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Review of crash effectiveness of Intelligent Transport Systems

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Abstract:

This report provides a review of currently available Intelligent Transport Systems (ITS) and their expected and observed safety enhancing effects. ITS are technologies applied to the transport domain that may enhance mobility, efficiency and safety, among other benefits. The potential for ITS to improve road user safety has been widely explored, and this report presents a review of what is known about the effectiveness of safety-relevant ITS. Each system has been classified as in-vehicle, infrastructure-based or cooperative, and further categorised as active, passive, or combined active and passive. The systems are described in terms of their functional and technical characteristics, their likely crash relevance, and available literature regarding safety enhancing effects or disbenefits has been reviewed. In total, 138 systems have been reviewed in this report. Overall, it can be seen that while there may be inconsistencies among the literature regarding the expected degree of effectiveness of these systems, there is considerable evidence to suggest that ITS have had, and will continue to have, substantial positive effects on road user safety.

Keyword list: Intelligent Transport Systems, active safety, passive safety, combined active and passive safety, infrastructure-based, in-vehicle, cooperative, passenger vehicle, commercial vehicle, motorcycle, vulnerable road

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1 Executive Summary

TRACE addresses two main issues of road safety, **Causation Analysis** and the **Evaluation of the expected and observed effectiveness of safety functions**.

The second issue is covered in the context of WP4 "Evaluation". More specifically**,** Task 4.1 is dealing with the evaluation of the expected effectiveness of safety functions, so called a-priori evaluation**,** while Task 4.2 is dealing with the observed effectiveness of safety functions, so called a-posteriori evaluation.

In order to cover the objectives of the Task 4.1 (and partly of the Task 4.2), the following steps have to be done:

- **STEP 1: Review the most critical safety functions and their relevance to accidents**
- STEP 2: Look for the best way to classify the accidents as well as to review the most critical accident configurations or scenarios (contents of D4.1.2)
- STEP 3: Review and select the most promising and suitable methodologies for the a-priori evaluation of the TRACE selected safety functions (contents of D4.1.3) and a-posteriori evaluation (contents of D4.2.1)
- STEP 4: Perform the evaluation and report the results (contents of D4.1.4 & D4.1.5 & D4.2.2).

This deliverable covers STEP1 and has been created in cooperation with TRACE WP4 "Evaluation " and WP6 "Safety Functions".

In order to perform evaluation in safety systems (Intelligent Transport Systems – ITS[1]) and then in functions, a list of the most promising ones must be prepared and analysed. This work has two goals: first to collect all the available information about existing and future safety systems and then to select the ones that will be evaluated according to the criteria/goals of TRACE (objective of WP6).

A total of 138 systems are presented in this review giving a snapshot view of what is known about what currently exists as of mid-2006. Each system is described in terms of its technical and functional characteristics, likely crash relevance, and of what has been reported regarding their safety benefits and disbenefits.

The vast majority of the described systems are in-vehicle systems. Some of them (i.e. ESC, ISA, weather management systems, automated enforcement systems, for example) have been widely investigated, while other systems (i.e., pop-up bonnets, pedestrian signal systems, railway crossing systems, intelligent lighting systems) have not been as thoroughly evaluated. The major findings of estimations and evaluative studies have been reported. Caution must be taken in interpreting these findings, as they may vary in terms of sample size, simulation versus real-world crash data, location, system variations, vehicle type and numerous other factors. Likewise, less emphasis has been placed on identifying potential disbenefits of these systems. While some systems may show no reported disbenefits here, this does not mean that there are no disbenefits associated with those systems.

[1] Intelligent Transport Systems (ITS) are technologies that are applied to the transport domain with the aim of improving safety, efficiency, mobility and productivity. The potential for ITS to enhance the safety of road users has been widely acknowledged, however, as most of these technologies are relatively new, few studies of their effectiveness currently exist

Overall, it can be seen that while there may be inconsistencies among the literature regarding the expected degree of effectiveness of these systems, there is considerable evidence to suggest that ITS have had, and will have, substantial positive effects on road user safety. The wide variety of available systems reflect and address the large range of crash problems, vehicle and road users types, and the growing recognition of the value of ITS in transportation safety.

2 Introduction

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In order to perform evaluation in safety systems (Intelligent Transport Systems – ITS[2]) and then in functions, a list of the most promising ones must be prepared and analysed. This work has two goals: first to collect all the available information about existing and future safety systems and then to select the ones that will be evaluated according to the criteria/goals of TRACE (objective of WP6).

2.1 Aim of this report

The current report aimed to review the available literature regarding safety relevant Intelligent Transport Systems. The following chapters identify and describe intelligent transport systems that have been shown to, or have the potential to, enhance the safety of road users. Where available, evaluations or estimations of the effectiveness of these systems have been provided. This report describes what is known about the safety enhancing effects of in-vehicle, infrastructure-based and cooperative ITS as of mid-2006.

2.2 What are Intelligent Transport Systems?

Intelligent Transport Systems is an umbrella term for a number of electronic, information processing, communication, and control technologies that may be combined and applied to the transport domain. There is no clear definition of what is ITS and what isn't. However, intuitively any ITS must show at least some form of information processing, computing, or vehicular or road network control to be considered intelligent. ITS may refer to a single technology, an integrated system, or a network of systems. As noted by Mitretek (1999), ITS is not a monolithic system, nor the integration of systems. Rather "ITS is a multi-faceted approach for addressing transportation needs" (p.1).

ITS serve a number of functions in a number of ways. They may interact with a single user or vehicle, or influence an entire road network. ITS can be used to improve traffic safety, traffic flow and capacity, public transport and commercial vehicle efficiency and productivity, and reduce vehicle emissions and resource consumption. While the potential for ITS to enhance the environment and economic productivity is promising, perhaps the greatest impact ITS has is in the improvement of the safety of road users. Many systems have been developed with the specific aim of enhancing occupant protection, or the protection of vulnerable road users.

Several studies have estimated the potential for ITS to enhance safety. For example, McKeever (1998) estimated that 26% of fatal and 30% of injury crashes could be prevented with total system wide deployment of in-vehicle, infrastructure-based and cooperative ITS systems in the US. Another report (OCED, 2003) conservatively predicted that full deployment of ITS in OCED countries could result the

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prevention of up to 47,000 fatalities, the reduction of fatal and injury crashes by up to 40%, and estimated annual crash cost savings of $194 billion US. The savings from fatal crashes alone were expected to be $73 billion US. Likewise, ERTICO (1997, cited in Rumar, et al., 1999) reported a vision for the future of ITS in which the following predictions were made:

- ITS will significantly contribute to a 50% in road fatalities.
- 25% reductions in travel times due to ITS.
- 50% reductions in city centres due to traffic management systems
- Automatic Crash Notification will result in a 15% reduction in fatalities.
- 40 hours per road user saved due to automated tolling systems.
- 50% delay reductions due to public transport priority systems.
- 25% reductions in commercial vehicle operations costs due to fleet management systems.

Others have estimated the potential of ITS to influence certain crash types. For example, it has been suggested that systems which address lane-change, rear-end and off-path crashes have the potential to prevent 1.1 million crashes (17% of all crashes) in the US annually (FHWA, 1998). European Communities (2000) reported that a reduction in the magnitude of 120,000 fatalities and serious injuries per year can be expected with occupant protection (passive) systems. McKeever (1998) estimated that system-wide deployment of infrastructure-based ITS systems in the US has the potential to reduce the total number of fatal crashes by 11.2% and injury crashes by 14.4%. The systems included in this analysis were traffic (freeway) management systems, incident management systems, automated enforcement (speed and red-light cameras), signal control, rail crossing systems and weather information systems. Cooperative systems were estimated to have the potential to reduce the total number of fatal crashes by 4.3% and injury crashes by 1.7% with system-wide deployment in the US. The systems included in this analysis were in-vehicle navigation systems, automatic crash notification, intelligent speed adaptation, and electronic screening, which are cooperative systems.

While the overall effects of ITS on road user safety are difficult to assess at this early stage, it is possible to investigate the impact of individual systems or small classes of ITS. However, given the large number of ITS systems that are currently commercially available, there is a disproportionate lack of evaluative literature regarding their actual safety benefits. As most ITS are relatively recent developments in transport safety, in most instances there has not been sufficient time or market saturation to accurately assess their impact. At present, numerous studies have estimated the potential of ITS to reduce crash risk and severity, while others have investigated their benefits is simulator studies, test-track trails or naturalistic driving studies. The current study will report these findings.

2.3 Taxonomy of Intelligent Transport Systems

Intelligent transport systems may be categorised several ways, referring either to the physical location of the system, the timing of the effects of the system, the means by which the system enhances safety, or the transport domain to which it is applied.

One of the broadest and most common classifications regards the positioning of the system – i.e., whether system is in-vehicle, infrastructure-based or cooperative:

- **In-vehicle:** These refer to technologies based within the vehicle. These typically involve sensors, information processors and on-board units or displays that provide additional information to the user, automate or intervene with some part of the driving task, or provide warnings to the user about potential hazards.

- **Infrastructure-based:** These may serve one of two general functions: to provide drivers with additional information via roadside messages, or to better manage and control traffic flow. In both instances, various types of sensors are used to gather information from the road environment and road side signs or signals are used to influence traffic behaviour.

- **Cooperative:** Cooperative systems involve communication between vehicles and the infrastructure or between vehicles. This communication may be one way, e.g., where the vehicle receives information from the infrastructure but does not transmit information in return, or two-way where the vehicle both sends and receive information to another vehicle or infrastructure-based system.

Another popular means of considering ITS is to differentiate when the system takes effect:

- **Active:** These systems may be considered crash avoidance technologies. That is, they serve to prevent a crash from occurring. Active systems continuously monitor an aspect of the performance of the user, vehicle, road environment or transport network, and either alert the user/s to potential danger, intervene with the driving task to avoid danger, or automate part of the driving task.

- **Passive:** Passive systems may be considered crash mitigation or minimisation technologies. They serve to enhance the safety of the driver or other road users by minimising the severity of a crash once it has already occurred. A clear example of passive systems is airbags.

- **Combined Passive and Active Systems (CAPS):** CAPS is a relatively new concept. It describes systems that monitor the road environment, vehicle and/or driver for potential danger (the active components), and then applies passive safety measures when a crash has been deemed to be unavoidable. At this point, CAPS systems are only in-vehicle.

The methods of classification described above are able to encapsulate all currently existing ITS systems. They are not mutually exclusive – indeed they can be combined to further distinguish ITS, e.g., in-vehicle active systems, in-vehicle passive systems and in-vehicle CAPS systems.

Some authors have also described ITS in terms of the method they employ to enhance user safety (e.g., Lind, 1998; Regan, et al., 2001; Rumar, et al., 1999). ITS may serve to influence traffic exposure, influence crash risk (essentially active systems), and minimise crash consequences (passive systems). Systems which influence traffic exposure indirectly enhance safety by altering the route, distance or travel times of road users. However, influencing travel patterns is not always safety enhancing. Encouraging users to take unfamiliar routes, or use minor roads may actually increase crash risk, or the system may divert the user to a route that is quicker but more crash-prone.

It is also possible to differentiate ITS in terms of the transport domain they influence. These are often referred to as: Advanced Traffic Management Systems (ATMS); Advanced Traveller Information Systems (ATIS); Commercial Vehicle Operations (CVO); Advanced Public Transport Systems (APTS); Advanced Rural Transportation Systems (ARTS). These classifications may incorporate the same systems applied in different ways. For example, Automatic Vehicle Location (AVL) is a system applicable to both CVO and APTS.

2.4 Structure of this report

Given the wide variety of ITS types, applications, and classifications, this report as attempted to categorise ITS in a broad, user-friendly way. The report is divided in to three main chapters: in-vehicle systems, infrastructure-based systems, and cooperative systems. These chapters, first introduce some relevant European projects initiated to help implement and improve the systems and methods in use. The chapters have then been further sectioned into active, passive and CAPS. Each ITS fits into one of these categories, however, this differentiation has been blurred slightly in some instances. When a number of systems relate to a single application, e.g., fleet management systems, these systems have been combined into a general category, even though some of these technologies may be cooperative while others are in-vehicle. Also, some systems may represent a class of similar technologies (e.g., Advanced Driver Assistance, which may encapsulate many technical variants), or a specific device (e.g., some categories may not contain any systems as yet (e.g., infrastructure-based CAPS systems).

Information regarding each system is provided under the following headings:

System name: Here the most common and generally accepted term has been used. However, often the labels assigned to ITS systems are often arbitrary – largely dependent on technology and vehicle manufacturers. In this report these systems have been categorised in terms of function, not according to their popularised names. That is, where systems which go by different names and show minor technical dissimilarities have been classed as the same system type when the function of the system is the same. Wherever possible, all other names that may be used to describe the same ITS have also been listed.

Vehicle type: Indicates which vehicle type the ITS has been applied to. This may be one or a combination of passenger, commercial vehicles or motorcycles, or specific vehicle types such as SUVs, convertibles, etc. It should be noted that the vast majority of in-vehicle ITS system have been developed for use in passenger vehicles but they may be applicable to other vehicle types.

Description: A functional and technical description of the system is provided. This includes what the system aims to do, an overview of the technologies involved in the system, and notable features of the system. This is a broad description only. The specific technical and functional details these systems vary between different products and applications. Where significant variations in system specifications exist, these have been described as variants of the system.

Crash relevance: This identifies the types of crashes that are most relevant to the system. These are based on the major crash categories from the VicRoads Definitions for Classifying Accidents. The major crash types considered in this review are:

- **Multiple-vehicle crashes at intersections:** Crashes between two or more vehicles from adjacent angles in an intersection.

- **Head-on crashes:** Vehicle collisions at opposing angles.

- **Rear-end crashes:** Crashes from the same direction where one vehicle strikes the rear of another moving or stationary vehicle.

- **Side-swipe crashes:** Crashes for the same direction where one vehicle strikes the lateral side of another (e.g., when overtaking).

- **Manoeuvring & emerging crashes:** Multiple-vehicle crashes where the vehicle is struck by another vehicle while performing a u-turn, leaving a parking spot or emerging from a driveway.

- **Parking crashes:** Crashes when the vehicle is entering a parking spot.
- **Pedestrian crashes:** Crashes where the vehicle striking a pedestrian on the roadway.
- **Animal crashes:** Crashes where the vehicle strikes an animal on the roadway.
- **Object crashes:** Collisions with objects or stationary vehicles on the roadway.
- **Off-path on straight crashes:** Single-vehicle crashes where the vehicle leaves the roadway on a straight section of road.
- **Off-path on curve crashes:** Single-vehicle crashes where the vehicle leaves the roadway on a curved section of road.
- **Rollover crashes:** Crashes where the vehicle rolls over.
- **Secondary crashes:** Crashes resulting from the delay or congestion caused by another crash.

Additionally, some systems may serve to address contributing crash factors. Crash factors are characteristics of the driver, vehicle or environment where the crash would not have occurred, or would have been less severe, had these factors not been involved. The major crash factors considered in this review are: intoxication (alcohol and/or illicit drugs); excessive speed; inattention/ distraction; fatigue; vehicle malfunction; poor visibility; poor road surface conditions; weather; conspicuity; and unlicensed vehicle use.

In addition, some systems may show safety benefits in reducing emergency service response times. Another safety benefit that should be considered is the reduction in crash exposure resulting from shorter journeys or the use of safer routes.

Effectiveness: An attempt has been made to review the literature for studies which have examined the effectiveness of ITS on vehicle safety. This has been sourced from both international academic resources and technology and vehicle manufacturers. A number of important factors must be considered when interpreting these findings. The nature of the study described will vary from simulator, test track or naturalistic driving studies, analysis of real-world crash data, benefit-cost ratios or estimates of potential effectiveness. Also, they may investigate different aspects of road safety, e.g.: the effect on total crash rates; specific crash types; specific crash severity; specific vehicle types; specific locations/times of day; or crashes involving specific contributing factors. Also, these labels and definitions are not always consistent between studies. Another factor is that these studies are from different regions where certain safety issues may be more pertinent. For example, weather management systems may show higher effectiveness estimates in northern hemisphere countries than would be seen in regions with warmer climates. This is not a critique of these studies.

Disbenefits: Any findings, estimates or discussions of the potential negative effects of ITS on road user safety have been reported in this section.

3 In-vehicle systems

3.1 Active systems

3.1.1 Active Front Steering

Description

Vehicle Type: Commercial and passenger.

Active front steering (AFS) automatically adjusts the steering input required from the driver to suit the current speed and road conditions. The system adjusts the ratio of the steering transmission depending on the speed and geometry of the road. At low speeds, the ratio is ratio is lower, or more direct, so that the vehicle is more 'agile' when manoeuvring. At high speeds and when cornering, the steering system becomes stiffer, so that the vehicle is more responsive to less driver input. AFS reduces the need to cross the arms over when cornering, and reduces steering effort by up to a third while increasing vehicle stability and responsiveness (www.delphi.com).

The system involves a mechanical link between the front and rear wheels. Vehicle factors such as steering input, speed, yaw rate, lateral acceleration are constantly monitored to determine the appropriate steering ratio for the current driving conditions. AFS works in conjunction with hydraulic or electric power steering systems. AFS also augments ESC, reducing the need for ESC action and giving more control over the vehicle trajectory to the driver. In this sense, ASF has an intervening function, where the system corrects over steering situations.

Crash relevance

Off-path on straight crashes; off-path on curve crashes; manoeuvring crashes.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.2 Active Rollover Protection

Also: *Rollover Mitigation*

Description

Vehicle type: Commercial and passenger, typically SUVs and vans.

Active rollover prevention (ARP) serves to avoid rollover crashes by adjusting the braking pressure and engine torque distributed to the vehicles individual wheels. Rollover situations are imperceptible to drivers until the rollover has actually begun, in which case a crash is largely unavoidable. ARP augments ESC by monitoring the tilt of the vehicle. As in ESC, vehicle speed, traction and yaw rate are continuously monitored, plus the vehicles centre of gravity. ARP is typically only applied to vehicles with a higher centre of gravity, such as vans, SUVs etc. When the vehicle approaches a rollover threshold of lateral acceleration, i.e. when cornering rapidly, the system applies additional torque and/or braking pressure to each wheel individually. This maintains contact between all wheels and the road surface. The system may also include an in-vehicle unit that informs the driver when a near-rollover event has occurred.

Crash relevance

Rollover crashes.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.3 Adaptive Cruise Control

Also: *Autonomous Intelligent Cruise Control; Intelligent Cruise Control*

Description

Vehicle type: Passenger vehicles

Adaptive Cruise Control (ACC) serves to reduce driver workload in dense traffic. Bishop (2005) refers to ACC as a "longitudinal control co-pilot" (p. 127). ACC aids the user in maintaining a safe headway with the leading vehicle. As in normal cruise control, the vehicle's desired speed is preset by the user, and this is maintained by the system if the roadway ahead is unobstructed. Alternatively, a desired time or distance headway from the leading vehicle can be selected in some systems. However, if a leading vehicle is travelling at a lower speed than the user's vehicle, or is located within the preset time or distance headway, the ACC system intervenes via braking pressure or throttle/engine torque control so that the headway increases. The system only intervenes if the current preselected speed or headway would lead to a likely collision. ACC may employ radar, laser or machine vision to continuously monitor the leading vehicle. Auxiliary detectors also monitor the speed, yaw and cornering rate of the vehicle to maintain tracking of the leading vehicle in the same lane when cornering.

Crash relevance

Rear-end crashes.

Effectiveness

A benefit-cost ratio of 0.9 for ACC in the year 2010 was predicted by Abele, et al. (2005). This ratio improved to 1.2 in the year 2020, due to suggested greater market penetration and lower crash costs. It was assumed in this study that ACC has the potential to rear-end collisions by 25%.

A US study estimated that at speeds of 88 km/h and over, 5.2% of crashes rear-end crashes may be avoided with ACC, while at speeds of 48 km/h and over a 29% reduction was expected (Najm & Mironer, 1998, cited in Regan, et al., 2001).

Minderhound and Bovy (1998) estimate various ACC designs at different headway settings and market saturation points, and found increased traffic capacities ranging from -1.6-12.4%.

