line community. Some of the features of the information to be collected and displayed allow for individualised or personal tutoring – including information and advice on vehicle proximity to other road users, lane positioning and departure warning, driving efficiency, gear changes, off-board trip analysis, as well as providing general access to driving information services. Overall, it is anticipated that the project outcomes will include:

- Potential cost savings (fuel consumption, and vehicle insurance costs);
- Improved driving skills for drivers, with continuous driver development, and a corresponding reduction in unsafe behaviours;
- Increased awareness of environmental responsibility; and
- A reduced carbon footprint and improvements in fuel economy

The Foot-LITE project addresses Future Intelligent Transport Systems' (FITS) Innovation Platform priorities as jointly defined by the UK Department for Transport (DfT), the Technology Strategy Board (TSB) and the Engineering and Physical Sciences Research Council (EPSRC) in October 2006, and is due for completion in 2010. The environmental and financial costs of road transport are a key issue for governments, car manufacturers and consumers. Alongside these issues remain longstanding concerns about road safety. One way in which the costs of driving can be reduced is by adopting ‘smart’ behaviours, which include a combination of both fuel efficient (eco-driving) and safe driving styles. An initial focus of the Foot-LITE project is to review the relevant literature on driver behaviour and performance as it pertains to safe and environmentally efficient driving, as well as research and ergonomic guidelines for in-vehicle interface design. The project aims to provide pertinent advice on driving style, enabling drivers to adapt their behaviour and to make informed decisions about the trade-offs between eco-driving and safe driving. Part of the project is focused on the ergonomics of the system, with particular emphasis on the in-vehicle human machine interface (HMI) which presents information to the user while they are driving while avoiding the negative consequences of distraction [34, 35].

Outfitting and retrofitting IVTs

An important issue for safety-related IVTs relates to the take up of the technologies. This can be as OEM (Original Equipment Manufacturer) installation, that is, the development is part of the vehicle design, and installation of the IVT is at the time of vehicle manufacture. Alternatively, the installation of the IVT can be as a specification for vehicle registration or approval of operation, or installation can be through voluntary retrofitment.

The ability to retrofit a particular into the existing motor vehicle fleet can mean a significantly faster uptake, and can allow for regulatory interventions to support an IVT, such as requiring all vehicles to have a particular IVT by a specified date. The latter process is more typically done for vehicles used commercially (e.g., for taxis, buses, etc.).

Two safety-related IVTs that have been identified as very suitable for retrofitment into the existing vehicle fleet are intelligent daytime running lights [36] and intelligent speed adaptation technologies [7].

There is a particular issue regarding IVTs such as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems linking vehicles and the roadway infrastructure through wireless communications. For the effective introduction of these IVTs, there is a requirement that all motor vehicle companies that sell vehicles in a country must agree to consistent communications standards and that governments must agreed to the allocation of spectra to support the communications. And although outfitting motor vehicles to operate in roadway V2I networks may not be too costly, installing the necessary devices across an entire road transport network infrastructure would likely be a major and expensive investment (Ashley, for example, noted one estimate for a nationwide V2I system in the US to involve a projected US$1,000 billion cost of installation [37]).

A final note

In a recent Scientific American review article (December 2008), Ashley [37] opined that next-generation automotive safety technology could give us motor vehicles that are difficult to crash—and eventually may not need drivers at all. He suggested that the key concepts are:

- Smart safety systems on today’s high-end motor vehicles are taking ever greater control from drivers to avoid crashes or, at least, reduce injuries and fatalities. Within a few years, cars will steer clear of crashes without any driver input at all.
- So-called crashless cars will emerge because of customer expectations of safety, government pressure, crowded roads, an older, less capable population, and the adoption of lightweight vehicles with less crashworthy structures.
- Engineers have meanwhile demonstrated robotic vehicles. Together with the crashless car, this development means that the driverless car cannot be far off.

The latest generation of advanced safety devices designed to prevent or avoid road crashes are currently available on many high-end car models, and these technologies are starting to migrate to lower-cost cars and trucks as well. The next major iteration of collision avoidance technology should be even more effective, as it will be able to engage the brakes automatically without any input from the driver at all. These and related safety capabilities may herald a new era for the automobile, a time in which car owners become increasingly willing to accept automated assistance on the road, even if that means ceding to robotic systems some of their traditional feelings of mastery over their vehicles. Within a few decades, many advanced cars will be able to avoid most crashes. At some point, in fact, they will drive themselves.