Other estimates have suggested ACC may reduce the incidence of all types of crashes by 5.9% (Elvik, et al., 1997, cited in OECD, 2003), while conservative estimates reported by the OCED (2003) show a reduction in all injuries and fatalities by 1.4% and 0.7, respectively.

ACC can reduce braking reaction times from 0.7-1.5 seconds to 0.1 seconds (Chira-Chavala & Yoo, 1994, cited in Regan, et al., 2001). Regan, et al. also proposed that the intervening function of ACC may additionally serve to alert inattentive drivers.

Disbenefits

Behavioural adaptation to the system may actually counteract its safety benefits, where users compensate for the action of the system by driving more riskily (Kulmala, 1997). Other pertinent issues include reliability, user ability to recognise a system malfunction, acceptability, and so on (Regan, et al., 2001).

Various studies have demonstrated ACC can be effective at reducing speed variability, but may be associated with increase average speed and reduced headway, although these findings are not consistent (see Regan, et al., 2001). It was suggested by Regan, et al. that ACC may serve to increase driver comfort but not necessarily safety.

Studies reviewed by HUMANIST (2006) revealed inconsistencies in the effectiveness of ACC. While some studies showed a reduction in maximum speed and speed variability and an increase in braking and accelerator pedal use, the associated reduction in driver workload was shown to result in driver inattention in other studies. Other negative findings included smaller minimum headways, greater speed, larger braking force, greater lane position variability and longer hazard detection reaction times.

Current systems are only effective at speeds of 40 km/h or above, and do not exert sufficient braking force to prevent a crash should the lead vehicle slow very rapidly (Bishop, 2005).

3.1.4 Advanced Driver Assistance Systems

Description

Vehicle type: All.

Advanced driver assistance systems (ADAS) serve to reduce user error, leading to a reduction in crashes, improved vehicle and traffic network efficiency, and decreased congestion. ADAS may serve a variety of functions: provide additional information to the user (as in ATIS systems); provide warnings of potential hazards; aid the user in avoiding potential hazards; or provide autonomous intervention to avoid potential crashes (Schoenburg & Breitling, 2005). In order to do this, ADAS may employ a variety of telematics and/or intervening and advisory active safety systems, such as navigation systems, curve speed warnings and forward collision warning and avoidance. ACC is the base of many ADAS systems, with the addition of further collision warning and avoidance technologies (OECD, 2003). Other systems that may be incorporated into ADAS include driver vigilance monitoring, road surface monitoring and vehicle diagnostic systems.

Advanced driver assistance systems create a human-machine interface which combines information from in-vehicle devices and communication systems and presents these to the user in an unobtrusive visual and/or auditory form. The purpose of these systems is to reduce the workload of the user, allowing rapid detection of potentially hazards situations, in turn leading to faster decision making and responding. ADAS is largely considered (and marketed) as a driver comfort enhancing system rather than safety enhancing. However, the incorporation of a number of collision warning and mitigation technologies make this an active safety system.

The eImpact project suggested that the advanced Adaptative Cruise Control system will allow a reduction of 25% in all related accidents (rear-end). It also estimates by another 20% the reduction of fatal injuries into serious, and of serious injuries into slight (2005).

Crash relevance

Depending on the types of active systems incorporated into ADAS, it may be relevant to: rear-end crashes, object crashes, multiple-vehicle crashes at intersections; and crashes where speed, inattention/distraction, fatigue and poor visibility are factors.

Effectiveness

Lind, Lindqvist and Persson (2003) estimated that systems that provide advanced warnings and automate elements of the driving task, i.e. traffic signal detectors, automated windscreen wipers, have the 'verified' potential (based on the results of other studies) to reduce all road fatalities by less than 0.5%, while the 'full' crash reduction potential (an optimistic estimate based on full deployment) of ADAS was suggested to be 3%.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.5 Alcohol Detection and Interlock

Description

Vehicle Type: All.

Alcohol detectors typically analyse the level of alcohol intoxication of the user, and determine whether the individual is fit to operate the vehicle. Alcohol interlocks are integrated into the ignition of the vehicle, so that the vehicle is immobilised unless the user passes an alcohol detection test. Some systems may also require re-testing at continuous intervals while travelling (Kullgren, et al., 2005). The acceptable blood alcohol content (BAC) of the user may be set at zero, the legal limit for that region, or another predetermined level. Various forms of alcohol detectors and interlocks exist:

- **In-vehicle breath test:** These are the most common interlock systems. Users blow I into a tube connected to an in-vehicle unit which contains alcohol sensors, similar to what is used in roadside breath testing. If an excessive BAC is detected, the engine remains immobilised. Some systems may 'lock out' the user for a set period if the test has been failed. In order to prevent circumvention in repeat drink-driving offenders, some systems may require the user to hum as they blow into the system, are able to detect filtered air or shallow breaths, and are able to detect attempts to tamper with the system (Regan, et al., 2001).

- **Key-based breath test:** These systems are functionally very similar to in-vehicle tests; however the testing unit is more subtle, and therefore may be more acceptable to users. A small breath testing unit is integrated into the fob of the vehicles keys. When the driver unlocks the vehicle, the alcohol detector is activated. The user blows into a small mouthpiece in the fob of the key. If the driver is under the prescribed BAC the engine is mobilised. If the driver is intoxicated, the key will not immobilise the engine. These systems are also less likely to be adversely effected by cold temperatures.

- '**Sniffer' systems:** These monitor the level of alcohol in the ambient air of vehicles cabin as the vehicle is being driven. If alcohol is detected, the system informs the driver that a breath test is required. If the driver refuses, or the test is failed, the system disconnects the electrical system of the vehicle within a set time frame. 'Sniffer' systems are not designed for use by recidivist drink-drivers. These systems do not require the user to provide a breath test every time the vehicle is being driven. If the driver's BAC is below the predefined limit, some systems requires additional regular breath tests. These are also known as 'passive' alcohol detectors.

- **Skin contact systems:** Alcohol detection and/or interlock systems that analyse BAC through the hands in contact with the steering wheel have also been developed. These assess blood pressure, glucose and cholesterol, eliminating the for need breath-testing. Wearing gloves does not 'cheat' these systems (Ivey & Lightner, 1995).

Other variants of alcohol interlock systems require the user to perform psychomotor tests to detect performance impairment resulting form alcohol use (Young, et al., 2003b).

Crash relevance

Crashes where alcohol is a contributing factor.

Effectiveness

Evidence cited by Kullgren, et al. (2005) show alcohol interlocks to be reduce the incidence of repeat drink-driving offences by between 40-95%, in the US, Canada and Sweden.

Estimations of the approximate reductions expected with alcohol interlock systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 25% of alcohol-related crashes would be affected, leading to a 17.5% reduction in these crashes. This would equate to a 1.1% reduction in all crashes.

Lind, et al. (2003) estimated that alcohol interlocks have the potential to affect 18% of alcohol related fatalities in Sweden, and predicted that by the year 2015, these systems would reduce alcohol related fatalities by 9%. It was also suggested that systems that restrict some individuals from operating vehicles (alcohol interlocks and electronic licences) have the 'verified' potential (based on other studies) to reduce all road fatalities is 1%, while the 'full' potential (an 'optimistic' estimate based on full deployment) is 5%.

Regan, et al. (2002) estimated that alcohol interlock systems could reduce the number of crashes associated with a BAC>0.05 by 96%, saving approximately $263 million (AU) per year. For males aged 18-24 alone, these systems were estimated to prevent 233 crashes and save $68 million (AU) annually. Depending on the effectiveness and acceptability of the system, it was estimated that up to 9% of all crashes would reduce in severity (i.e., fatal becomes serious injury, serious injury becomes other injury).

Canadian trials of alcohol interlock systems has shown 60% fewer injury related crashes for participants in the trial. Additionally, this improvement endured for six months following the removal of the interlock system (Dussault & Gendreau, 2000).

Harrison and Fitzgerald (1999) estimated that interlock systems would result in the following reductions in alcohol related crash costs in Australia. This analysis assumed that 90% of the effects of the system would be the prevention of crashes, while the other 10% would be the reduction of crash severity (i.e., fatal becoming serious injury). It was also assumed that there would no discernable difference in acceptability or effectiveness for either breath test or psychomotor systems. Assuming 90% effectiveness, crash cost reductions of 53% were predicted with 100% fleet penetration, while 7% reductions were predicted with only 10% penetration.

In a review of six studies assessing the effectiveness of alcohol interlock in recidivist drunk drivers, Coben & Larkin (1999) noted offenders with interlock systems fitted to their vehicles showed significant reductions in re-arrests than controls, ranging between 15-69%. However, what caused these differences in effectiveness was unknown.

It should be noted that the above studies refer only to systems which require the user to blow into the device, not Sniffer systems or hand-steering wheel contact systems.

Disbenefits

Some evidence suggests that the effectiveness of alcohol interlocks reduces over time (Kullgren, et al., 2005), particularly when the device has been removed from the users vehicle (Schonfeld & Sheehan, 2004).

It has also been noted that in order to be acceptable to users, alcohol interlock must be reliable (Regan, et al., 2002; Young, et al., 2003b).

There is concern that these systems are vulnerable to circumvention and tampering (Frank, 1997; Schonfeld & Sheehan, 2004).

Interlock systems are currently expensive to install and maintain, which may impede implementation in the wider community (Olssen, et al., 2006).

3.1.6 Animal Detection Systems

Description

Vehicle Type: All.

Animal detection systems alert users to potential collisions with animals. Animal detection systems rely on radars, lasers or other visual imaging techniques such as infrared sensors to detect the presence of animals on the roadway. These systems address crashes involving large animals, such as elk, deer, moose, etc. These systems need to be sensitive enough to detect moving objects, but still have a low rate of false alarms. The different characteristics of animals as opposed to pedestrians or vehicles, in terms of height, shape and speed means these systems have different technical specifications to other object-detection systems, such as forward collision warning and pedestrian detection. Another strategy involves vehicle-mounted whistles that emit an ultrasonic noise when the vehicle is travelling at high speeds. These variants of animal detection systems do not employ forward-facing sensors.

Knapp, et al. (2004) completed an extensive review of deer-vehicle crash countermeasures. They noted that while a number of relevant in-vehicle technologies have recently been developed, these are largely night vision enhancement systems that are not specifically designed to detect animals. Rather, these systems enhance the driver’s view of the road ahead allowing earlier detection of the animal.

According to Rigney and Mitchell (2000), early animal detections systems involved short-range, limited coverage vision enhancement technologies with low background contrast. Rigney and Mitchell investigated the use of long-wave infrared imaging and thermal image processing in animal detection system. This allowed visualisation of animals ahead, based on the detection of their radiant heat relative to the environment. This image is presented to the driver using temporal imaging to give a real-time moving image, and range calibration allows the relative size of objects to be determined. Algorithms were incorporated into the system to enable better detection of motion, size, shape, contrast and various animal behaviours.

Crash relevance

Animal detection systems are relevant to crashes involving animals, including both collisions with animals, and crashes that result from avoiding animals on the roadway. Gunson and Clevenger (2003) found that crashes involving large wildlife were more likely to occur at night, on dry roads, and involve large vehicles. These factors lead to reduced visibility and longer stopping distances.

Effectiveness

Knapp, et al. (2004) noted that given that most existing vision enhancement and forward facing sensor technologies are relatively new and that they are not specifically designed for animal-vehicle crashes, evaluations of their effectiveness in mitigating animal-vehicle collisions have not yet been conducted.

Hedlund, et al. (2004) suggested that in-vehicle animal detectors may be an effective animal-vehicle crash prevention strategy; however this has not yet been investigated. It was also noted that vehicle whistles appear to be ineffective.

The Western Transportation Institute has investigated both in-vehicle and infrastructure based ITS in animal-vehicle crash mitigation. No deliverables regarding in-vehicle systems are available at this stage.

Disbenefits

Knapp, et al. (2004) suggested that the high costs of current in-vehicle systems may deter users from purchasing them. They also expressed concern regarding user negative behavioural adaptation and distraction.

3.1.7 Anti-lock Braking System

Description

Vehicle Type: All.

Anti-lock brake systems (ABS) optimise the braking performance of the vehicle, by maximising the contact between the vehicles tyres and the road surface during forceful braking. ABS ensures smooth and constant braking pressure is applied, where the system continuously monitors and adjusts the braking pressure. ABS monitors the rotational speed of the wheels and releases the braking force if the wheels begin to lock. Braking force is maintained at the maximum pressure just below the threshold of the wheels locking. By preventing the wheels from locking and skidding during emergency braking situations, the driver retains control of the stability and path of the vehicle and stopping distances are shorter than if the vehicle skids.

ABS systems may be four-wheel or rear-wheel only. Rear wheel systems are typically only implemented in light commercial vehicles, while four-wheel systems are installed on passenger vehicles. ABS is applied to both wheels in motorcycles.

Crash relevance

All crashes where braking is applied by the driver. ABS may be relevant to off-path crashes, sideswipe crashes, lane departure crashes, rear-end crashes, frontal impact crashes, and jack-knife crashes in commercial vehicles (NHTSA, 2000).

Effectiveness

In a review of previous studies of the effects of ABS, Burton, et al. (2004) reported significant reductions in the incidence multiple-vehicle crashes and pedestrian-vehicle crashes associated with ABS. It was also noted that ABS demonstrates greatest safety-enhancing benefits in wet weather conditions.

Paine (2003, cited in Paine, 2005) estimated a benefit cost ratio of 0.83 for ABS in Australia.

In a study of the effects of ABS in Great Britain, Broughton and Baugha (2002) analysed 1684 crashes and found a 3% fewer crashes occurred in vehicles equipped with ABS.

Farmer (2001) noted that early studies of the effects of ABS on crash risk found that while light vehicles equipped with ABS were less likely to be involved in multiple vehicle crashes, they were over-represented in single vehicle off-path crashes. Furthermore, ABS equipped vehicles were 24% more likely to be involved in crashes involving fatality to the occupants of that vehicle, but 20% less likely to be involved in crashes involving fatality to other vehicle occupants. However, after 1996 these effects appeared to attenuate. In the period of 1996-1998, fewer ABS equipped vehicle than non-ABS vehicles were involved in single vehicle off-path crashes. These crash patterns require further confirmation and investigation.

Four-wheel ABS systems in passenger vehicles have been shown to differ in effectiveness on different road surfaces. Significant reductions in stopping distances were observed on wet roads, dry surfaces showed a lessened reduction, while braking distance actually increased on gravel roads (Kahane, 1994). On wet roads, ABS was reported to reduce the incidence of multiple vehicle crashes by 14% and fatalities by 24%. ABS was most effective at reducing rear-end crashes and collisions with stationary vehicles. These effects were similar for snowy and icy roads, but were not observed for dry roads, although the 27% reduction in fatal crashes with vulnerable road users was observed on both wet and dry surfaces.

Rear-wheel ABS systems in light commercial vehicles have been reported to be effective in reducing almost all types of crashes in all road surface types by between 5-40%, with the exception of fatal off-path crashes (Kahane, 1993).

Disbenefits

Delaney and Newstead (2004) investigated the primary and secondary safety benefits of ABS on Australian real-world crash data. ABS was not associated with any significant secondary safety benefits, and there were no net primary safety benefits associated with ABS. Vehicles with ABS were significantly less likely to be involved in multiple vehicle crashes (ranging 19-23% for various crash types). However, this was negated by an increased risk of off-path crashes on straight (24%) and curves (35%) for ABS equipped-vehicles.

Burton, et al. (2004) noted that numerous studies have shown that the increase of rollover crash risk. This increased risk has been estimated to be between 3-39%, and up to 60% for fatal rollover crashes.

Kahane (1994) noted that the increased braking capacity of the user's vehicle resulting from ABS actually increased their likelihood of being rear-ended by a following vehicle. All types of off-path crashes also showed significant increases with ABS, where injury and fatal crashes increased by an estimated 19% and 28% respectively. Loss off control crashes also increased by 28% for injury crashes and 40% for fatal crashes, while front impact crashes increased by 15-20% for both injury and fatal crashes. Kahane suggests that as ABS retains trajectory control, users may be incorrectly steering in emergency situations. These results negated the overall net effect of ABS on both fatal and injury crashes.

Evans (1999) noted that while ABS has shown consistent positive effects on braking performance, there is less evidence to suggest that this results in an actual reduction in crashes, particularly on wet roads. Evans investigated the effects of ABS on wet roads, and found a 32% decrease in the occurrence of rear-ending a leading vehicle, but a 30% increase in the risk of being rear-ended by a following vehicle. These changes in crash risk were not observed on dry roads.

Similarly, Evans and Gerrish (1996, cited in HUMANIST, 2006) found no decrease in crash risk on dry roads, suggesting users may adapt to ABS with shorter headways and/or higher speeds. Sagberg, Fosser and Sætermo (1997) also noted reduced time headways in taxis equipped with ABS, but no change in speed (although this effect was also linked to seatbelt use and the presence of airbags).

3.1.8 Automated Windscreen Wipers

Description

Vehicle Type: Passenger and commercial.

Automated windscreen wipers activate the windscreen wipers when rain is detected on the vehicle's windshield. These systems reflect infrared beams onto the external surface of the windshield. In dry conditions the reflection of the beams so maximal. However, when raindrops interrupt the beams, causing diffraction within the raindrops, this reflection is reduced proportional to the amount of water on the windshield. This allows the system to determine not only whether the windscreen wipers need to be activated, but also at what speed. These systems aim to reduce driver workload and eliminate the need for the user to take eyes of the road when activating and adjusting the windscreen wipers.

Crash relevance

Crashes occurring in wet weather is a factor, or where inattention or distraction are factors.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.9 Brake Assist

Description

Vehicle Type: All.

Brake assist systems maximise the braking potential of the vehicle, reducing stopping distances. Brake assist aids the user in achieving maximum braking force in an emergency situation. When rapid and forceful braking pressure is applied, the brake assist system intervenes with additional hydraulic pressure to the front and rear brakes. The threshold of what constitutes an emergency brake is predetermined by the system. Brake assist systems may either react to the speed or force with which the brake pedal is applied by the driver. Braking assistance works in conjunction with ABS, where the braking pressure from both the front and rear brakes are assessed, and an acceleration sensing unit automatically intervenes and applies maximum braking pressure in an emergency situation, while also preventing the brakes from locking.

Anticipatory brake assist systems also exist. These incorporate forward scanning radar or other forward-facing sensors to detect objects or vehicles on the road ahead. If the system deems that a crash is eminent, and that the drivers braking response is inadequate, brake assist will automatically be applied. These systems may also incorporate an in-vehicle warning that informs the driver when the system is active. Essentially, these advanced brake assist systems are pre-crash system. Indeed, they may also be incorporated with in-vehicle passive safety measures, such as motorised seatbelts.

Crash relevance

Any crash where braking is applied by the driver. Page, Foret-Bruno and Cuny (2005) suggest brake assist systems will be relevant to loss of control crashes, pedestrian crashes and multiple vehicle crashes (at both intersections and non-intersections).

Effectiveness

DaimlerChrysler (2005) reported that rear-end crashes at 80 km/h were be reduced by 75% with brake assist plus crash avoidance technology (in a simulator-based study) while brake assist plus injury mitigation resulted in a 45% reduction in crash speed.

Page, et al. (2005) estimated the expected safety benefits for braking assist systems. They reported an expected reduction of all passenger vehicle occupant fatalities in the order of 6.5-9%, and a reduction in pedestrian fatalities in the order of 10-12%. The total number of injuries was expected to reduce by 11% due to brake assist.

Becker, Busch and Zobel (2004) estimated that brake assist in passenger cars could reduce the German annual road toll by approximately 200 (approximately 5% of the average German road toll for passenger vehicles).

Lawrence, et al. (2004) suggested that brake assist can reduce stopping distances by 45% at 100 km/h. Lawrence and colleagues estimated the effects of brake assist and improved bumper and bonnet design standards on vulnerable road user safety. These were the European Enhanced Vehicle-safety Committee Working Group 17 (EEVC WG17) testing procedures and acceptance levels, and a 'relaxed' version of these standards (termed 'proposal'). The range of numbers in these tables represents different maximum and minimum results provided by two different estimation methods.

Mercedes-Benz (2004) reported that vehicles with brake assist have 26% less crashes than those without in an emergency brake situation at 50 km/h.

Daimler-Chrysler (2006) reported a reduction of a 40% in related accidents, accounting for a total of 20% in all types of accidents, regarding German data.

Busch (2004, cited in Lienkamp, 2005) estimated that with 100% penetration of the German vehicle fleet, brake assist could result in the following safety benefits for various vehicle types and vulnerable road user (table 3-1).

Vehicle type	Reduction in fatality	Reduction in injury
Passenger vehicles	1.3%	5.1%
Commercial vehicles	0.8%	1.7%
Motorcycles	1.3%	1.5%
Bicycles	12.6%	5.2%
Pedestrians	7.0%	15.9%
Total	3.0%	5.5%

Table 3-1: Estimated fatal and injury crash rate reductions in Germany for various road user types.

Lind, et al. (2003) estimated that brake assist has the potential to affect 40% of multiple vehicle fatalities and 18% of off-path fatalities in Sweden, and predicted that by the year 2015, these systems would reduce these fatalities by 20% and 9%, respectively. The cost-benefit ratio for the combined proposal and brake assist option was estimated to be 1:5.8. Table 3-2 shows the estimated effects of brake assist from this study.

Road user type	EEVC		Proposal		Proposal + Brake Assist	
	Fatal	Serious Inj.	Fatal	Serious Inj.	Fatal	Serious Inj.
Pedestrian	11.5-22.6%	20.8-17.5%	9.6-16.9%	17.5-13.3%	10.4-17.8%	18.3-14.6%
Bicyclist	4.2-8.3%	8.4-7.0%	3.5-6.2%	7.1-5.3	3.8-6.5%	7.4-5.8%

Table 3-2: Estimated minimum and maximum effects of vehicle safety strategies on fatal and serious injury crashes.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.10 Daytime Running Lights

Description

Vehicle Type: All.

Daytime running lights (DRLs) aim to address the issue of vehicle conspicuity during daylight. Using the existing headlight, DRLs provide a constant beam, typically 80% of the headlights normal luminance, whenever the vehicle's ignition is activated. Illumination of the frontal view of the vehicle serves to increase its visibility to other road uses, and resulting in more rapid perception of the approaching vehicle. Dedicated DRLs have greater conspicuity-enhancing effects during daylight than traditional low-beam headlights, which project the illumination to the road surface and create glare for other road users.

DRLs have been shown to be effective in increasing the visibility of the vehicle to other road users. Additional positive effects from this system include more rapid detection of the vehicle, more accurate perception of the speed and distance of the vehicle. A large amount of research suggests DRLs are effective and economic vehicle safety technologies (Olsson, et al., 2006).

Crash relevance

Crashes where vehicle conspicuity is a contributing factor.

Effectiveness

Estimations of the approximate reductions expected with DRLs in Germany were reported by eSafety Forum (2005). These estimates assumed DRLs achieved 70% penetration of the passenger vehicle fleet. It was expected that 25% of conspicuity-related crashes would be affected, leading to a 17.5% reduction in these crashes, equating to a 0.03% reduction in all crashes.

Koornstra, Bijleveld and Hagenzieker (1997) reviewed 24 studies of the effectiveness of DRLs. They concluded that this technology has the potential to prevent 25% of fatal, 20% of injury and 12% of property damage daytime multiple vehicle crashes, and 28% of daytime pedestrian fatalities.

In an Australian on-road evaluation of a low-beam headlight DRL (Poole, 1999), vehicles fitted with the system were eight times less likely to be involved in conspicuity related crashes, and 5 times less likely to be involved in rear-end crashes. Other estimates within Australia show that DRLs may be able to reduce serious injury and fatal crashes by approximately 3-15% (Cairney & Styles, 2003; Paine, 2003a). Also, Paine (2003, cited in Paine, 2005) estimated a benefit cost ratio of 7.67 for DRLs in Australia.

Farmer and Williams (2002) investigated the role of automatic DRLs on multiple-vehicle crashes occurring during daylight hours in the US over 4 years. It was found that vehicles equipped with DRLs were involved in 3.2% fewer of these crashes than vehicles without, resulting in an 1.6% reduction in overall crash risk.

Failure on the part of the other driver to see the motorcyclist is a leading cause of motorcycle crashes (ACEM, 2004; Hurt, Ouellet & Thom, 1981). Motorcycle DRLs have been mandatory in Malaysia since 1992, and in the years immediately following this legislation, crashes in which conspicuity was cited as a factor decreased by 29%, with a compliance rate of 82% (Umar, Mackay & Hills, 1996). Given that approximately 60% of Malaysia's vehicles are motorcycles, the benefits of this system were high. DRLs were also implemented in Singapore in 1995, resulting in significant reductions in fatal and serious injury crashes (Yuan, 2000).

Disbenefits

Evidence exists suggesting that the effectiveness of DRLs may depend on the level of ambient light in the environment. Koornstra, et al. (1997) reported that in countries with higher levels of ambient light (e.g., USA, Australia) DRLs may only be one-third as effective as in Scandinavian countries.

In a review of the effectiveness of DRLs in Australia, Cairney and Styles (2003) noted that while small reductions (2%) in motorcycle crashes had been observed since the implementation of this law, there were no statistically significant reports of improved safety linked to DRLs.

3.1.11 Driver Vigilance Monitoring

Also: *Drowsiness Detection Systems; Fatigue Monitoring Systems; Driver & Vehicle Monitoring*

Description

Vehicle type: Passenger and commercial.

These systems monitor the performance of the driver, and provide alerts or stimulation if the driver is determined to be impaired, and in intervening systems, take control of the vehicle and bring it to a stop. The driver is alerted to their impaired state, either through visual, auditory or haptic stimulus. The systems may monitor driver inattention and/or fatigue in a number of ways involving both the vehicle and the driver. These systems are often referred to as driver and vehicle monitoring systems, as they may monitor both driver and vehicle behaviour. Information can be gathered from driver input and control of the vehicles lateral position and speed, such as acceleration, steering wheel movement and lane position. Likewise, user behaviour such as eye movement, facial feature movement, brain waves (EEG) and steering wheel grip may all be monitored.

More sensitive systems may use a combination of these sensors (Olsson, et al., 2006). As Bishop (2005) notes, the key to these systems is that they detect the early signs of drowsiness to allow the driver to effectively counteract this impairment. Regan, et al. (2001) suggested that systems that monitor the user's eye movements, such as blinking behaviour, have perhaps the greatest potential to accurately detect drowsiness.

Drowsiness relieving systems are an extension of drowsiness detection systems. They detect and alert the user to fatigue lapses in attention in the same manner as drowsiness detection systems. However, as an additional function they actively attempt to increase the driver's alertness rather than just making the driver aware of their condition. This may be in the form of auditory alerts, vibration of the seat and/or steering wheel, or the release of fragrance into the driving cabin. Heitmann, et al. (2001) suggested that haptic systems may be an effective way to maintain alertness in drivers.

For example, the Drowsiness Warning System equipped on Mitsubishi's Advanced Safety Vehicle (ASV) produces warning sounds, steering wheel and seat vibration, and a 'stimulating' fragrance if drowsiness is detected within the driver (Mimuro, et al., 1996). Nissan's ASV contains a similar system which emits a buzzing sound and 'refreshing' fragrance in order to alert the driver (Sugasawa, et al., 1996). The fragrance discharger can also be manually activated by the driver.

Crash relevance

Crashes where driver inattention, fatigue or distraction are factors

A study of the ROSPA (Royal Society for the Prevention of Accidents) suggests that up to 20% of accidents on monotonous roads in Great Britain are fatigue related and could benefit from the driver drowsiness detection system. Moreover, truck driver fatigue may be a contributing factor in as many as 30% to 40% of all heavy truck accidents (2001).

Effectiveness

Estimations of the approximate reductions expected with lane driver monitoring systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 50% of fatigue-related crashes would be affected, leading to a 35% reduction in these crashes. This would equate to a 2.9% reduction in all crashes.

Regan, et al. (2002) estimated that a fatigue monitoring system could reduce 4% of all single vehicle crashes, and result in an estimated saving of $64 million (AU) annually. Depending on the effectiveness and acceptability of the system, it was estimated that up to 24% of fatal crashes would become serious injury and up to 26% of serious injury crashes would become injury crashes as a result of its use. Reductions in other injury and minor injury crashes were predicted to be up to 9.6%.

It has also been estimated that driver monitoring systems could reduce injury crashes by as much as 20%, while Regan, et al. (2001) suggested such systems show the potential to reduce both fatal and serious injury crashes by at least 10%.

Rumar, et al. (1999) suggested that driver and vehicle monitoring systems have the potential to reduce fatal and injury crashes on motorways by 10-15%, and may reduce injury crashes on rural roads by more than 10%.

Driver monitoring systems have been estimated to reduce injury-related crashes by up to 20%, but also more conservative estimates of 4% crash reduction, with wide implementation (Kulmala, 1997; Rumar, et al., 1997).

Yoshimoto, Nakayama and Mikami (1996) predicted that a drowsiness monitoring system could result in 330 less fatalities per year in Japan (approximately 3% of the Japanese annual road toll).

The AWAKE programme (“System for effective Assessment of driver vigilance and Warning According to traffic risK Estimation”) suggested an 80% efficiency in detecting driver drowsiness (80% reduction of related accidents) and another 84% reduction in single-vehicle roadway departure crashes or collisions with parked vehicles. The study concluded that it depends a lot on the driver (2004).

Disbenefits

Issues such as acceptability and negative behavioural adaptation are important to driver vigilance monitoring systems. There is concern that driver vigilance monitoring systems will actually encourage users to continue to drive even when impaired, due to over-confidence in the system (OECD, 2003). Road users may be reluctant to accept vigilance monitoring systems unless they are totally reliable (Young, et al., 2003b; Regan, et al., 2002).

Vincent, Noy and Laing (1998) completed a test track evaluation a fatigue warning system that measured ocular and face monitoring, vehicle speed, steering position and lane position. They found the users of the system did not take more or longer breaks, and did not show different fatigue levels to controls.

3.1.12 Electronic Brake Force Distribution

Also: *Electronic Brake Proportioning*

Description

Vehicle type: Passenger and commercial.

Electronic Brake-force Distribution (EBD) is an additional component to ABS. EBD serves to prevent the vehicle skidding sideways during an emergency brake by adjusting the braking pressure to each side of the vehicle. This is different to ESC, as EBD is only applied when the user activated the vehicle’s brakes. The system applied maximum braking force to the wheels that currently have the maximum grip. Emergency stopping situations that activate the ABS system will also activate EBD.

Crash relevance

Crashes where braking is applied by the driver.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.13 Electronic Licence

Also: *Smart card systems*

Description

Vehicle type: All.

Electronic licences aim to decrease the occurrence of unlicensed vehicle operation or the use of a vehicle outside the conditions of their licence. The licence, or smart card, must be inserted into the vehicle to unlock the ignition system. Only valid licences or cards which have been registered to that particular vehicle, will unlock the ignition of the vehicle. Smart cards are not legal licences, but can be used to restrict and/or monitor vehicle use. These are commonly used in commercial vehicle operations.

Electronic licenses also have the potential to be used to monitor and record the activity of learner or at risk road users (Faulks, Drummond & Rogers, 1998). Logs of driving/riding conditions, distances and durations could be recorded and collated as a means of ensuring learners gain experience in a variety of situations, or do not drive (or ride) outside their limitations. Electronic licenses can also be combined with a smart card ignition system. A wide variety of information can be stored on these systems, including traffic law violations and medical details.

Crash relevance

Crashes involving unlicensed road users, or road users operating outside the conditions of their licence.

Effectiveness

Lind, et al. (2003) estimated that systems that restrict some individuals from operating vehicles (electronic licences and alcohol interlocks) have the 'verified' potential (based on other studies) to reduce all road fatalities by 1%, while the 'full' potential (an optimistic estimate based on full deployment) is 5%.

Regan, et al. (2002) estimated that electronic licences could reduce the occurrence of crashes involving unlicensed drivers by 98%, with an annual predicted economic benefit of $134 million AU. Depending on the effectiveness and acceptability of the system, it was estimated that up to 8.1% of all crashes would be reduced in severity with the use of electronic licenses (i.e., fatal becomes serious injury, serious injury becomes other injury).

Rumar, et al. (1999) suggested electronic licenses have an 'outstanding potential' (p.27) to enhance road safety, as the issue of authorisation and the individual ability of the user to operate the vehicle is addressed.

In Sweden, an electronic licence system was developed which functioned as an ignition key. Goldberg (1995; 1998; 2000) estimated that this system would prevent all unlicensed driving and reduce the instance of drink-driving by 60% as, in Sweden, 82% of intoxicated drivers that are involved in fatal crashes have been registered for previous offences, and half of these do not have valid licences. Also, a number of unlicensed drivers may be under the influence of other illicit drugs. Goldberg (2005) further estimated that throughout Europe and the US between 5,000-10,000 fatalities and 50,000 injuries could be prevented, saving $30-40 billion annually.

Disbenefits

As Regan, et al. (2001) noted, there are considerable acceptability issues associated with this technology. Road users may see electronic licensing as a 'big brother' device. Some motorists feel that an electronic licence system must have additional identification features, such as fingerprint or PIN, and must be difficult to circumvent (Regan, et al., 2002; Young, et al., 2003b).

3.1.14 Electronic Stability Control

Also: *Active Handling System; Active Skid and Traction Control; Active Yaw Control; Active Stability Control; Automatic Stability Regulation; Automotive Stability Control; Automotive Stability Management System; Cornering Brake Control; Dynamic Control Systems; Dynamic Stability Control; Dynamic Stability and Traction Control; Dynamic Stability Control; Electronic Differential-lock System; Electronic Stability Program; Integrated Chassis Control System; Integrated-Vehicle Dynamics; Precision Control System; Stability Control System; Vehicle Dynamic Control; Vehicle Dynamics Control; Vehicle Dynamics Integrated Management; Vehicle Stability Assist; Vehicle Stability Control; Vehicle Swerve Control; Vehicle Stability Enhancement System; Yaw Control Stability. Also various product names: StabiliTrak, Traxxar, etc.*

Description

Vehicle type: Passenger

Electronic Stability Control (ESC) is a system which serves to maintain control of the vehicle's trajectory when the vehicle looses optimum contact with the road surface. This may occur when cornering too fast, on poor road surfaces, or in emergency stopping situations. ESC continuously monitors traction, lateral acceleration, yaw data, steering wheel position and vehicle speed. Input from these sources is compared to that of normal driving conditions to determine whether the vehicle has, or is about to, loose control. Different braking pressure is applied to the effected wheel/s to prevent over or under steering. Engine torque to the relevant wheel/s is also reduced. When the ESC system intervenes, the driver is typically informed via a visual display on the dashboard.

ESC coordinates ABS and traction control systems (TCS) to provide greater control when cornering and braking. Any vehicle equipped with ESC always has TCS and ABS, but the reverse is not necessarily true. These systems control the yaw and tyre spin of the vehicle to prevent skidding and traction-less cornering, and allow maximum contact between the tyre and the road. ESC can correct under- or over-steering, stabilise the vehicle during emergency evasive manoeuvres, and improve traction and handling on unsealed, icy or wet road surfaces (www.vicroads.vic.gov.au).

ESC is standard on 40% of 2006 models of passenger vehicles, and optional on a further 15% (IIHS, 2006a). The proportion of SUVs with ESC as standard is growing more rapidly than in passenger vehicles. ESC has not been applied to motorcycles.

Crash relevance

Off-path on straight crashes; off-path on curve crashes; rollover crashes; crashes where speed and poor road surface are contributing factors.

Effectiveness

The IIHS (2006a) has recently updated an earlier evaluation of ESC, suggesting that ESC has the potential to prevent almost one third of fatal crashes, and 80% of rollover crashes for SUVs and 77% for passenger cars. More than 40% of single vehicle crashes could be avoided with ESC – including 56% of all fatal single vehicle crashes. The effect of ESC on single and multiple vehicle crashes in the US was compared between SUV and passenger vehicles. SUVs equipped with ESC were involved in significantly fewer single vehicle crashes than passenger vehicles (49% compared with 33%). Multiple vehicle crashes were reduced by 59% for SUVs and 53% for passenger vehicles. Overall, ESC was associated with a 43% reduction in fatal crashes.

In a similar study, Lie, et al. (2006) estimated that up to 20% of fatalities in Sweden could be avoided if all cars featured ESC. Even greater benefits were predicted by Sferco, et al. (2001), who suggested that ESC would positively affect 18% of injury crashes and 34% of fatal crashes. Risk of loss of control crashes alone were predicted to reduce by 42% for injury and 67% for fatalities.

Estimations of the approximate reductions expected with dynamic control systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 25% of off-path injury crashes would be affected, leading to a 17.5% reduction in these crashes. This would equate to a 1.5% reduction in all crashes.

An extensive review of studies of the effectiveness of ESC estimated that, with full deployment in all cars, the number of fatal and injury crashes in Germany would reduce by -15-20% and 7-11%, respectively (Langwieder, 2005, cited in eSafety Forum, 2005).

Kreiss, Schüler and Langwieder (2005) found ESC to be effective at reducing loss of control crashes in Germany by at least one-third, and reduced fatal loss of control crashes by at least 55.5%

Paine (2005) estimated that 29% of all light vehicle fatal crashes could be avoided with the ESC in Australia. A benefit/cost ratio of 0.51 was estimated.

Bahouth (2005) compared US crash data between vehicles equipped with ESC and those without ESC for the period of 1998-2002. It was found that ESC is associated with a 52.6% decrease in single vehicle crash risk, and an 11.2% decrease in forward multiple vehicle crashes.

An analysis of the potential safety benefits of ESC in passenger cars in Germany was conducted. Becker, Buesh and Zobel (2004) estimated that the risk of running off-road crashes could be reduced by 40.7%, and that 44.7% of crashes caused by skidding could be avoided if these vehicles were equipped with ESC.

Dang (2004) analysed the effects of ESC on single vehicle crashes. It was found that 35% fewer cars and 67% fewer sport utility vehicles (SUVs) equipped with ESC were involved in single vehicle crashes that those without ESC. This equated to 30% and 63% fewer fatal single-vehicle car and SUV crashes, respectively. Additionally, near-significant reductions in multiple vehicle crashes were observed in cars equipped with ESC.

Tingvall, et al. (2003, cited in HUMANIST, 2006) found ESC to be effective at reducing all crashes by 22.1% (excluding rear-end crashes on dry roads). Highest crash reduction benefits were observed for wet and snowy road surfaces (31.8% and 38.2%, respectively).

Lind, et al. (2003) estimated that ESC has the potential to affect 15% of rear-end fatalities in Sweden, and predicted that by the year 2015, these systems would reduce rear-end fatalities by 8%.

Mercedes-Benz (2004) reported that the number of Mercedes passenger cars involved in 'driver related' crashes declined by 42%, and the number of rollover crashes reduced by 12%

Farmer (2004) investigated the effectiveness of ESC in the US over several. The following crash risk reductions were found for ESC equipped vehicles compared with non-ESC equipped vehicles. These reductions are presented in Table 3.

Crash type	Fatal crashes	All crashes
Single-vehicle	56%	41%
Multiple-vehicle	17%	3%
All types	34%	7%

Table 3-3: Expected crash risk reductions attributable to ESC for various crash types.

The following additional findings from studies of the effectiveness of ESC were reported by Bosch (2005):

- NHTSA, 2004 (US): 35% reductions in single-vehicle passenger car crashes, and 67% of SUV single-vehicle crashes. Single vehicle crashes decreased by 63% for SUVs and 30% in passenger vehicle crashes.
- IIHS, 2004 (US): 41% reduction in single vehicle passenger car crashes, 56% reduction in fatal single vehicle passenger car crashes.
- University of Iowa, 2004 (US): 34% increase in drivers able to maintain control of their vehicle in a simulator study.
- Toyota, 2003 (Japan): 35% reduction in all single vehicle crashes, 50% reduction in 'severe' single vehicle crashes, a 30% reduction in head-on crashes, and 40% reduction in severe frontal crashes (Aga & Okada, 2003).
- National Agency for Automotive Safety & Victims Aid, 2005 (Japan): 44% reduction in single vehicle crashes, 62% reduction in 'severe' crashes.
- Daimler Chrysler, 2004 (EU): 42% reduction in the number of Mercedes-Benz vehicles involved in crashes.
- Volkswagen, 2004 (EU): 35% reduction in fatalities, and 80% reduction in skidding crashes. Stated that ESC is a more effective safety system than airbags, second only to seatbelts.
- Ford, 2004 (EU): up to 35% reduction in single-vehicle crashes. Analysed German crash data over seven years.
- Swedish National Road Administration (2002): best estimate of a 22.1% reduction in all crashes except rear-end crashes on dry road surfaces. Greater reduction estimates were observed for crashes on low friction surfaces, with 31.8% for wet roads and 38.2% for icy/snowy roads.
- LAB, 2004 (EU): 44% reduction in single vehicle crashes

Disbenefits

ESC is known my many terms, and this may be confusing to consumers while it is still an optional extra on many vehicle models (IIHS, 2006a).