Ashley suggested that two trends are pushing toward greater automation in cars. First, the average age of most of the world's driving populations is rising rapidly. As motorists' faculties and capabilities decline, technology can increasingly be introduced to keep vehicle occupants—and others on the road—safe. The second trend is a bit less obvious—there is a demand for greener, more environmentally responsible cars that consume less energy. While most efforts focus on developing more energy-efficient engines, much the same effect can be achieved by building motor vehicles that are lighter weight. As "lightweighting" often results in vehicles with less robust structures that tend to sustain more damage in collisions, the development of motor vehicles that avoid crashes can compensate for that drawback.

On the other hand, some factors are limiting the speed at which advanced safety technology is coming online:

- it is still rather expensive;
- motor vehicle manufacturers remain wary of any costly legal ramifications that might arise from injuries or deaths caused by safety system failures; and
- perhaps paramount, motor vehicle manufacturers are careful not to intrude too much on customers' perception (and even demand) that they have control over their motor vehicles.

The technologies discussed by Ashley included:

- Antilock brakes (ABS);
- Traction-control systems (TCS);
- Enhanced stability control (ESC);
- Pre-emptive collision preparation (e.g., using sensors to verify that a side collision is occurring and preparing side air bags to deploy immediately if a door-pressure sensor alert is detected);
- Forward-collision warning systems (including following distance warnings, active braking systems for forward collisions);
- Adaptive cruise control (ACC);
- Lane departure systems;
- Side blind-spot detection and lane-change assistance and warning systems;
- Reversing collision avoidance;
- Night vision enhancement (detection of pedestrians and animals on the roadway);
- Traffic-sign recognition systems that, for example, detect speed limit signage or prevent drivers from running stop signs and lights;
- Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems (linking vehicles and the roadway infrastructure through wireless communications); and
- Autonomous vehicles (driverless vehicles or robotic cars; see the US Defense Advanced Research Projects Agency's challenges races designed to demonstrate that robot road vehicles can become practical).

Interestingly, Ashley did not identify or discuss IVTs developed to limit, control and manage vehicle speeds (e.g., through top speed limiting, or through Intelligent Speed Adaptation), a point drawn in a comment in response by Paine [38]:

> "This article is stunning for its omission of a simple, practical technology that is available now and can be easily retrofitted to existing vehicles. This is intelligent speed assist (ISA) which uses GPS signals to determine location and vehicle speed. A built-in database then informs the driver if the current speed limit is being exceeded. Numerous trials have been conducted in Europe,

> Australia and Canada but not the USA. This month an Australian SatNav device was released that "knows" the speed limits for nearly all populated areas of Australia. The unit which has the usual maps and the SpeedAlert function costs less than US$200. My research in this field suggest that voluntary ISA will save 5% of serious road injuries. As a side benefit it will also reduce fuel consumption by 3%. It is time that compliance with speed limits got attention from ITS researchers in the USA.."

Ashley argues that the combination of these advanced sensor systems, particularly if they were networked, could establish a virtual "safety bubble" around a vehicle, one that could detect nearly any hazard in the vicinity. But such an onboard system would probably be complex and costly, perhaps more than car owners would want to spend.

Concluding comments

The main observations arising from this review of the 2008-2009 research literature and commentaries on safety IVTs are:

- Several researchers and regulators are expressing caution about the estimated potential benefits of IVT where compensating driver behaviour may offset the safety benefits. For example, with ESC – a prominent safety IVT - there is concern that ESC will lead to more aggressive driving [17], while there are reports of varying effects of ESC in multiple vehicle crashes [39].

- Researchers are paying attention to the characteristics of the drivers using IVTs, see, for examples, the recent studies of IVT use by older drivers [40], teenagers [41], or drivers using vehicles fitted with IVTs for work purposes [29]. The possibility of behavioural adaptation to IVTs by drivers continues to be a focus of interest.

- Researchers are also paying attention to the characteristics of the roads used by drivers using IVTs, see, for examples, IVT use in road tunnels [42] or on motorways and major transport routes and corridors [25].

- Driver distraction caused by warning signals from numerous unco-ordinated IVT is a concern.

- Intelligent phones that know when to delay a call or SMS by detecting driver-critical situations are being considered

- There is a major IVT-related project in Western Australia where road vehicles used for pipeline maintenance have been fitted with various IVTs [29, 30].

- IVTs associated with work-related driving may be a mechanism to increase market penetration and create demand (e.g., the PRAISE project in Europe [23]).

- At the 2009 ESV conference in Stuttgart, Germany, Adrian Lund (President of the US Insurance Institute for Highway Safety) pointed out that many of the technologies being showcased by vehicle manufacturers will have little, if any, effect on some of the most common types of serious crashes such as head-ons [43].

- Injury to far-side occupants in side impacts is being recognised as a problem, particularly where driver and front passenger heads collide. This might be exacerbated by curtain airbags. A possible countermeasure is an airbag that deploys between the driver and front passenger. This is a new IVT to monitor, although the extent of the problem and the effectiveness of the countermeasure are unclear at this stage.