3.1.15 Emergency Brake Advisory System

Also: *Rear Impact Countermeasures; Adaptive Brake Lights*

Description

Vehicle Type: All.

Emergency brake advisory systems serve to rapidly alert drivers when a leading vehicle is braking forcefully. A number of studies have shown that the likelihood of being rear-ended by a following vehicle actually increases when advanced braking systems such as ABS are implemented in vehicles (e.g., Evans & Gerrish, 1996). Emergence brake advisory systems activate the rear brake lights earlier in the braking process, allowing more time for the following vehicle to react. Rather than relying on pressure of the brake pedal to activate the rear-brake light, these systems detect an emergency brake via the rapid depressing of the accelerator. This decreases the time required to detect an emergency brake by milliseconds, increasing the potential reaction time of the following driver. Some emergency brake systems illuminate the brake lights with greater intensity to indicate an emergency braking situation to other road users (eSafety Forum, 2005; Lind, et al., 2003).

Crash relevance

Rear-end crashes.

Effectiveness

Estimations of the approximate reductions expected with adaptive brake lights in Germany were reported by eSafety Forum (2005). This estimation assumed these systems achieved 70% penetration of the German passenger vehicle fleet. It was expected that 25% of rear-end crashes in moving traffic and 15% in stationary traffic would be affected, leading to a 14% reduction in these crashes. This would equate to a 1.5% reduction in all crashes.

Mercedes-Benz (2004) found a flashing rear brake light reduce braking reaction time by up to 0.2 seconds in following drivers, equating to a 4.4 metre braking distance reduction at 80 km/h, or 5.5 metres at 100 km/h (DaimlerChrysler, 2005).

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.16 Following Distance Warning

Also: *Safe Gap Advisory*

Description

Vehicle Type: Commercial and passenger.

Following distance warnings serve to assist the driver in maintaining a safe following distance between the motorcycle and the leading vehicle. Following distance warning systems monitor the time or distance headway between the current and lead vehicle, and issue an auditory or visual warning this distance is deemed to be unsafe. The system continuously monitors the gap between the vehicles via radar or laser and acceleration sensors. If this distance is breached, the system comes into effect issuing a visual or auditory warning, or intervention via automatic braking pressure. The current headway, in either time or distance, may be continuously presented on an in-vehicle display. Different levels of alerts of headway size (e.g., green, orange, red) may also be presented to the driver.

These systems are one of a number of collision avoidance technologies. As Bishop (2005) notes, unlike intervening collision warning systems, following distance warning is a retrofittable technology. This may allow greater market penetration.

Crash relevance

Rear-end crashes; object crashes. Crashes where fatigue or inattention are factors.

Effectiveness

Kullgren, et al., 2005 estimate following distance warning and forward collision warning systems may be able to reduce the incidence of rear-impact crashes by 57%.

In an on-road trial of following distance warning, Regan, et al. (2005) found the system to increase the average headway between vehicles, and showed some reduction in the time spent driving in headways of less than 0.8 seconds. It was estimated in this study that FDW systems will reduce the proportion of time spent driving too close to the leading vehicle by 34%. It was suggested that these systems will result in significant savings to the community in terms of injury and property damage costs.

Harrison and Fitzgerald (1999) estimated that following distance warning systems would result in the following reductions in rear-end related crash costs in Australia, presented in Table 4. This analysis assumed that 50% of the effects of the system would be the prevention of crashes, while the other 50% would be the reduction of crash severity (i.e., fatal becoming serious injury). It was also assumed that there would no discernable difference in acceptability or effectiveness for either breath test or psychomotor systems.

System type	Effectiveness	Penetration	Cost reduction
Warning	60%	100%	47%
	60%	10%	6%
Avoidance	60%	100%	44%
	60%	10%	7%

Table 3-4: Reduction in crash costs expected with following distance warning and avoidance systems in Australia.

This analysis assumed that avoidance systems were likely to be less acceptable to users, limiting their potential effectiveness (Harrison & Fitzgerald, 1999).

Disbenefits

Regan and colleagues (2005) suggest that following distance warning would be less effective when the leading vehicle is engaged in very soft or hard braking. Vehicles rarely drive in with a headway too short to collide with a vehicle that is braking softly, while in the range of current FDW systems is too below what is needed to avoid collisions in hard braking situations. Also, Young, et al. (2003b) found young drivers viewed FDW as potentially annoying in heavy traffic.

3.1.17 Forward Collision Warning and Avoidance

Also: *Forward Collision Mitigation; Rear End Crash Driver Warning Systems*

Description

Vehicle Type: Commercial and passenger.

Forward collision warning systems monitor the roadway ahead and provide alerts to the user when upcoming hazards are detected. Alerts are issued if a stationary obstacle or vehicle moving slower than the user's vehicle is detected at a range close enough to be hazardous. These systems employ radar, laser, lidar and/or computer vision technologies to monitor the roadway. Information about steering wheel position and speed relative to the object ahead is monitored to determine whether or not the object is in the vehicles path, and whether a crash is likely. Warnings about obstacles are presented to the user via auditory or visual alerts or heads-up displays, and some systems may incorporate haptic feedback such as seat vibration or seatbelt tension (Bishop, 2005). Forward collision avoidance systems feature an additional active avoidance component. If a hazard is deemed imminent, automatic braking force is exerted by the system if the driver does not respond rapidly or forcefully enough to avoid a crash.

Crash relevance

Rear-end crashes; head-on crashes; object crashes.

Crashes where fatigue and/or distraction/inattention are factors.

Effectiveness

Kullgren, et al. (2005) estimated that forward collision warning and following distance warning systems may be able to reduce rear-end crashes by 57%.

Estimations of the approximate reductions expected with obstacle collision warning systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 25% of crashes in longitudinal traffic would be affected, leading to a 12.5% reduction in these crashes equating to a 3.1% reduction in all crashes.

Lind, et al. (2003) estimated that collision avoidance systems have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 4%.

Regan, et al. (2002) estimated that approximately 7% of all rear-end crashes could be reduced with forward collision warning systems, resulting in an economic benefit of $40 million (AU). Depending on various levels of effectiveness and acceptability, it was estimated up to 30% of fatal crashes could become serious injury and up to 30% of serious injury crashes becoming injury crashes, while reductions of up to 12% of other injury and minor injury crashes were predicted.

In a simulator study, Lee, et al. (2002) found that forward collision warning systems that issues early auditory warnings reduced the number of crashes by 80.7% and reduced crash severity by 96.5%. Late warning systems were associated with a 50% reduction in crash occurrence and an 87.5% reduction in severity.

Numerous estimates of the effectiveness of forward collision warning systems were reviewed by Regan, et al. (2001). Predictions in crash reduction ranging between 33-80% were reported for cars. The use of forward collision warning systems also appear to result in longer headways with leading vehicles (Regan, et al.).

Several authors have provided predictions that up to 45-80% of fatal crashes could be avoided with forward collision avoidance systems (Archer, 2000; Kulmala, 1997).

McKeever (1998) reported an estimated reduction in the number of fatal rear-end crashes in the order of 48% in the USA.

Kanianthra and Mertig (1997) found rear-end crash warning systems to be reduce crashes by 42% when the lead vehicle was decelerating, and 75% effective when the lead vehicle was stationary. They estimated an overall effectiveness of 51% for all rear-end crashes.

Rumar, et al. (1999) suggested that around 10-15% of injury and fatality crashes on motorways could be avoided with all collision avoidance technologies (including forward and lateral systems), as well as more than 10% of injury crashes on rural roads.

Forward collision avoidance systems are expected to be applicable to almost 90% of all rear-end crashes, and have been estimated to prevent almost 50% of rear-end crashes in the US (FHWA, 1998).

McKeever (1998) estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that a 1.7% reduction in fatalities and a 9.1% reduction in injuries could be expected with forward collision systems.

Hiramatsu, Sitoh and Matsuaka (1997; cited in Rumar, et al., 1999) estimated that collision avoidance systems have the potential to reduce road fatalities by 45% in Japan.

Collision avoidance systems (including lateral systems, see Section 1.21) have been estimated to reduce the total number of crashes by 17%, resulting in an economic benefit of $25 billion US (Mitretek, 1996).

The combined effects of integrated collision avoidance, lane change and road departure systems could prevent over 1.8 million crashes annually in the US (Ference, 2006).

Paine (2003b) suggested forward collision warning systems could reduce 25% of crashes if installed in heavy vehicles.

Combined forward and lateral collision warning systems installed on a bus fleets have resulted resulting in a crash reduction of approximately 25% in the US (Woll, 1995), and 34% in Canada (Maccubbin, et al., 2005).

The use of collision warning systems in heavy trucks have been associated with collision reductions as high as 50% or greater (Bishop, 2000).

The NHTSA (National Highway Traffic Safety Administration) estimated that collision avoidance systems may be able to reduce rear-end crashes of passenger cars by 48% and by another 21,5% for buses in the United States (2001).

A study of Daimler-Benz suggested that, if passenger car drivers have a 0.5-second additional warning time, about 60% of rear-end collisions can be prevented. An extra second of warning time can prevent about 90% of rear-end collisions (2001).

Sugimoto, et al. (2005) suggested that around 38% of rear-end collisions on motorways could be avoided with the Collision Avoidance system, as well as more than 44% of injury crashes.

Disbenefits

False alarms or 'nuisance alerts' must be minimal in these systems to maximise driver acceptance and prevent drivers learning to ignore warnings (Regan, et al., 2001; Taylor & Khan, 2004). Regan, et al. (2002) found that young drivers were reluctant to accept the intervening function of the system, but felt it would be useful for older drivers. Young, et al. (2003b) found young drivers deemed the intervening function to be potentially dangerous.

Rumar, et al. (1999) caution the interpretation of very high estimated of effectiveness, of forward collision systems (such as Perrett and Stevens, 1996, who estimated an 80% fatality reduction) for the following reasons: these systems are not yet technically mature; these systems are not relevant to all crash types; the behavioural adaptation of users is not yet known.

Lind (1998) estimated the long-term potential effects of various emerging ITS technologies in reducing crashes, using expert assessment of various areas of potential safety impact. It was estimated that at 10% implementation of obstacle detection systems, there would be a 1% increase in crashes, and with 100% implementation, this was expected increase to 5%. This increase was expected to stem from drivers tending compensate with higher speeds.

3.1.18 Heads-Up Display

Description

Vehicle type: All vehicles.

Heads-up display (HUD) project visual information to a position within the user's field of view so that the display is visible to the user while they are looking at the road ahead. HUDs serve to ease driver workload and minimise the need for the driver to take their eyes off the road to gather information from the instrumentation panel or consol. HUDs have been widely employed by the aviation industry and military. In vehicles, the display is projected onto the windshield, typically at a focal point just in front of the vehicle, giving a floating appearance. This reduces the need to re-focus when glancing between the roadway and display, as there is less discrepancy in the focal length of the driving task and the display (Tufano, 1997). HUDs may also reduce mental workload, while improving reaction times, task efficiency, safety and enjoyment (Merryman, 2004).

The content of the HUD may vary depending on what aspect of the vehicle it is integrated with. This may be information from the dashboard instrumentation panel, such as speedometer, RPM, fuel level, vehicle warnings and so on. Also, HUDs may be incorporated into other ITS technologies, such as collision warning and vision enhancement systems. The systems consist of a projector, a combiner, which reflects the images from the projector while allowing the road ahead to be seen, and an electronic circuit which controls the display information and brightness (Aono, 1990).

Crash relevance

The direct safety relevance of HUDs is difficult to determine as the systems may vary in terms of what and where the information is displayed. However HUDs may show relevance to crashes where distraction/inattention are factors.

Effectiveness

Horrey, Alexander and Wickens (2003) found that while no differences were observed in driving task performance between HUD and heads-down displays (HDDs), performance in a secondary task (number recall) was slower and longer for the HDD condition. Also, longer reaction times to critical hazards were observed for the HDD condition.

Watanbe, et al. (1999) found that response times to warnings presented via a HUD varied as a function of the location of the display. HUDs located in the upper right and lower left of the field of view showed significantly response times than other display locations. It was also noted that the presence of HUDs did not significantly reduce reaction times to events occurring on the road.

Hada (1994) found drivers were able to look at HUDs for up to 180 ms longer than HDD without compromising driving performance. Also, Liu and Wen (2004) found drivers responded to warnings presented on a HUD almost one second faster than when presented on a HDD in both high and low driving load conditions.

eSafety Forum suggested that, assuming 70% penetration of the passenger vehicle fleet, 25% of crashes involving this system would be affected leading to a 17.5% reduction in these crashes, equating to a 0.1% reduction in all crashes (2001).

Disbenefits

Tufano (1997) expressed concern that HUDs may be too effective at making vehicle information salient and accessible. That is, users may become distracted or overloaded by this additional continuous visual information. Also, Tufano suggests that display focal length may interact with cognitive workload, highlighting the need for further research into the efficacy of HUDs.

3.1.19 Helmet-Mounted Displays

Description

Vehicle type: Motorcycle.

In order to enhance the availability of information to motorcyclists, additional visual displays can be presented to the rider via the motorcycle helmet. Helmet mounted displays (HMDs) are essentially heads-up displays integrated into the visor of the helmet. Information that is typically provided on the instrument panel, such as speed, fuel levels, RPM can be displayed with these systems, as well as information form other ITS applications of ISA. These systems eliminate the need for the rider to take their eyes off the road. Mini-projectors within the helmet superimpose visual displays over the riders viewing field so that the user does not have to adjust the focus of their viewing distance to see the display. The visual information can also be enhanced by auditory information

Crash relevance

The direct safety relevance of HUDs is difficult to determine as the systems may vary in terms of what and where the information is displayed. However, HUDs may show relevance to crashes where distraction/inattention are factors.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.20 Intelligent Lighting Systems

Also: *Adaptive Front Lighting; Additional Cornering Lights; Automated Headlights*

Description

Vehicle type: All.

Intelligent lighting systems may incorporate one or a number of technologies that serve to enhance the visibility of other road users, the road environment, and/or automate control of the headlights. Adaptive headlights improve the illumination of the vehicles path on curves and to suit varying speeds and road environments, while automated headlights control the activation of the headlight and/or high beam without driver input. Intelligent lighting systems may include the following system variants and functions:

3.1.20.1 Automated Headlights

Automated headlights automatically turn of the vehicles headlights when low ambient levels of luminance are detected. These systems aim to reduce driver workload and eliminate the need for the user to take eyes of the road when activating the headlights. Ambient light sensors monitor the luminance of the environment, and a control unit turns the headlights on if a minimum threshold of luminance is detected. The system differentiates the total level of ambient light, the frontal sources of light, and can distinguish different conditions such as tunnels compared with night time.

3.1.20.2 Cornering/Axis Controlled Headlights

When cornering, traditional headlights illuminate the area directly in front of the vehicle, leaving the intended path of the vehicle dark. Sensors detect the vehicles speed and the rotation of the steering wheel and/or axles, and direct additional lighting to the left or right of the vehicle depending on the direction of the curve.

In motorcycles, the changing optical axis of the headlight that occurs when the motorcycle tilts when cornering creates reduced visibility, where the beam illuminates the shoulder, not the road. Vehicle speed and angular velocity sensors are incorporated with a rotating mechanism behind the headlight. The position of the headlight is adjusted in accordance with the speed and position of the bike, so that it maintains a horizontal axis that is parallel with the road surface. Adaptive headlights ensure that the illumination from the headlight is projected on the motorcycles intended path when banking.

According to Bishop, future cornering headlight systems will be cooperative, featuring satellite maps that inform the system of upcoming curves. This would allow pre-emptive adjustment of the auxiliary beam.

3.1.20.3 Speed Adapting Headlights

Headlight systems may also adjust the pattern of luminance to suit the vehicle speed (Bishop, 2005). The beam is projected downward and outward at low speed to increase the visibility of the road environment and road surface, and projected in a narrower, longer beam for faster speeds to allow greater viewing distances.

3.1.20.4 Auto-dimming Headlights

Other intelligent headlight systems may automatically dim the high-beam headlights when oncoming vehicles are detected.

Crash relevance

Crashes where poor visibility is a contributing factor.

Effectiveness

Lind, et al. (2003) estimated that both adaptive headlight and vision enhancement systems have the potential to affect 30% of pedestrian fatalities and 15% of bicyclist fatalities in Sweden. It was predicted that by the year 2015 these systems will have resulted in reduce pedestrian fatalities by 15% and bicyclist fatalities by 8%. The 'verified' potential of this adaptive headlights (based on the results of other studies) to reduce all road fatalities was reported to be less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 8%.

The expected effects of adaptive headlights in Germany were reported by eSafety Forum (2005). It was expected that, assuming 70% penetration of the passenger vehicle fleet, 25% of crashes involving vulnerable road users in low visibility conditions would be affected leading to a 17.5% reduction in these crashes, equating to a 0.1% reduction in all crashes.

Disbenefits

Negative behavioural adaptation may occur with these systems, where drivers compensate for the additional visibility by increasing vehicle speeds (eSafety Forum, 2005).

3.1.21 Lane Change Collision Warning and Avoidance

Also: *Blind spot monitoring; Lateral Collision Avoidance; Side Object Detection Systems.*

Description

Vehicle type: Commercial and passenger.

Lane change systems serve to monitor the vehicles lateral blind spot, detecting vehicles that are located in this space and warning the user to their presence. The lateral field is monitored by short-range laser, radar, lidar, computer vision or ultrasonic scanning techniques. Visual or auditory warnings are presented to the user when a vehicle is detected in this space. In order to minimise false alarms, the system should differentiate stationary objects that do not present a crash risk from moving vehicles in the lateral field. Some systems may delay the alert, so that overtaking vehicles are allowed time to pass. Other advanced systems may also monitor the road ahead, detecting oncoming vehicles that may present head-on crash hazards while overtaking (Bishop).

Crash relevance

Side-swipe crashes.

Effectiveness

Lind, et al. (2003) estimated that lane change assistance has the potential to affect 20% of off-path fatalities in Sweden, and predicted that by the year 2015, these systems would reduce run-off road fatalities by 10%.

Harrison and Fitzgerald (1999) estimated that lateral object detection systems would result in signification reductions in side-swipe crash costs in Australia. It was predicted that with 60% effectiveness and 100% penetration, a 46% reduction in annual crash costs could be expected. At 10% penetration, a 6% reduction was expected. The analysis assumed that 50% of the effects of the system would be due to the prevention of crashes, while the other 50% of the effects would be seen in the reduction of crash severity (i.e., fatal becoming serious injury). Lateral collision avoidance systems were also assumed to be highly acceptable to users.

McKeever (1998) estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that a 0.2% reduction in fatalities and a 0.7% reduction in injuries could be expected with lane changing systems.

McKeever (1998) suggested crashes could be reduced by 37% with lane changing and merging systems.

Lane change collision avoidance systems have been estimated to be relevant to 96% of all lane change crashes annually in the US, and approximately 40% of these are expected to be prevented (FHWA, 1998).

Kanianthra and Mertig (1997) estimated that lane change collision avoidance technologies would reduce 37% of relevant crashes.

The effects of collision warning and/or avoidance technologies are often discussed as a general class of ITS. Many studies have considered forward and lateral collision systems as collision avoidance systems, while others may also include lane or road departure systems. The following studies refer to combined warning and/or avoidance systems that include lateral collision warning with at least one other sensor type, typically forward collision warnings:

- The combined effects of integrated collision avoidance, lane change and road departure systems could prevent over 1.8 million crashes annually in the US (Ference, 2006).
- Abele, et al. (2005) expected a 60% reduction in the occurrence of side-swipe crashes and a 10% decrease in side-swipe crash injury severity with combined lateral collision warning and lane departure warning systems.
- Regan, et al. (2001) suggested all collision avoidance systems have the potential to reduce fatal and serious injury crashes by at least 10%.

- Collision avoidance systems have been estimated to reduce the total number of crashes by 17%, resulting in an economic benefit of $25 billion US (Mitretek, 1996). Also, the FHWA (1998) estimated that these systems (with lane keeping assistance) could prevent 19,000 rural running off road crashes in the US and 52,000 crashes in urban areas.

Mazzae and Garrott (1995, cited in HUMANIST, 2006) found no improvement in truck driving performance with the use of a side object detection system, largely because it was utilised by the drivers only some of the time. These drives tended to prefer to use their vehicle's side mirrors over the system.

Paine (2003b) suggested lateral collision warning systems could reduce 16% of heavy vehicle crashes and 6% of bus crashes.

The eImpact project suggested that the introduction of the "Lane changing assistant" system would achieve the following crash severity reductions (2005).

- **Head-on collisions: 25% reduction in accident severity**
- **Left roadway accidents: 15% reduction in accident severity**
- **Side collision accidents: 10% reduction in accident severity**

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.22 Lane Departure Warning and Control

Description

Vehicle Type: Commercial and passenger.

Lane departure warning systems monitor the position of the vehicle relative to lane markings and features, and provide alerts to the driver should the vehicle deviate from the lane. The lateral position of the vehicle may be monitored with laser, radar or video monitoring of the lane edge markings ahead and to the side of the vehicle. The vehicle's position and course is monitored via steering wheel movement. Feedback is provided to the driver through visual, auditory or haptic signals, such as a 'rumble strip' noise effect on the side appropriate to the lane deviation. This only occurs if the vehicle begins to drift, not when direct steering wheel force or indicators are used in deliberate lateral movement. Controlling systems also involve corrective steering movements that maintain a correct lane position.

Detection of lane edge markings is a complex process, particularly on curved or unmarked roads. This can be achieved with sophisticated computer imaging and processing, or in a cooperative fashion that uses GPS, digital maps, or magnetic markers embedded in the road. The most common types of systems employ monochrome video cameras mounted to the front of the vehicle and image processing technology (Bishop, 2005). Lane markings of various patterns, widths and lengths (for broken lines) are recognised by these systems. The vehicles lateral position relative to these features is continuously monitored.

The systems must be sensitive enough to detect road markings even when obscured by snow, ice, glare, pavement deterioration, etc. When lane markings are not present, some advanced systems search the roadway for other longitudinal cues to indicate the lane position. A variation of lane detection uses lateral infrared sensors projected downward onto the road surface. These monitor the painted lane markings relative to the bare road surface. The advantage of such systems is that they are not adversely affected by poor visibility conditions. However, they are unable to detect lane departure until it is actually occurring (Bishop, 2005).

Crash relevance

Head-on, off-path on straight; off-path on curve; sideswipe crashes. Crashes where fatigue or inattention/distraction are factors.

Effectiveness

It was predicted that lane departure warning systems have the potential to reduce head-on collisions and off-path crashes by 25%. A 25% and 15% reduction in injury severity for head-on crashes and off-path crashes, respectively, can also be expected (Abele, et al., 2005). A 60% reduction in the occurrence of side-swipe crashes and a 10% decrease in side-swipe crash injury severity were also expected when combined with lane change assistance systems.

Estimations of the approximate reductions expected with lane departure warning systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 25% of injury off-path crashes would be affected, leading to a 17.5% reduction in these crashes, equating to a 2.9% reduction in all crashes.

Lind, et al. (2003) estimated that lane departure warnings and lane keeping assistance have the potential to affect 40% of off-path fatalities in Sweden, and predicted that by the year 2015, these systems would reduce run-off road fatalities by 20%.

Lane departure warnings in heavy vehicles were expected to reduce the total number of heavy vehicle crashes by 10% (Korse, 2003, cited in eSafety Forum, 2005).

Regan, et al. (2002) estimated that around 5% of single vehicle off-path crashes and sideswipe crashes would be avoided with lane departure warning systems, resulting in an economic benefit of $3.3 million (AU) annually. Depending on the levels of effectiveness and acceptability of the system, it was estimated that lane departure systems could lead to up to 30% of fatal crashes becoming serious injury and up to 30% of serious injury crashes becoming injury crashes. Reductions in other injury and minor injury crashes were predicted to be up to 12%.

Regan, et al. (2001) reported that lane departure warning systems may be able to reduce the total number of crashes by 1%, and reduce off-path crashes by 24%.

Disbenefits

Young drivers tend to be reluctant to accept the intervening function of lane departure systems (Young, et al., 2003b).

3.1.23 Lane Keeping Assistance

Description

Vehicle type: Commercial, passenger

Lane keeping assistance (LKA) systems actively support the driver in maintaining lane position. These systems monitor the vehicles lane position with image processing technology in the same manner as lane departure warning systems. LKA provides additional torque to the steering wheel, which increases the resistance in the steering wheel. This makes it more difficult for the vehicle to drift, therefore reducing the occurrence of minor variations in lane position. This minimises the need for the driver to make small corrections in lane position, which as Bishop (2005) notes, can be a source of fatigue in long journeys on highways. LKA systems are typically only active at high speeds and on relatively straight roads. If sharp corners are detected (i.e. through frequent steering input from the driver) the system will disengage. Additionally, the system requires continuous driver steering input to ensure the driver is remaining vigilant and attentive.

Crash relevance

Crashes where fatigue and distraction/inattention are factors.

Effectiveness

Estimations of the approximate reductions expected with lane keeping assistance systems in Germany (assuming 70% penetration) were reported by eSafety Forum (2005). It was expected that 25% of injury off-path crashes would be affected, leading to a 17.5% reduction in these crashes, equating to a 2.9% reduction in all crashes.

Lind, et al. (2003) estimated that lane keeping assistance and lane departure warnings have the potential to affect 40% of off-path fatalities in Sweden, and predicted that by the year 2015, these systems would reduce run-off road fatalities by 20%. It was also estimated that LKA has the 'verified' potential (based on the results of other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 2%.

The FHWA (1998) estimated lane keeping and collision avoidance systems could prevent 19,000 rural running off road crashes and 52,000 of all urban crashes in the US. While McKeever (1998) suggested off-path crashes in the US could be reduced by 24% with LKA.

Perrett and Stevens (1996) estimated that 1% of all crashes on motorways could be avoided with LKA.

The eImpact project suggested that the introduction of the "Lane keeping assistant" system would allow the following accident and severity reduction (2005).

- Head-on collisions: 25% reduction in accident severity, 25% reduction in related accidents
- Left roadway accidents: 15% reduction in accident severity, 25% reduction in related accidents
- Side collision accidents: 10% reduction in accident severity, 60% reduction in related accidents
- The percentage of accidents where this system is relevant is about 19,5%.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.24 Linked Braking Systems

Also: *Combined braking systems*

Description

Vehicle type: Motorcycles.

Linked braking systems serve to maximise the stopping potential of the motorcycle. The independent action of the front and rear brakes of motorcycles can result in a failure to achieve maximum deceleration. One of these braking systems, usually the front, tends to be under-utilised by the rider. Linked braking systems automatically apply braking pressure from both wheels, where both the front and rear brakes are applied when only one of these is manually activated by the rider. These systems can also be combined with ABS, allowing greater vehicle control and stability as well as improved braking force.

Crash relevance

Crashes where braking is applied by the rider.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.25 Parallel Parking Assist

Also: *Intelligent Parking Assist*

Description

Vehicle type: Passenger and commercial.

Parallel parking assist is a semi-automated system which aids the user in reversing the vehicle into a parking space. Bishop (2005) describes the only currently known system of this type, modelled on the Toyota Prius at the ITS World Congress in Madrid, 2003. A rear-mounted camera and image processing system monitors the position of the vehicle relative to the desired parking space. The user informs the system of the location of the parking space by manually positioning a rectangle over a touch-screen image of the view behind the vehicle. The user remains in control of the acceleration and braking of the vehicle while the system automatically steers the vehicle into the desired position. The user must manually finish the parking manoeuvre when the vehicle is placed in forward gear. Earlier models of parking assistance systems have employed vocal prompts to guide the user into the parking space, but have not involved automated steering control.

Crash Relevance

Parking crashes.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.26 Pedestrian Detection Systems

Description

Vehicle type: All.

Pedestrian detection systems aim to detect the presence of pedestrians that are in close enough proximity that a crash is likely. These systems may employ video, laser, radar or infrared sensors to detect the presence of foreign objects in the path or periphery of the vehicle. Detection of moving pedestrians in a cluttered visual field is a challenge for any such system, as they may vary in height and width (depending on their physical size or orientation to the vehicle) as well as speed. Also, the sensors must be powerful enough to detect the object with enough time for evasive action to be taken, with a minimal risk of false alarms. The sensors used in this technology must be able to differentiate the characteristic shape and movement patterns of pedestrians of all sizes. It must also be able to recognise pedestrians when they are partially or temporarily completely obscured by objects in the road environment. The system must also be able to do this while the vehicle itself is moving.

Crash relevance

Pedestrian crashes.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.27 Rear-Impact Countermeasures

Also: *Rear-end Collision Warning System*

Description

Vehicle type: Commercial and passenger.

Rear-impact countermeasures have been developed to reduce the incidence of rear-end crashes involving buses, although they also are applicable to passenger vehicles and other commercial vehicles. Buses may be rear-ended when making stops along routes where other vehicles would not normally be stopping. Other driver inattention is often a factor in this (Bishop, 2005). In order counteract this inattention or inappropriate driving behaviour, rear-impact countermeasures employ sensors (lasers or radar, etc) to monitor the area directly behind the vehicle. If another vehicle is detected within this space at a distance that is incompatible with the bus's current speed, visual warnings (such as flashing or moving patterns of lights) are presented to the driver of the other vehicle in order to attract their attention (Burns, 2005). Bishop likens this to a forward collision warning system applied to the 'victim' (p. 140).

Crash relevance

Rear-end crashes.

Effectiveness

Burns (2005) found that drivers behaved less riskily, braked sooner and required less braking when following two buses that had been equipped with a flashing light bar. This system was effective in reducing aggressive closing behaviour in other drivers.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.28 Rear-View Displays

Description

Vehicle type: All.

Rear-view displays provide greater visibility of the road environment directly behind the vehicle to the driver. A rear-facing camera projects a view of the road and traffic behind the vehicle to a display system, providing a superior view than what is shown by rear-view mirrors. This technology may be in-vehicle or helmet mounted (for motorcyclists). Some rear-view displays for passenger vehicles may only be active when the vehicle is reversing.

Helmet-based systems incorporate both the camera and the display into the helmet itself. The camera is built into the helmet to avoid compromising its structural integrity. The visual display is projected to the top portion of the visor, above the frontward view of the road. This system does reduce some of the visual field, although it does remove the need to look away from the road.

Crash relevance

Rear-end crashes; side-swipe crashes, parking crashes.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.29 Reverse Collision Warning System

Description

Vehicle type: Passenger and commercial.

Reverse collision warning systems may employ a range of proximity detection sensors (ultrasound, radar or laser-based) or video cameras (rear-view displays) to detect objects behind vehicle when reversing. These systems typically have a range of around 15 feet, and are able to detect slow moving and stationary obstacles within this range and alert the user to their presence. These systems provide warnings to the driver that are typically auditory.

Reverse collision warning systems are relevant to reversing or parking crashes, where the vehicle is travelling in reverse at low speeds. There are two types of backing crashes (Dingus, et al., 1998): encroachment crashes, which involve stationary or slow moving objects in the reversing vehicles path, and crossing path crashes, where a vehicle or other obstacle collides with the reversing vehicle.

Crash relevance

Parking crashes; emerging crashes (when reversing).

Effectiveness

Lee and colleagues (2002) found reverse collision systems that provided early warnings to the user reduced backing collisions by 81%, while systems that provided late warnings resulted in reductions of 50%.

Glazduri (2005) investigated the effectiveness of six commercially available reverse proximity sensor systems in reducing pedestrian-vehicle crashes while reversing. It was found that the effectiveness of these systems is highly dependent on vehicle speed, where a 1 km/h reduction in reversing speed would result in up to a 20% increase in accuracy. All systems resulted in the avoidance 95% of test collisions when speeds were between 3-4 km/h.

Disbenefits

Current systems are limited by a compromise between range and accuracy. The greater the range of the system's sensors, the greater the rate of false alarm warnings. Also, small and irregularly shaped objects may be more difficult for these systems to detect (Regan, et al., 2005). Regan and colleagues also expressed concern that these systems will lead to negative behavioural adaptation effects.

3.1.30 Road Departure Warning and Avoidance Systems

Description

Vehicle type: Commercial and passenger.

Road departure warning/avoidance systems share similarities with lane departure systems. However, road departure systems typically incorporate curve speed warnings and object collision warnings. Visual imaging, GPS, and long- and short- range radar sensors monitor the vehicle's position in relation to the lane and road edge markings, upcoming curves and obstacles in the road environment. If the vehicle's speed is deemed to be too fast for an upcoming curve, or if the vehicle begins to drift laterally out of the road way, warnings and/or intervention from the system occur. This may be in the form of auditory, visual or haptic alerts, or corrective steering or braking control. Road departure systems are able to detect features and objects in the road environment and adjust warnings accordingly (Bishop, 2005). For example, drifting from the laneway on a wide shoulder would induce a less urgent response than drifting on a roadway with parked cars along each edge.

Crash relevance

Off-path on curve; off-path on straight crashes. Crashes where fatigue and inattention are factors.

Effectiveness

The combined effects of integrated collision avoidance, lane change and road departure systems could prevent over 1.8 million crashes annually in the US (Ference, 2006).

The FHWA (1998) suggested that if road departure avoidance systems were 65% effective, 296,000 crashes could be avoided annually in the US, while these systems may be relevant to approximately 38% of all road departure crashes.

McKeever (1998) estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that an 8.4% reduction in fatalities and a 4.0% reduction in injuries could be expected with road departure avoidance systems.

Kanianthra and Mertig (1997) estimate road departure countermeasure systems would reduce 24% of 'relevant' crashes.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.31 Road Surface Condition Monitoring

Description

Vehicle type: All.

Road surface condition monitors serve to alert the motorcyclist to abnormalities in the road surface ahead. Radar, laser or visual imaging of the road surface directly ahead of the vehicle is monitored for abnormalities such as potholes, debris, gravel, ice or oil spills. This information can also be integrated with ACC, ABS, collision avoidance and speed limiting systems so that vehicle performance is altered to suit the driving road surface conditions (Bishop, 2005). For example, ACC may adjust headway times to allow for longer braking distances in icy conditions.

A variant of road surface condition monitoring is road surface temperature monitoring. These systems monitor the temperature of the road. Road temperature information is gathered in order to detect the presence of ice on the road surface. This may be used to warn drivers of 'black ice' spots, or in road maintenance vehicles to determine the appropriate application of salt or other anti-icing liquids is necessary.

These systems may also employ a cooperative approach, where information from roadside beacons or other data collection points are transmitted to the vehicle or presented on variable message signs. This allows more advanced warning of changes in road surface conditions.

Crash relevance

Crashes where poor road surface is a contributing factor.

Effectiveness

Lind, et al. (2003) estimated outside temperature warnings have the potential to affect 40% of fatalities attributed to poor road surface in Sweden and predicted that by the year 2015, these systems would reduce these fatalities by 20%.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.32 Seatbelt Reminder and Interlock Systems

Description

Vehicle type: Commercial and passenger.

Seatbelt systems detect the presence of vehicle's occupants and ensure they are restrained. This may take the form of either visual or auditory alerts that persist or increase in intensity until the seatbelt is used (reminder systems), or disabling of the ignition (interlock systems) until all occupants present are restrained. These systems involve sensors in the seatbelt assembly that detect whether the seatbelt is in use. To detect the presence of other occupants aside from the driver (as the driver will always be present), the system may also involve weight and pattern recognition sensors built into the passenger seats.

Crash relevance

All crashes where occupants are unrestrained.

Effectiveness

It has been estimated that if seatbelt reminder systems in all vehicle were able to increase seatbelt usage by 6%, 730 driver fatalities could be prevented annually in the US (IIHS, 2006b).

A HARM analysis conducted by Regan, et al. (2005) showed that seat-belt reminder systems (not interlocking systems) would result in savings of $335 million AU in crash costs to the Australian community. Following an on-road trial of a seat-belt reminder system, it was predicted that these systems will lead to significant reductions in amount of unrestrained travel, although whether this effect is the same for passengers as drivers was inconclusive in this study.

A Swedish study (Meijer & Roos, 2004, cited in Kullgren, et al., 2005) suggested that installation of a retrofittable seatbelt reminder in 2 million cars would result in a 7% reduction in the annual road toll.

Kullgren, et al. (2005) estimate that if 100% of vehicle occupants were restrained in Europe, around 7600 fatalities could be avoided each year.

Lind, et al. (2003) estimated that seat belt reminders have the potential to affect 50% of unrestrained occupant fatalities in Sweden, and predicted that by the year 2015, these systems would reduce unrestrained fatalities by 25%. Lind, et al. estimated that occupant protection systems (that is, seatbelt reminders and airbag) have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 4%, while the 'full' potential (an optimistic estimate based on full deployment) is 10%.

It has been estimated that seatbelt reminding systems may reduce fatalities by 1.7% in the USA (IIHS, 2002).

A cost-benefit analysis of seat-belt reminder systems of varying levels of complexity was conducted by Fildes, et al. (2002). This study found cost benefit ratios ranging from 5.1:1 to 0.7:1 for passenger vehicle systems. An annual HARM reduction (the reduction injury costs resulting from road trauma) of 2.65% was also estimated.

In a further study Fildes, et al., (2004) estimated a HARM reduction between 0.14% and 0.55% ($12.1 million AU and $48.6 million AU) would be expected from seatbelt reminder devices retrofitted to Australian vehicles.

Harrison and Fitzgerald (1999) estimated that seatbelt interlocking systems would result in the following reductions in unrestrained occupant related crash costs in Australia. This analysis assumed that 100% of the effects of these systems would be seen in the reduction of crash severity (i.e., fatal becoming serious injury). With 100% effectiveness and 100% fleet penetration, a 63% reduction in crash costs was expected, while with only 10% penetration a 7% reduction in crash costs was expected.

Disbenefits

Seatbelt systems are associated with considerable acceptability issues. Interlock systems have shown to be unpopular, therefore many systems are only reminders (Regan, et al., 2005). Indeed, Young, et al. (2003b) found young drivers viewed an interlock system negatively while a reminder system was positively regarded by this group.

Kullgren, et al. (2005) noted that reminder systems are only effective for those that forget to use their seatbelts, rather than those that deliberately choose not to.

3.1.33 Speed Alerting and Limiting Systems

Also: *Speed Governors; Speed Retarders*

Description

Vehicle type: All.

Speed limiting systems take an active role in speeding prevention. Speed alerting and limiting systems typically use the same principles to determine the actual speed of the vehicle compared to the appropriate or desired speed. When an excessive speed is reached, the system employs mechanisms within the vehicle prevent further acceleration. This can occurs via mechanical control of the fuel and energy systems of the vehicle. The maximum speed may be absolute, or manually or variably determined. Absolute measures are typically used in commercial vehicles, where the top speed of the vehicle is fixed at a certain point which cannot be over-ridden by the driver. Manually set systems can be changed or modified by the user, while variable systems adapt to the speed limit of a given area (as in ISA).

Two types of speed limiting systems are retarders and governors. Speed retarders continuously dissipate energy, typically using a magnetic field in the vehicles transmission that creates a braking force in the drive system (Regan, et al., 2001). Speed governors restrict the engine’s fuel input. Speed governors are mandatory in heavy vehicles in Australia and the European Union (OECD, 2003).

Crash relevance

Crashes where excessive speed is a contributing factor.

Effectiveness

Elvik and colleagues (1997, cited in OECD, 2003) suggest 2% of all injury crashes may be prevented with speed governors on commercial vehicles.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.34 *Stop-and-Go*

Also: *Low-speed Adaptive Cruise Control*

Description

Vehicle type: Commercial and passenger.