- Research on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications continues apace [26], but it is not clear how widespread implementation would be achieved without some control on access of non-V2V vehicles to the road system. In the meantime, a beta trial is underway in Australia of an ISA system that uses the mobile phone network to locate vehicles and pass on current speed limit and traffic related information to a GPS-equipped smart phone within the vehicle. This appears to overcome many of the implementation hurdles associated with V2V and V2I.

- There is a trend to combining IVTs (either as a package of safety-related IVTs, or safety-related IVTs in combination with other communication, entertainment or information IVTs).

- There is a need for better design of field operational trials to evaluate IVT. Good work has been undertaken in Europe for the design and conduct of field operational trials, with Australian research involvement [44].

- There is no simple equivalent of the vehicle crash test for evaluating the performance of crash avoidance systems. Gathering real-world accident data is therefore important [45]. Better methodologies for gathering and analysing these data are needed [46]. The large delay in obtaining crash data for vehicles fitted with new technologies does not seem to be addressed by most researchers.

- A caution is noted, as with the large or widespread introduction of IVTs, there may be problems in the procurement, installation, software and use, including maintenance, deployment, vendor responsiveness and assistance, and data extraction and use (see Sapper, Cusack & Staes [47] for a recent discussion of such issues associated with the introduction of electronic data recorders for incident investigation, driver performance, and vehicle maintenance in a bus transportation agency). As well, there are discussions concerning issues associated with OEM fitment and retrofitment of IVTs.

- ISA appears to have received little coverage in research papers over the past two years, excepting the publication of several ISA-UK project reports by Leeds University in the UK [48, 49] and preliminary reports from a number of European field operational trials.

- Several ISA trials are underway [7], so it is expected that further research – European and Australian research – will be published soon. The conference on Intelligent Speed Adaptation in Sydney in November 2009 has provided new insights and information (see the Intelligent Speed Adaptation conference website at http://www.rta.nsw.gov.au/roadsafety/2009_conference.html).

- Motorcycle ABS has been found to be highly effective, with the potential to reduce serious crashes by 50%. By design, the IVT analysis did not cover separate classes of vehicle such as motorcycles. There may be a good case for a separate evaluation of motorcycle IVTs in the future.

- IVT applications in heavy vehicles might also merit a separate evaluation.

- The literature regarding safety-related IVTs is expanding quickly. There is a substantive number of new projects examining IVTs in progress or about to commence, and increasing interest in IVTs in Europe, the US, Asia and Australia. The literature regarding safety-related IVTs is expected to continue to develop rapidly.

Previously, a method for prioritising government involvement in the promotion of IVTs was developed [1, 2, 4,5]. This method takes into account road safety benefits, readiness of the technology, regulatory and infrastructure requirements, costs, user acceptance and the potential influence of government initiatives on the uptake rate. This update has found no major new safety IVTs that deserve to be added to the list established previously because they would (or are likely to) rank highly in the evaluation process. Paine and his colleagues [1, 2] have concluded previously that the most desirable technologies that deserve governmental support, as assessed with road trauma reductions as a major consideration, are:

- Intelligent Daytime Running Lights
- Side airbags with head protection

- Intelligent Speed Adaptation
- Seat belt interlock/reminder
- ABS with electronic brake distribution
- ESC (Electronic Stability Control)

Updates to estimates of effectiveness could be undertaken, but they are likely to be a refinement of the established findings, rather than cause any major changes to rankings. In any case, there is little, if any, improved confidence in the estimates of effectiveness.

Several of the technologies identified and recommended for priority action by government are related to driver compliance issues (i.e., they may be seen as "enforcement" related technologies) [1]. Such technologies are unlikely to succeed through market forces alone - a co-ordinated, co-operative approach involving industry, government, and advocates within the community, is appropriate.

Several European projects have attempted to develop methodologies for prioritizing IVT. However, they are considered to rely too much on uncertain estimates of the potential benefits of the technology. The Transport Accident Commission methodology that uses a business-case approach [1,2] is still regarded as the most robust approach in view of this uncertainty.

Some emerging issues identified included: the possibility of behavioural adaptation to IVTs by drivers; a trend to combining IVTs (either as a package of safety-related IVTs, or safety-related IVTs in combination with other communication, entertainment or information IVTs); an increased focus on conducting robust field operational testing of IVTs; and issues associated with OEM fitment and retrofitment of IVTs.

It is clear that IVT developments should continue to be monitored, on an annual or biennial basis, as the relevant research and commercial literature is growing rapidly in number and involving a broad range of research, technology, manufacturing, and governmental bodies. It may therefore be appropriate in future to conduct specific studies to review particular vehicle types (e.g., cars, trucks, motorcycles) or individual IVTs.

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