Stop-and-go operates under similar mechanisms to Adaptive Cruise Control, with a greater automotive function. In addition to automatically braking when the leading vehicle slows (as in ACC), stop-and-go systems automatically accelerate to follow the lead vehicle when it moves forward. With high-speed ACC the user must manually accelerate the vehicle to begin moving, and ACC does not operate below a certain threshold, typically 40 km/h. Different versions of these systems may operate differently. Some systems require the driver to manually begin acceleration if the vehicle's speed drops below 5 km/h (so called *stop-and-wait systems*).

The term 'Stop-and-go' has also been used to refer to cooperative systems which are linked to traffic light signals, so that the vehicle automatically decelerates when red/amber signals are detected, and accelerates or continues through the intersection when green signals are detected.

Crash relevance

Rear-end crashes in low-speed, high density traffic.

Effectiveness

Hoetink (2003, cited in HUMANIST, 2006) suggested that ACC systems that feature Stop-and-go functions may have safety enhancing effects, as well as benefits in reducing traffic congestion. However, no reported evidence has been found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.35 *Traction Control*

Also: *Active Traction Control*

Description

Vehicle type: Commercial and passenger.

Traction control systems (TCS) maintain maximum contact between the tyres and road when accelerating. These systems provide additional control while accelerating, in a similar way to ABS when braking. Essentially, traction control is the reverse of ABS. Traction control prevents tyre skidding by applying brakes or reducing the fuel or power supply. Rotation sensors in all wheels detect the spin of all wheels relative to each other. If one or more wheels begin to skid when accelerating on slippery surfaces, the system applies braking force to the relevant wheels. Engine torque is also transferred to the wheels with good grip. If the other wheels also loose traction, the system reduces the torque of the engine until the skid is overcome (www.renault.com). Traction control is able to prevent wheel skid and therefore maintain trajectory control, during acceleration from a stationary position and while in motion, and on curved sections of road. TCS, along with ABS, make up the major components of ESC.

Crash relevance

Off-path on curve crashes; off-path on straight crashes. Crashes where poor road surface or weather are contributing factors.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.36 *Tutoring Systems*

Description

Vehicle type: All.

These systems provide feedback to drivers regarding their driving performance. Information from vehicle acceleration and deceleration, lane position, speed limiting systems and stability sensors may be monitored. Drivers are provided with feedback and recommendations for speed, following distance and lane position. When a potentially hazardous situation occurs, or if vehicle speed, position or stability are deemed to be inappropriate, the driver is 'tutored'. This my be in the form of visual, auditory or haptic feedback. Haptic feedback in the form of accelerator pressure (for speed system) may be more effective and less cognitively demanding than visual messages (Rumar, et al., 1999).

Tutoring systems may also be infrastructure-based. The systems employ roadside beacons that continuously monitor the passing traffic. If a vehicle is deemed to be travelling too fast or too close to the leading vehicle, a message specific to that road user is presented.

Crash relevance

Rear-end crashes; off-path on curve crashes; off-path on straight crashes. Crashes where speed, inattention/distraction and fatigue are contributing factors.

Effectiveness

Lind, et al. (2003) estimated that the 'verified' potential (based on other studies) of in-vehicle tutoring systems (in combination with enforcement strategies) to reduce all road fatalities is 3%, while the 'full' potential (an optimistic estimate based on full deployment) is 7%.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.37 *Vehicle Diagnostic Systems*

Description

Vehicle type: All.

Vehicle diagnostic systems monitor various systems and components of the vehicle and alert the user to potential malfunctions or problems. It provides feedback on the "physical condition of the vehicle" (Green, 1996). These systems may monitor the pressure and/or temperature of the tyres, brake fluid, brake pads, oil pressure, headlamp burnouts, and so on. Any abnormality is immediately detected and the driver is alerted to the system status.

Crash relevance

Crashes where vehicle system malfunctions are contributing factors.

Effectiveness

Estimations of the approximate reductions expected with tyre condition monitoring system in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 50% of personal injury tyre malfunction crashes would be affected, leading to a 35% reduction in these crashes, equating to a 0.15% reduction in all crashes.

Disbenefits

No reported evidence of disbenefits found as yet.

3.1.38 Vision Enhancement

Also: *Night Vision*

Description

Vehicle type: All.

Poor visibility, due to either environmental factors or factors related to the driver, such as age-related visual changes, can greatly increase the risk and severity of crashes. The ability to detect changes in the road surface and geometry, obstacles and other vehicles is essential to safe driving. Vision enhancement systems provide the road user with an improved view of the vehicles path by projecting an improved or higher contrast view of the visual field during poor visibility conditions.

Two types of vision enhancement systems exist. Passive systems detect the naturally radiated energy from objects in the environment with infrared cameras. Active systems employ illumination or scanning techniques to visualise the roadway. This information, outside the user's current field of view, is overlayed onto a video image of the road ahead. The enhanced image of the environment is presented to the user via a heads-up display overlayed on the windscreen, or in the case of motorcycles, this may be a display on the consol or a helmet-mounted display.

A system described by Lawrence, et al. (2004) involves a set of infrared headlights. An infrared sensitive camera mounted on the front of the vehicle detects the reflected infrared radiation. This scene is projected from a display module to a heads-up display over the entire windscreen. High-contrast images of other vehicles, vulnerable road users and obstacles are projected at the same focal length as the regular field of view. The result appear similar to a photographic negative. This display can also incorporate information from the instrumentation panel as in HUDs.

Crash relevance

Crashes where poor visibility is a contributing factor. The OECD (2003) has suggested reduced visibility is a factor in 42% of all traffic collision.

Effectiveness

Estimations of the approximate reductions expected with vision enhancement systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 25% of vulnerable road user crashes occurring in low visibility would be affected, leading to a 17.5% reduction in these crashes, equating to a 0.1% reduction in all crashes.

Cadillac's "Night Vision" system increases the viewing distance of the user from 90 metre with standard headlights, to up to 450 metres (Simon, 1998, cited in Lawrence, et al, 2004).

Lind, et al. (2003) estimated that vision enhancement systems that include adaptive headlights have the potential to affect 30% of pedestrian fatalities and 15% of bicyclist fatalities in Sweden, and predicted that by the year 2015, these systems would reduce pedestrian fatalities by 15% and bicyclist fatalities by 8%. The 'verified' potential of this system (based on other studies) to reduce all road fatalities is less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 8%.

Disbenefits

Archer (2000) suggests that the benefits of vision enhancement systems may be negated by a tendency for users to drive at higher speeds.

3.2 Passive systems

3.2.1 Active Head Restraints

Also: *Intelligent Head Restraints; Self Aligning Head Restraint*

Description

Vehicle type: Commercial and passenger.

The proper alignment of both the seat and headrest can play a vital role in minimising injury in traffic crashes. However, evidence suggests that a large proportion of drivers and passengers fail to satisfactorily adjust their headrest for their height, most commonly leaving it in the lowest position (Olssen, et al., 2006). With standard, incorrectly aligned, headrests the head rolls backward over the headrest causing sudden and forceful hyper-extension of the neck (Fielding, et al., 2005). For this reason, some manufacturers have introduced fixed head restraints, while others have invested in ITS technology.

Active head restraints should address three key issues associated with traditional head rests: the head rest must be high enough to prevent the head rolling backwards; the gap between the back of the head and the head rest must be minimal; and the headrest must have controlled flexibility to prevent forward propulsion of the head. Active head restraints may do this in two ways: either reactively or proactively. Proactive systems, detect the height of the occupant and adjust the headrest accordingly before any crash occurs. Reactive systems, respond to the additional force in the driver or passenger seat cause by a collision by adjusting the head restraint into a more upright and forward position immediately after a collision is detected. This may occur through either a mechanical system located in the back of the seat, or with inflatable headrests. As an alternative, some manufactures have included electronically adjustable headrests. These lack the direct safety benefits of active head restraints, but make it more convenient to set a correct headrest position (Fielding, et al., 2005).

Crash Relevance

Active head restraints are primarily aimed at reducing whiplash related injuries caused by rear-end crashes.

Effectiveness

Nissan's active head restraint system has been reported to reduce the bending force of the neck in a rear-end collision by 45% (Nissan, 2006).

Farmer, Wells, and Lund (2003) reported a 44% reduction in the incidence of neck injuries with the instillation of a number of (reactive) varieties of active head restraints in 409 vehicles.

Viano and Olsen (2001) found a 51% reduction in neck extension during crashes with the use of a reactive Self-Aligning Head Restraint (SAHR), and an reduction of injury risk from 11% to 3% with the use of SAHR.

Bigi, et al., (1998) found inflatable head restraints to reduce head acceleration by 30% to 50%.

Disbenefits

No reported evidence of disbenefits found as yet.

3.2.2 *Airbag Jackets*

Vehicle type: Motorcycles.

Description

Jacket-based airbags involve the same principles as vehicle-mounted airbags, where upon detection of a crash situation the airbag is automatically deployed to minimise injury to the rider. However, the mechanisms of airbag jackets are quite different. Jacket airbags come into effect once the motorcyclist has been thrown from the vehicle, rather than preventing this from occurring. The jacket is connected to the vehicle through a cable, and when this connection is severed (when the force of the rider being thrown from the motorcycle uncouples a pin or key in the jacket) the airbag inflates. The rider will still hit the ground with the same force, but they will be protected with a cushion or air surrounding their upper body. Airbag jackets are inflated by a carbon dioxide cylinder built into the jacket, which is less flammable than the gases used to inflate vehicle-mounted airbags.

Crash relevance

Motorcycle crashes where the rider is thrown from the vehicle.

Effectiveness

There are a number of commercially available airbag jackets in the United States, however, there is no existing independent evaluation of their effectiveness. One manufacturer, Hit-Air conducted a shock-absorbing test on their airbag jacket, showing that this system was more effective than both a regular riding jacket and a jacket with additional padding (www.hit-air.com).

Disbenefits

No reported evidence of disbenefits found as yet.

3.2.3 *Airbags*

Description

Vehicle type: All.

Airbags serve to reduce injury severity by absorbing the kinetic energy of the occupant when they are propelled forward in a crash. Airbag systems involve crash sensors, typically a unit that continuously monitors the acceleration and deceleration of the vehicle. Rapid deceleration that exceeds a threshold of intensity (i.e. a collision) triggers the deployment of the airbag. A pyrotechnic pump rapidly releases gas into the airbag, which inflates within hundredths of a second.

In motorcycles, the system comprises the airbag mounted on the front of the vehicle below the handlebars, and acceleration sensors and impact sensors located on either side the front wheel suspension. Frontal impact is detected by these sensors, and the airbag is deployed. The airbag acts to cushion the forward propulsion of the rider and prevent them from being thrown from the vehicle. The sensors of the system are calibrated to deploy the airbag in collision impacts only, not in other situations such as riding over potholes or curbs. To increase its stability, straps hold the airbag in place.

Crash relevance

All crash types.

Effectiveness

Airbags have been associated with reductions in fatal frontal impact crashes by 25% for drivers and 15% for front passengers when combined with seatbelt usage. For both drivers and passengers, thoracic injuries have decreased by 65% and head injuries have decreased by 75% (www.renault.com).

Lind, et al. (2003) estimated that occupant protection systems (that is, airbags and seatbelt reminders) have the 'verified' potential (based on other studies) to reduce all road fatalities by 4%, while the 'full' potential (an optimistic estimate based on full deployment) is 10%.

Paine (2003, cited in Paine, 2005) estimated a benefit cost ratio of 0.81 for driver airbags, 0.19 for front passenger airbags and 0.20 for side curtains airbags in Australia.

The NHTSA (1996) found airbags to be effective in reducing driver fatalities in frontal-impact crashes by 19% (31% for purely front-impact crashes), and 11% in all crash types. It was estimated that airbags reduced fatalities risk by 9% for restrained drivers and 13% for unrestrained drivers.

Torpey, et al. (1991) calculated a 12:1 benefit-cost ratio for the Australian community associated with the use of driver airbags.

Disbenefits

An issue that must be addressed in the design and evaluation of motorcycle airbag systems is that the position of the rider is not always upright (Takeshi, 2000). The rapid deployment of the airbag should not injure the rider if they are in a forward-leaning position. Also, the presence of a pillion passenger must be considered. The additional force from the passenger behind the rider may injure the rider, or the passenger may be offered no protection from the airbag. Similarly, the development and evaluation of the system should consider that not all front impact crashes occur at 90 degrees to the other object.

Airbags may present an additional danger in impact crashes. The deployment of airbags may result in serious or injury or fatality in some circumstances. This typically occurs when the occupant is very close to the airbag when it is deployed, or the occupant is an unrestrained child or infant in a rear-facing seat. Numerous adaptations to airbags have been made to counteract these problems, and are described below.

A number of additional in-vehicle airbag and supplementary systems exist. These supplementary systems adjust the deployment of the airbag to suit the number and type of occupants present. Also, variants of traditional airbag systems exist that aim to reduce deployment times and prevent occupant injury resulting from airbag deployment (Olsson, et al., 2006). Airbag systems may integrate a number of these technologies in order to provide maximum protection for occupants who may be of different size, weight or position.

3.2.3.1 Adaptive Steering Column

These systems direct the motion of the steering column away from the occupant during airbag deployment. When the airbag is deployed, the steering column pin is also released by a pyrotechnic mechanism, causing downward motion of the steering column. This increases the space between the driver, the steering column and airbag.

3.2.3.2 Buckle Sensors

Seatbelt buckle sensors detect whether the occupant is restrained, and adjust the impact severity thresholds of the airbag for that seat. These also involve occupant sensors. The airbag threshold is modified so that it deploys at lower impact intensity and higher inflation rate for unrestrained occupants.

3.2.3.3 Dual-stage Airbag

These airbags deploy during two stages. The activation of these stages depends on the severity of the crash. Stage two, or full deployment, occurs during severe crashes.

3.2.3.4 Inflatable Carpet

Inflatable carpet systems are airbags located in the floor of the vehicle, under where the feet rest. These lift the feet away from the floor upon inflation, reducing impact force to the lower limbs.

3.2.3.5 Inflatable Seatbelt

Inflatable seatbelts involve a tube along the shoulder strap of the seatbelt which inflates upon impact. This reduces load on the seatbelt and protects the upper body of the occupant during a crash. This serves to absorb and spread force, as well as tensioning the seatbelt.

3.2.3.6 Knee Airbag

Knee airbags protect both the knees and hips during a collision, prevents the occupant submarining. This also ensures the occupant in the optimal upright position for airbag protection.

3.2.3.7 Radial Deployment Airbag

Radially deploying airbags inflate the airbag in a radial motion, increasing the time between airbag deployment and contact with the occupant. The bag first inflates radially before inflating toward the occupant. This may be especially beneficial for occupants positioned close to the airbag.

3.2.3.8 Roofbag

Heudorfer, et al. (2005) described an airbag concept to protect occupants during a rollover crash. A multi-chamber airbag located in the top of the seat inflates slowly (around 250 ms), pushing the occupants head forward. This forces the occupant to flex their neck, increasing the load the head and neck are able to withstand without injury, provided additional cushioning between the head and roof, and increases the space between the head and roof.

3.2.3.9 Seat Position Sensor

Detection of the position of the seat allows the modification of the deployment of the airbag. If the seat is positioned further forward, the airbag may be deployed at stage one instead of stage two (for dual stage airbags).

3.2.3.10 Side Airbags

Airbags located in the side of the vehicle (e.g., inflatable tubular structure, inflatable curtain, torso side airbags) protect the occupants head during side-impact and rollover crashes.

3.2.3.11 Weight and Pattern Recognition Sensor

Weight and pattern recognition sensors determine the presence of a passenger, and to discriminate adults from children. The physical characteristics of the occupant are evaluated with weight and pressure sensors in the base and backrest of the seat. If a child is detected, the airbag may be disabled or modified to deploy at a lower inflation rate.

3.2.3.12 Child Seat Detector

Child seat sensor systems deactivate the passenger seat airbag when a child seat is in place.

3.2.4 Anti-Submarining Seat

Description

Vehicle type: Commercial and passenger.

Anti-submarining seats prevent the occupant slipping under the lap belt, which can result in injury to the internal organs of the abdomen. This may occur when there is slack in the seatbelt or when the seat cushion allows downward and forward occupant displacement. The anti-submarining seat contains an inflatable or up-ward moving structure in the base of the seat which supports the occupant during a crash. This prevents the occupant slipping downward during a crash without compromising the comfort of the seat during normal driving.

Crash relevance

All crashes.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.2.5 Automatic Rollbars

Description

Vehicle type: Convertible.

Automatic rollbars for convertibles provide protection for rear-seat occupants during a rollover crash. Convertibles lack protective structures around the rear-seat, rendering passengers particularly susceptible to upper body injury during a rollover. Automatic rollbars are located within the head restraint of the rear seats, and move upward during a rollover event. They are triggered when the tilt of the vehicle exceeds a certain threshold. Deployment of the rollbars is not affected if the roof is in use. The system is electromechanical, not pyrotechnical, allowing more gradual deployment of the rollbar so as to minimise risk to the occupants. This also allows the rollbars to be retractable (www.renault.com).

Crash relevance

Rollover crashes involving convertibles.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.2.6 Crash Data Recorders

Also: *Black-box recorders; Event data recorders*

Description

Vehicle type: All.

Crash data recorders in passenger vehicles perform the same function as black boxes in the aviation industry. They record information regarding the activities and physical condition of the vehicle prior to and during a crash, which can be later accessed and analysed. Crash data recorders consist of a variety of vehicle system sensors and detectors to measures factors such as acceleration, location, pre-crash activity, time of crash, rollover and yaw data, braking activity and airbag deployment. Data is provided only for the seconds leading up to a crash. These are not logs of driving behaviour over extended periods, but recordings of the crash event only. According to the IIHS (2003), crash data recorders are essentially extensions of airbag sensors, which measure vehicle deceleration and velocity. Other data, such as time, date, speed prior to impact, seatbelt use and the activation of other active and passive systems can also be included.

Crash relevance

All crash types.

Effectiveness

Crash data recorders will have no direct effects on safety. However, they provide crash investigators a better understanding of the factors contributing to crashes, which may lead to better road and vehicle design.

Kulmala (1997) reported that event recorders have actually been shown to reduce number of crashes and crash severity when installed in commercial vehicles as a means of driver performance monitoring.

Disbenefits

The IIHSA (2003) suggests that standards regarding the type of information gathered by crash data recorders are needed to maximise the usefulness of these systems.

3.2.7 Emergency Lighting Systems

Description

Vehicle type: All.

Emergency lighting systems illuminate the vehicle post-crash. When a crash event has occurred, detected through airbag crash sensors, tilt sensors, ACN sensors or similar, the system automatically activates the vehicles lighting systems. This may be the interior lights, headlights, hazards lights or other emergency lights.

The conspicuity enhancing effects of this system may serve to reduce the severity of crashes by decreasing critical response time, particularly in rural and night time crashes where the vehicle may be difficult to locate. This may be especially relevant to single-vehicle motorcycle crashes.

Crash relevance

All crash types.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.2.8 *External Airbags*

Description

Vehicle type: Passenger.

External airbags systems are fitted to the exterior of a motor vehicle in order to increase the safety of vulnerable road users in the event of a vehicle-pedestrian collision. A collision with a pedestrian triggers the inflation of airbags located in the bumper and bonnet. These serve to absorb some of the kinetic energy of the pedestrian as their legs, torso and head make contact with the front of the vehicle. Some external airbags are designed to inflate upward over the windshield to protect the occupant from directly hitting the glass.

These systems may also be pre-crash, where an eminent collision with a pedestrian triggers the inflation of the airbags. These systems involve forward facing collision detection systems. As well as determining whether a collision with a pedestrian opposed to a vehicle has occurred, the sensors of the system must be able to distinguish children from adults. Children require greater protection from the bumper and lower bonnet, while adults are more likely to strike the upper bonnet (Holding, Chinn, & Happain-Smith, 2001). The pedestrian detection component of the system may involve thermal imaging, radar, laser or infrared imaging.

Crash relevance

Pedestrian crashes.

Effectiveness

Holding, et al. (2001) studied the effects of external airbags on a sedan vehicle on collisions with adult and pedestrian crash test dummies. They found significant reductions in the acceleration forces of chest, pelvis, and knees in collisions at 40 km/h and concluded that head injuries could be reduced by 20% with these systems.

Disbenefits

No reported evidence of disbenefits found as yet.

3.2.9 *Impact-Sensing Cut-Off Systems*

Description

Vehicle type: All.

Impact-sensing systems disable fuel and electrical systems to prevent the vehicle igniting after a crash has occurred. The system may involve crash sensors and fuel leakage detectors (i.e. vapour sensors) which detect a crash or malfunction of a vehicle system (Olssen, et al., 2006). For example, Delphi's Pyrotechnical Safety Switch disconnects the main power cable from the vehicles battery in the early stages of a crash (Delphi, 2005). This prevents a short circuit from occurring. The system does not cut off power from the vehicles passive safety systems, interior lighting or door locks.

Crash relevance

All crash types.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.2.10 Impact-Sensing Door Unlock

Also: *Easy Exit Features*

Description

Vehicle type: Commercial and passenger.

Impact-sensing door unlock systems detect the occurrence of a crash and automatically unlock the vehicle's doors. A crash severe enough to trigger the vehicles airbags will trigger this system. This enables rapid escape from the vehicle and easy access for emergency services to occupants trapped inside the vehicle.

Crash relevance

All crash types.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

3.2.11 Pop-Up Bonnet Systems

Also: *Active Hood*

Descriptions

Vehicle type: Passenger.

Pop-up bonnet systems increase the 'crush' space between the pedestrians head and torso in the event of a pedestrian-vehicle crash. In frontal impacts, the pedestrian is particularly vulnerable to head injury resulting from the densely packed components under the bonnet of the vehicle (Fredriksson, Håland & Yang, 2001). When contact between the front bumper and a pedestrian occurs, the system pushes the bonnet upward from the rear creating a larger gap between the bonnet and engine beneath. This cushions some of the pedestrian's kinetic energy, minimising injury. Alternatively, some systems may differentiate contact between a pedestrian and another vehicle. If the impact is with another vehicle, the system makes the bonnet more rigid, affording greater occupant protection.

These systems may involve sensors within the front bumper, which detect a collision with a pedestrian as contact is made with the front of the vehicle. Alternatively (and ideally), the system may involve sensors that detect the vulnerable road user in the path of the vehicle before a collision has occurred. This allows more rapid activation of the system, ensuring the pop-up mechanisms have deployed and the bonnet has been stabilised before the pedestrian makes contact with the vehicles front structures. This is a CAPS version of the system.

Crash relevance

Pedestrian crashes.

Effectiveness

A recently developed external airbag system has been reported to reduce the risk of fatality from a frontal pedestrian-vehicle crash at 40 km/h from near-certain to less than 15% (Autoliv, 2006).

Lawrence, et al. (2004) estimated the benefit-cost ratios of pop-up bonnet systems in various types of vehicles. Best estimates for benefit cost ratios were:

- No pop-up bonnet: 7.4
- Pop-up bonnets on all sports cars: 6.6
- Pop-up bonnets on all sports and executive cars: 6.1
- Pop-up bonnets on all sports, executive and large family cars: 4.6
- Pop-up bonnets on all cars: 3.3

Lind, et al. (2003) estimated that vulnerable road user protection systems such as pop-up bonnets and extendable bumpers, have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 0.6%.

Disbenefits

Systems which cannot be re-set, such as irreversible pyrotechnic activation systems, may be associated with considerable cost to the vehicle owner as these parts must be replaced once activated (Lawrence, et al., 2004).

3.2.12 Seatbelt Pre-Tensioners

Part of *Intelligent Restraint Systems*

Description

Vehicle type: Passenger and commercial.

Seatbelt pre-tensioners decrease the amount of slack in the seatbelt during a crash. Upon detection of an impact, excess seatbelt slack is taken up by the system, reducing the forward propulsion of the occupant and the likelihood of them submarining in the seat. In order for this to be effective, the seatbelt must pre-tension before the occupant is propelled forward by the force of the crash. This of course relies on accurate crash sensors. The pre-tensioners can retract as much as 15cm of seatbelt in 5ms (Zellmer, Lührs & Brüggemann, 1998).

Crash relevance

All crashes involving restrained occupants.

Effectiveness

Paine (2003, cited in Paine, 2005) estimated a benefit cost ratio of 1.12 for front seat seatbelt pre-tensioners in Australia.

Intelligent restraint systems have been estimated to reduce the probability of a severe head or chest injury by 14%, and up to 17% for an occupant of small stature (Clute, 2001).

Disbenefits

Olssen, et al. (2006) noted that pre-tensioners are not compatible for all vehicle types, such as convertibles.

3.2.13 Seatbelt Load Limiters

Part of *Intelligent Restraint Systems*

Description

Vehicle type: Commercial and passenger.

Seatbelt load limiters operate in conjunction with pre-tensioners. Load limiters gradually reel out additional seatbelt slack after the seatbelt has been pre-tensioned. This reduces the load from the seatbelt on the occupant during the rapid deceleration that occurs in a crash.

Adaptive load limiters are more sophisticated variants of this technology. These systems can determine the occupants size and position and the force of the impact, and adjust the load limiting of each belt accordingly. This may incorporate a gearbox system that releases slack into the seatbelt in various stages (Olssen, et al., 2006). The first gear has the strongest grip, releasing minimal additional belt, while the second gear allows more constant release of the seatbelt. High severity crashes cause the system to stay in the first gear for longer before transferring into lower gears.

Crash relevance

All crashes involving restrained occupants.

Effectiveness

Intelligent restraints have been estimated to reduce the probability of a severe head or chest injury by 14%, and up to 17% for an occupant of small stature (Clute, 2001).

Disbenefits

No reported evidence of disbenefits found as yet.

3.3 Combined Active and Passive Systems

3.3.1 Extendable Bumper

Vehicle type: Commercial and passenger.

Description

The extendable bumper system serves to increase the crush space of the front of the vehicle during a frontal collision. Pre-crash sensors detect and eminent crash and the bumper is extended laterally by around 6 inches and is locked in place. This 'softens' the front end of the vehicle, allowing it to absorb greater force from the other object or vehicle during a frontal collision. This enhances the safety of not only the occupants of the vehicle with the extendable bumper, but also the occupants of the other vehicle involved in the collision (www.gm.com).

Crash Relevance

Multiple-vehicle crashes at intersections; head-on crashes; rear-end crashes; pedestrian crashes.

Effectiveness

Lind, et al. (2003) estimated that vulnerable road user protection systems such as extendable bumpers and pop-up bonnets, have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) was estimated to be 0.6%.

Disbenefits

No reported evidence of disbenefits found as yet.

3.3.2 Motorised Seatbelts

Also : *Active Control Retractor; Pre-crash Seatbelt System*

Description

Vehicle type: Commercial and passenger.

Motorised seatbelts automatically retract to take up excess slack in the seatbelt when a crash is deemed to be likely or unavoidable. These may be linked to active emergency control systems, such as brake assist, ESC, pre-crash or collision warning systems. In these systems the activation of the active or pre-crash safety systems also activates the seatbelt retractor. For example, Nissan's pre-crash seatbelt system is linked to the Intelligent Brake Assist system. These active and pre-crash safety systems can also be linked to other intelligent restraint systems, such as pre-tensioners and load limiters. Alternatively, eminent crashes may be detected via a forward-facing radar. A system described by Nishikaji (2006) also tightens the seatbelt during cornering to reduce occupant discomfort during such manoeuvres. This system incorporates lateral sensors to determine turning movements as well as longitudinal sensors to determine braking action.

Crash relevance

All crashes involving restrained occupants.

Effectiveness

Pre-crash seatbelt systems have been estimated to reduce serious injuries by up to 20% (Regan, et al., 2006).

Nissan expects a 25% reduction in fatalities and serious injuries to be associated with a motorised seatbelt system linked to brake assist (Takagi & Pal, 2003). A simulation study found that the peak G force on the thorax decreased by 7% with this system compared to a normal belted occupant.

Disbenefits

No reported evidence of disbenefits found as yet.

3.3.3 Pre-Crash Systems

Description

Vehicle type: All.

Pre-crash systems come into effect when an inevitable crash is been detected. Forward-facing sensors, such as those in collision avoidance systems, determine the eminent crash and prepare the vehicle to minimise the effects of the crash. For example, passive safety systems such as braking assist, airbags and seatbelt pre-tensioners may be pre-charged to minimise delays in their deployment. The system may use radar sensors (or similar) to monitor the road environment ahead or directly behind the vehicle. The speed and trajectory of the user's vehicle is continuously monitored in relation to the speed and position of other objects. If a crash is calculated to be inevitable or unavoidable, the system may employ active safety systems (e.g., brake assist) as well as passive safety features. Also, the course of the vehicle may be altered. If the system determines that a single vehicle crash will be less serious than a high speed head-on collision, for example, the system will veer the vehicle onto the roadside (Rumar, et al., 1999).

Current systems, such as that offered by Mercedes-Benz, do not involve detection of hazards in the road environment. Rather, they detect activation of other active safety measures, such as brake assist or ESC, and take additional safety measures such as closing the sunroof and activating seatbelt pre-tensioners (Olssen, et al., 2006). More advanced pre-crash systems may also become cooperative, incorporating GPS and inter-vehicle communication functions to better predict (and therefore protect against) a potential crash.

Crash relevance

The type of crash effected depends of the sensors of the system (e.g., forward facing, rear-facing or lateral sensors).

Effectiveness

Sugimoto and Sauer (2005) modelled the effects of a pre-crash 'collision mitigation brake system' (CMBS) on 50 accident scenarios. This system provides auditory, visual and haptic warnings, tensions the seatbelts and automatically applies light braking pressure if a crash is deemed likely. It was estimated with CMBS, 38% of the crashes investigated in this study would have been avoided, with a 44% reduction in the probability of a fatal outcome. Sugimoto and Sauer noted that it is difficult to assess the outcomes of pre-crash systems in real-world crash data, as the conditions leading up to crash are rarely known.

Lind, et al. (2003) estimated that pre-crash systems, including those that intervene with the path of the vehicle, have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) was estimated to be 1%.

A study from Daimler Chrysler and Mercedes, suggested a reduction of 30% to 50% for head injuries, and another 20% to 40% reduction in neck injuries (2002).

Disbenefits

No reported evidence of disbenefits found as yet.

4 Infrastructure-Based Systems

4.1 Active Systems

4.1.1 Animal Detection Systems

Description

Animal detection systems serve to detect the presence of large animals on the road ahead and provide alerts to approaching drivers. To maximise their effectiveness, animal warning signs should serve to both increase driver awareness and decrease vehicle speed (Huijser, 2006). These systems are generally designed for and implemented in regions where collisions with large animals, such as elk and deer, are common.

Four variants of animal detection systems exist (Huijser, 2006). In all cases, the detection of an animal on or in the roadway triggers a visual alert that is presented via roadside signs. This is typically a flashing light and picture of an animal (e.g., a deer), and may incorporate speed warnings. The systems differ in how they detect the presence of animals:

- **Area cover systems:** Monitor a given area with video, radar or infrared to detect movement and/or body heat of an animal crossing or near the roadway.
- **Break-the-beam systems:** Rely on an infrared beam between two sensors parallel to the road. An animal passing through this beam will interrupt this signal and trigger a roadside warning. A limitation to this system is that the direction of movement and the number of the animals cannot be determined, leading to false alarms when animals leave the roadside.
- **Geophone systems:** These consist of units buried in the ground that detect the vibration caused by large animals walking over the crossing area.
- **Radio collar systems:** Animals with radio collars trigger alarms when they come within a certain proximity roadside sensors. This relies on a high proportion of a herd of animals being collared, and that 'lead' animals within the herd are collared. Animals without radio collars are only detected when they are accompanied by a collared animal.

Area cover and break-the-beam systems are the most commonly used types of animal detection system.

Huijser (2003) outlined an additional form of animal collision prevention system. Animal *warning* systems alert the animal to the presence of motor vehicles, as opposed to *detection* systems which have the reverse action. Vehicle sensors in the area leading up to the areas where animals frequently cross detect approaching vehicles and trigger signals that either alert the animals or encourage them to move from the area. This may occur through auditory (i.e. whistles) and/or visual alerts on the roadside.

Crash relevance

Animal crashes.

Effectiveness

In a review of animal crash countermeasures, Huijser (2006) noted the lack of available literature regarding the effectiveness of animal warning systems. What is currently available tend to report small reductions in average vehicle speed but not effects on animal-vehicle crashes. These effects tend to be more pronounced in poor visibility or adverse weather conditions, and local drivers tend to reduce their speed more than non-locals. For example, Hedlund, et al. (2004) noted that as of 2004, no studies of the effects of active animal crossing signs on deer-vehicle crashes had been conducted, although a US study had observed small reductions in vehicle speeds (4 m/ph). This literature review reported that animal detection systems have been associated with in 82% reduction in collisions with large animals (Huijser, 2006). A cost-benefit analysis was also conducted, showing if an animal detection system prevented at least 5 collisions with deer (or 3 with elk or 2 with moose), the economic benefits of the system outweigh the costs.

Disbenefits

As already noted, less sensitive systems may result in frequent false alarms, reducing the effectiveness of the system as drivers learn to ignore the warnings. Huijser (2003) suggested that the benefits of animal detection systems are affected by frequent false positive and false negatives. Also, they are associated with high implementation and maintenance costs, and their impact on the environment may be an issue.

4.1.2 Automated Enforcement Systems

Description

Automated enforcement systems encompass a number of technologies that serve to enforce road traffic laws. Automated enforcement systems have a number of advantages, including improved traffic safety and crash reduction, deterrence of law violations, greater efficiency in the use of police time, continuous enforcement and objective evidence (FHWA, 2000; Retting, Ferguson & Hakkert, 2003). They also allow the punishment of offenders who violate red lights and railway crossings, when it may not be safe for police to pursue the offenders. These systems may be integrated with the infrastructure, or hand-held devices used by law enforcement individuals.

Crash Relevance

Multiple-vehicle crashes at intersections. Crashes where speed, intoxication (both alcohol and illicit drugs) are contributing factors.

Overall Effectiveness

McKeever (1998) estimated 20% of crashes within the US could be avoided with automated enforcement of speeding and red light running. Conservative estimates show a reduction in injury crashes of 8.3% and fatality crashes by 4.4% with automated enforcement systems (OECD, 2003).

Lind, et al. (2003) estimated that the 'verified' potential (based on other studies) of enforcement and education strategies (i.e., red light and speed cameras, in-vehicle-tutoring) to reduce all road fatalities is 3%, while the 'full' potential (an optimistic estimate based on full deployment) is 7%.

The overall effectiveness of automated enforcement systems in reducing injury crashes has been estimated to be 17% (Rumar, et al., 1999). Red light cameras alone are estimated to reduce injury crashes by 12%. While it was suggested that automated speed enforcement systems have the potential to reduce injuries and fatalities on motorways by around 10-15% and reduce injuries by over 10% on rural roads.

McKeever (1998) estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that a 4.4% reduction in fatalities and an 8.3% reduction in injuries could be expected with video camera based automated enforcement systems (e.g., red light and speed cameras).

A Korean application of automated speed enforcement, utilising automatic license plate detection, speed cameras and inductive loop detectors resulted in a 60% reduction in fatalities and 28% reduction in all crashes in the area immediately around the enforcement system (Kang & Hong, 1998).

An assessment of the initial safety benefits of speed detection and red light camera systems in London found a 10% reduction in overall speed, a 20% reduction in all types of casualties, and a 50% reduction in fatal and serious injury crashes (Harris & Sands, 1995).

Overall Disbenefits

Automated enforcement strategies which identify the road user are often regarded as an invasion of privacy within the USA (Savage, 2004; OECD, 2003).

4.1.2.1 Breath Testing

Roadside alcohol breath testing is used to determine the BAC of drivers. Drivers are required to blow into a device which analyses the alcohol content of their breath. If a BAC higher than the legal limit is detected, the individual is required to provide a blood sample to verify their BAC.

Alcohol breath testing has been an internationally successful enforcement strategy. In a review of literature regarding the effectiveness of breath testing checkpoints in the US, Europe and Australia, all studies in all locations showed that roadside breath testing strategies were associated with a reduction in the number of crashes of up to 36%. (Centre for Disease Control and Prevention, 2002).

4.1.2.2 Electronic Licence Plates

Electronic license plates are one of a number of automatic vehicle identification (AVI) technologies. Electronic licence plates can employ simple two-way transmitter systems or satellite communication. Information about the vehicles registration, type, current speed, vehicle specifications and so on are stored in an on-board unit that communicates this information to infrastructure-based receivers. This can either occur at continuous intervals while travelling, or when beacons are detected (Hubaux, Čapkun & Luo, 2004).

Electronic licence plates are relevant to enforcement in the location of stolen or offending vehicles and automatically detect speeding vehicles. Electronic licence plates also have particular relevance to the commercial vehicle industry in fleet management (e.g., automatic vehicle location), electronic clearance and weigh-in-motion strategies (Walton, 1991).

No reported evidence of effectiveness or disbenefits found as yet.

4.1.2.3 Headway Monitoring

The headway between two vehicles can be determined using hand-held or fixed laser devices. The system measures the speed of the leading vehicle, then the speed of the following vehicle. This information, as well as the distance from the laser, is used to determine the following distance between the two vehicles.

No reported evidence of effectiveness or disbenefits found as yet.

4.1.2.4 Laser Speed Detectors

Photo radar systems employ a combination of radar technology to determine the speed of vehicles and supplementary photographs to identify offending vehicles. Alternatively, speed enforcement may hand held radar devices.

Numerous studies of the effectiveness of laser speed detectors in the US have reported reductions in the number of total crashes by as much as 51% (ITE, 1999). Speed cameras in the UK have been associated with a 35% reduction in fatal and serious injury crashes at camera sites (Gaines, et al., 2003), while in London, reports have shown 10% speed reductions and crash reductions ranging 20-80% (Jernigan, 1998). Various studies in Europe and Australia have given estimates in crash reductions as high as 56%. PIARC (2000, cited in OECD, 2003) reported a benefit-cost ratio of 4.1 for speed enforcement technologies, and that speed cameras have been shown to prevent up to 50% of crashes in Australia and Europe.

Maccubbin, et al. (2005) reported that speed enforcement technologies have resulted in substantial positive impacts on road user safety in the US. Reductions in fatality and serious injury as high as 35% have been observed at speed camera sites.

Lind, et al. (2003) estimated that speed cameras have the potential to affect 17% of speed related fatalities and 12% of intersection crash fatalities in Sweden, and that by the year 2015, these enforcement systems would reduce speed related fatalities by 12% and intersection fatalities by 8%.

Regan, et al. (2001) suggested automated speed enforcement technologies have the potential to reduce fatal and serious injury crashes by at least 10%.

Rumar, et al. (1999) suggested that automated speed enforcement systems have the potential to reduce injury crashes on rural roads by 20%, and injury and fatality crashes on motorways by more than 10-15%.

Speed enforcement technologies have been estimated to decrease the number of injury crashes by up to 17%, and reduce the number of drivers exceeding the speed limit by 10% (Kulmala, 1997).

4.1.2.5 Rail Crossing Enforcement

Railway crossing enforcement systems are similar to red light camera systems. They involve a photographic camera which faces the direction of traffic over a barrier or signalised railway crossing. An inductive loop detector senses when a vehicle violates the railway crossing signals or drivers around the crossing barriers, and photographs of the vehicle are taken. These systems must be integrated with the timing of the railway system.

Reductions in the number of rail crossing violations as high as 92% have been reported in the US (Meadow, 1998). This was also associated with a 70% reduction in vehicle-train collisions.

4.1.2.6 Red Light Camera

Red light camera systems consist of a photographic camera facing the direction of traffic in the intersection which is synchronised to the light sequence. When activated by a vehicle travelling over an inductive loop within the intersection during a red light sequence, the camera typically takes two photographs to identify the vehicle, confirm the traffic signal was red, and that the vehicle continued to travel through the intersection.

Red light cameras are one of the most widely investigated ITS in terms of safety benefits. Numerous evaluations of their effects have reported reductions 20-87% in violations at intersections with red-light cameras in the US (e.g., Retting, Ferguson & Hakkert, 2003; ITE, 1999; Maccubbin, Staples & Salwin, 2001; Hansen, 2000; Fleck & Smith, 2001). However, other studies have also reported significant reductions in crashes (e.g., Passetti, 1997). Across various studies in Australia, the USA and Singapore, red light cameras have been estimated to reduce injury crashes by between 7-46% (OECD, 2003). After various instillations throughout the USA, red light cameras were found to reduce violations by up to 42%, and reductions in crashes of up to 70% (Savage, 2004). Reductions in violations and crashes were also observed for intersections that were did not have red light cameras. Similarly, Retting and colleagues (2004) reviewed seven international studies of the effects of red light cameras, reporting reductions in red light violations ranging 22-56%, and four of theses studies also showed a 'halo effect' where intersections that were not installed with red light cameras also showed a reduction in violations. Additionally, an overall reduction in injury crashes ranging between 25-30% was found, with most significant reductions in crashes involving vehicles at adjacent directions.

However, red-light cameras have been associated with a 28.2% increase in the number of rear-end crashes in Australia (Passetti, 1997). Also, red light cameras were concluded to be effective at reducing traffic signal violations, but not crashes, in a literature review by Betchel, Geyer, and Ragland (2001). Maccubbin, et al. (2005) reported that the effects of red light cameras in the US are so far inconclusive.

4.1.2.7 Saliva Testing

Saliva testing of drivers for illicit drugs is a relatively new enforcement strategy. Saliva tests for methamphetamines and THC (the active component of marijuana) currently exist. Drivers are required to place an absorbent material in their mouth, which is analysed by a hand-held device. If an illegal substance is detected, further samples are taken to verify the initial sample.

No reported evidence of effectiveness or disbenefits found as yet.

4.1.2.8 Tagging and Tracking Systems

In order to avoid potentially dangerous high-speed pursuits, projectile tracking devices have been developed. A small dart containing a GPS receiver, radio transmitter, power supply is fired from a hand-held or vehicle-mounted launcher (www.starchase.org). The offending vehicle is allowed to drive off, and it is remotely tracked so that authorities can organise road blocks to apprehend the offender.

No reported evidence of effectiveness or disbenefits found as yet.

4.1.3 Bicycle Signal Systems

Description

Bicycle safety countermeasures serve to specifically enhance the safety of bicycles at signalised intersections. The systems detect the presence of the bicycle and alter traffic signals to facilitate the safe movement of bicyclist through intersections. These strategies may involve one or both of the following technologies:

- **Bicycle detection systems:** Control of traffic at signalised intersections to better suit the needs of bicyclists. Bicycles may be detected passively, through infrared, video camera or inductive loop detectors, or via manual push buttons. The presence of a bicycle at an intersection may alter the traffic signal timing or activate bicycle-specific signals.
- **Bicycle signals:** These are traffic signals for specifically bicycles and no other road users. This provides cycles of green, amber and red signals specific to bicycles that are coordinated with signals for other vehicles and pedestrians, allowing the passage of bicycles through the intersection with no conflicting vehicles or pedestrians.

Crash Relevance

Bicycle crashes.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

Bicycle signals are high-cost systems to implement (www.bayareatrafficsignals.com).

4.1.4 Construction Zone Systems

Description

Various ITS may be used to enhance the safety of motorists and workers in construction zones. Lowered speeds, merging traffic, changed road conditions, foreign material on the road and the presence of workmen are factors which may increase crash risk in these areas. These systems serve to reduce crashes occurring in or around road construction zones. At least in the US, a disproportionately high number of crashes occur in these areas (Bushman, Berthelot & Klashinsky, 2003). ITS can be used to manage traffic flow around the construction zone and to inform drivers of the upcoming changed traffic conditions.

4.1.4.1 Dynamic Lane Merging

These systems employ variable message signs to control the behaviour of merging traffic leading up to a construction zone (Bushman, et al., 2003). These systems enforce a “no-passing zone”, in which traffic from one lane only can pass a given point. After a set interval, the message changes so that the other lane may proceed. A variable message sign displays a message such as “left lane – do not pass when flashing”, while a roadside beacon flashes to indicate which lane has the right of way. The length of the flashing phase can be adapted to suit the current level congestion, which is indicated by traffic monitoring devices. Similarly, the position of the signal can be moved up or down stream to suit traffic flow at specific points.

4.1.4.2 Real-time Information Systems

The provision of information regarding upcoming conditions to road users may reduce frustration and confusion among road users and alert them to upcoming hazards. Information regarding merging traffic, road closures, alternative routes, reductions in speed, duration of road works, and so on.

4.1.4.3 Variable Speed Limits

Variable speed limits adjust the speed limit to suit the current road conditions. Fixed alternative speed limits in construction zones may be ignored by road users, who see them as advisory or irrelevant when construction work is not being carried out (Bushman, et al., 2003). Variable message signs can also be adapted to suit the current traffic flow or construction zone activity.

Crash Relevance

Rear-end crashes; side-swipe crashes; pedestrian crashes. Crashes where speed and poor road surface area are contributing factors.

Effectiveness

(Bushman, et al., 2003) evaluated the use of ITS in various construction zones in the US. The use of VMS to convey information to motorists approaching a construction zone resulted in a 33% reduction in fatal crashes and a 7% reduction in rear-end crashes. Dynamic lane merging was associated with decreases in peak travel times, fewer and shorter stops, and reductions in aggressive driving behaviours at merging points. One-third fewer fatal and rear-end crashes occurred in construction zones with information systems compared to similar sites without these ITS.

Disbenefits

No reported evidence of disbenefits found as yet.

4.1.5 Pedestrian Signal Systems

Description

A number of systems exist that are designed to enhance pedestrian protection at intersections. These aim to increase the duration of the green 'walk' signal, increase the frequency of green 'walk' signals, or adapt the signal patterns to suit vulnerable road user's needs. However, Ekman and Hyden (1999) suggest that the extension of 'walk' times has no real safety benefit. Rather, preventing pedestrians walking across a red 'don't walk' signal is more important. This relies on the accurate detection of pedestrians and coordination of traffic signals.

Crash relevance

Pedestrian crashes.

Overall Effectiveness

A literature review of studies of various pedestrian safety countermeasures at intersections revealed inconsistencies in performance (Bechtel, Geyer & Ragland, 2003). Systems varied in the reduction of signal violations, pedestrian and traffic delays, vehicle speeds, pedestrian-vehicle conflicts, and the reliability in accurately detecting pedestrians at the curb and in the intersection. The following conclusions about pedestrian crossing ITS were made:

- **Automated Pedestrian Detection:** Effective at reducing pedestrian-vehicle conflicts.
- **Flashing Crosswalk Lights:** Associated with an overall crash reduction.
- **Countdown Signal:** Increase in proportion of pedestrians who complete crossings before 'don't walk' signal.
- **Scanning Eyes:** Effective at reducing pedestrian-vehicle conflicts.

Overall Disbenefits

Systems that involve signals or camera sensors, such as the high-intensity activation crosswalk and smart lighting systems are associated with high implementation costs (www.bayareatrafficsignals.com).

Descriptions and Evaluations of System Variants

4.1.5.1 Accessible Pedestrian Signals

These systems supplement signalised intersections by providing additional traffic information for visually or hearing impaired pedestrians. This may be in the form of audible tones, 'talking signs', vibrating surfaces (www.bayareatrafficsignals.com). This can be used to communicate the location of the intersection or the status of the crossing signal to the pedestrian.

Transport and infrastructure information can be provided to specific vulnerable road users with these systems. The Czech Republics Command Rig System provides information to visually impaired pedestrians via transmitters that can be integrated into the 'white stick' commonly used by visually impaired individuals (ERTICO, 2002). Audible traffic signals have also been shown to improve traffic signal compliance in sighted pedestrians as well as visually impaired individuals (Ragland, et al., 2003).

No reported evidence of effectiveness or disbenefits found as yet.

4.1.5.2 Automatic Pedestrian Detection

Pedestrian detection systems involve sensors which detect the presence and speed of pedestrians at crosswalks. The system senses approaching pedestrians and triggers the green 'walk' signal in place of traditional push-button systems. The duration of the 'walk' signal may be adjusted to accommodate slow-moving pedestrians. This may be achieved with the use of infrared, radar and/or microwave pedestrian detectors, or pressure sensitive mats.

Automated pedestrian detection appears to be effective at reducing pedestrian-vehicle conflicts when combined with traditional manual push buttons systems, but are associated with an increase in conflicts when they are used to replace pushbuttons (Ragland, et al., 2003).

A trial of automatic pedestrian detection system in four sites in the US was associated with an 81% decrease in pedestrians crossing during the 'don't walk' signal (Hughes, et al., 2001). A 89% reduction in pedestrian-vehicle 'conflicts' (where either the pedestrian or vehicle must stop or slow down to avoid a collision) was observed in the first half of the crossings but in the second half of the crossing this reduction was 42%.

A roadside warning sign that was activated by the presence of pedestrians on a zebra crossing was associated with an increase in the number of vehicles that stopped for pedestrians from 12% to 50%, and this effect persisted for a year. (Ekman & Hyden, 1999). However, it was also noted that these systems may have a high level of false alarms, which may detract from their effectiveness.

Pedestrian detection systems have been shown to significantly decrease the number of pedestrians who violate 'don't walk' signals in the US (Maccubbin, et al., 2005).

4.1.5.3 Countdown Signal

Countdown signals supplement traditional signalised pedestrian crossings. When the green 'walk' signal becomes a flashing red signal, a timer is also presented indicating how many seconds until the signal changes to 'don't walk'. This discourages people entering the roadway when the countdown is nearly complete and speeds up crossing clearance times.

No reported evidence of effectiveness or disbenefits found as yet.

4.1.5.4 Flashing Crosswalk Lights

Flashing lamps located in the pavement leading up to the cross walk provide advanced warning to approaching drivers that a pedestrian is on the crossing. The lights are activated by the manual crossing push-button.

No reported evidence of effectiveness or disbenefits found as yet.

4.1.5.5 High-intensity Activated Crosswalk

Also: *Modern Flashing Beacon*

These are a type of signalised crossing, where the pedestrian presses a button on the roadside which activates a traffic signal. The signal is initially a flashing yellow lamp, followed by a solid yellow and finally solid red lamp. This indicated to the driver to prepare to stop and then that they must stop. When the signal becomes a flashing red lamp, the vehicle may proceed. This minimises the delay associated with normal traffic signals, but increases the likelihood of the vehicle stopping (www.bayareatrafficsignals.com).

No reported evidence of effectiveness or disbenefits found as yet.

4.1.5.6 Pedestrian Warning Sign

These are illuminated signs on the roadway that are triggered when a pedestrian crosses at a particular intersection or crossing. The movement of the pedestrian across the road is detected with infrared sensors, indicative loops, etc., and the sign is activated to warn approaching road users (Ekman & Hyden, 1999).

No reported evidence of effectiveness or disbenefits found as yet.

4.1.5.7 Scanning Eyes

Scanning eyes systems use an animated LED sign of eyes scanning laterally to remind pedestrians to scan the roadway (www.bayareatrafficsignals.com).

Scanning eyes systems have been shown to reduce pedestrians failing to see vehicles by 22-29% and reducing pedestrian-vehicle conflicts be 59-94% in various studies in the US (Ragland, et al., 2003).

4.1.5.8 Smart lighting

Smart lighting systems detect pedestrians in a crossing area and increase the lighting intensity. This serves to increase the visibility of the pedestrian and increase alertness in the road users. Also, there are economic benefits from the reduced luminance when the crosswalk is not in use, and pedestrians may feel safer at night (Ragland, et al., 2003).

No reported evidence of effectiveness or disbenefits found as yet.

4.1.5.9 Wheelchair Detection

Pedestrians in wheel chairs may be detected in a number of ways. This may be with automatic mechanisms including video detection or in-pavement wheelchair loops, or additional manual pushbuttons. The signal timing may also be adapted to accommodate pedestrians in wheelchairs.

No reported evidence of effectiveness or disbenefits found as yet.

4.1.6 Speed Feedback Indicators

Description

Speed feedback indicators are self-contained roadside units that serve to remind road users of the speed limit. The system monitors the speed of passing vehicles via laser or radar detectors. The actual speed of the vehicle is displayed on a variable message sign next to the actual speed limit. For example, a typical speed feedback indicator may read: “Your speed 65. Speed limit 60”.

These systems may also be used to monitor traffic headways. The speed and distance of the following vehicle relative to the lead vehicle is determined with laser sensors, and present either feedback or recommendations regarding the following distance. This may be either speed or distance information, or both.

Crash relevance

Crashes where speed is a contributing factor.

Effectiveness

As of 2003, speed feedback indicators had been shown to be effective in reducing speeding around schools in the US; however no information regarding crash reductions was available at that point (Ragland, et al., 2003).

Elvik (1997, cited in OCED, 2003) estimated that speed feedback systems may result in 65% reductions in pedestrian crashes, 41% of injury crashes, 16% of rear-end crashes, while Elvik, et al. also reported that a headway feedback system was found to reduce crashes by 6%.

Disbenefits

According to the FHWA (2000), speed feedback indicators are associated with high implementation costs.

4.1.7 Traffic Control Systems

Descriptions

These systems aim to 'harmonise' the flow of traffic, thereby reducing congestion. Traffic control systems may be introduced on urban networks and freeways. Traffic control systems involve the continuous monitoring and management of the transport network. Various systems and strategies are involved in the gathering of this information and control the flow of traffic, such as CCTV, inductive loop detectors, and probe vehicles. This may be localised to specific area or intersection, or applied across an entire network.

Crash relevance

Rear-end crashes; multiple vehicle crashes at intersections; side-swipe crashes.

Overall Effectiveness

Estimations of the approximate reductions expected with dynamic traffic management in Germany were reported by eSafety Forum (2005). It was expected that 20% of motorway crashes would be affected for roadways equipped with these systems, leading to a 0.7% reduction in these crashes equating to a 0.17% reduction in all crashes.

Lind, et al. (2003) estimated that flow control systems, i.e., ramp metering, lane control, route diversion, have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is less than 0.5%.

Regan, et al. (2001) suggested urban and motorway management systems have the potential to reduce fatal and serious injury crashes by at least 10%. Traffic management strategies have been shown to reduce crashes occurring in peak times by up to 35% (Jernigan, 1998).

Lind (1998) estimated the long-term potential effects of various emerging ITS technologies in reducing crashes, using expert assessment of various areas of potential safety impact. 'Flow control' systems were expected to reduce crashes by 20% at full implementation.

Turner, et al. (1998) reported 15-16% crash reductions with an integrated traffic control systems in the US, which resulted in a $4.3 million economic benefit.

Rumar, et al. (1997) suggested that full implementation traffic control systems have the potential to reduce injury crashes by 30% in urban areas.

Overall Disbenefits

Systems which alter the flow of traffic, particularly route diversion systems and congestion tolling, may actually increase the risk exposure of road users (Archer, 2000; Kulmala, 1997; eSafety Forum, 2005; Lind, et al., 2003). Also, the costs associated with the implementation and maintenance of these systems may be considered a limitation (FHWA, 2000).

Descriptions and Evaluations of System Types

4.1.7.1 Automated Tolling; Electronic Toll Collection

Automated tolling allows an immediate transaction between a toll collection point and a tolling agency. The tolling agency provides road users with on-board technologies that allow recognition of the vehicle as it passes through the tolling point. Automated tolling may involve a number of technologies, including smart cards, dedicated short-range communication and licence plate recognition. Automated tolling is expected to reduce safety by reducing congestion and stopping around toll booths (eSafety Forum, 2005).

With the exception of licence plate recognition, automated tolling strategies have been regarded as successful within the USA (FHWA, 2000). Traffic capacity has been increased by 200-300% with these systems (FHWA, 1998), and while improvements in mobility, capacity and emissions have been observed (Maccubbin, et al., 2005; Loukakos, 2003).

The introduction of an automatic tolling system that involve both manual and automatic tolling lanes in the US was associated with a 53% increase in crashes due to road user confusion over the new types of lanes (Mohamed, Abdel-Aty & Klodzinski, 2001).

Lind (1998) estimated the long-term potential effects of various emerging ITS technologies in reducing crashes, using expert assessment of various areas of potential safety impact. It was estimated that at with 100% implementation of automatic debiting systems crash reductions of 5% were expected.

4.1.7.2 Congestion Tolling

Congestion tolling is a traffic management strategy that automatically tolls motorists for using certain roadways during certain times. It is a means of discouraging road users from making journeys on congested roadways during peak travel times. Another strategy involves both tolled and non-tolled lanes on the same roadway, where users are able to choose to not pay (i.e., drive in the congested lane/s), not pay and carpool, or pay to drive in the non-congested toll lane. Congestion tolling may be carried out in the same way as automated tolling, however, its purpose is unique.

Smith (2003) suggested that the effects of congestion tolling are hard to distinguish, as while fewer crashes may occur in less congested traffic, those crashes that do occur tend to be more severe.

Lind, et al. (2003) suggest that congestion tolling, as a demand management strategy, has the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 1%.

4.1.7.3 Dynamic Lane Control

Dynamic lane control involves altering the direction of traffic flow of one or more lanes on a multiple-lane roadway. The direction of traffic flow is typically controlled by over-head signals. The direction of the lane is determined by traffic demand.

Lane control, in conjunction with other traffic management strategies, was associated with a 23% reduction in crashes in the Amsterdam (Maccubbin, et al., 2005).

Several authors have suggested lane control strategies show little effect on reducing injury crashes (e.g., Kulmala, 1997; Rumar, et al., 1999).

4.1.7.4 Probe Vehicle; Floating Car;

Also: Extended Environmental Information

Probe vehicles are instrumented vehicles that monitor the characteristics of traffic flow and the road environment while travelling within the road network. The vehicles monitor factors such as congestion, speed, weather, road surface friction and air quality. Information from the speedometer, temperature sensors, windscreen wipers, navigation systems and so on continuously gather information from the road environment. This information is transmitted via GPS to road management centres to provide real-time updates of driving and weather conditions. This information can be supplied to road information networks and maintenance services.

Estimations of the approximate reductions expected with extended environmental information gathering techniques in Germany were reported by eSafety Forum (2005). It was expected that 25% of injury crashes in slippery conditions would be affected, leading to a 12.5% reduction in these crashes equating to a 0.7% reduction in all crashes.

The FHWA (2000) stated that "the jury is still out" as to whether these systems are effective, with limited deployment throughout the USA. A pilot study in the UK found a fleet of probe vehicles to be an effective measure of road network performance (Ilgaz, Gates & James, et al., 2002).

4.1.7.5 Ramp Control/Ramp Metering

Ramp control systems regulate the flow of traffic at freeway on-ramps. Depending on the level of congestion, ramp metering limits the number of vehicles simultaneously entering the freeway using signal controls. This is achieved with either a very brief green signal or a sign denoting the number of vehicle permitted to proceed at each signal interval. Ramp control systems involve continuous monitoring of the traffic flow of both the freeway and on-ramps. Vehicles are only permitted to enter the freeway if there is no traffic blocking the merging area of the on-ramp.

Maccubbin, et al. (2005) reported that ramp metering has resulted in significant positive impacts on mobility, capacity, environment effects and safety on US freeways, with crash reductions ranging between 24-50% at various sites.

Pearson, Black and Wanat (2001) reported that ramp metering has been shown by various evaluative studies in the US to increase vehicle speeds on freeways by up to 60% by eliminating congestion, with crash reductions of up to 50%. A single study in Michigan reported a 71% reduction in injury crashes associated with ramp metering as part of a wider traffic management strategy. A Minnesota ramp metering system resulted in 1041 crashes being avoided, resulting in an economic benefit of over $18 million US.

PIARC (2000, cited in OECD, 2003) reported a benefit-cost ratio of 3.6 for ramp monitoring systems.

This strategy has been shown reduce crashes on highways by up to 10%, and up to 15% when integrated with other traffic control systems (Kulmala, 1997). Ramp metering has been successfully deployed in some regions of the USA (FHWA, 2000). McKeever (1998) suggested that ramp metering systems may reduce crashes fatal crashes on urban freeways in the USA by 24%.

Various studies have reported reductions in crashes as high as 15% with ramp control as part of a wider traffic control system (Rumar, et al., 1999).

The FHWA (1998) reported that ramp metering (as the major component of a wider freeway management system) has been associated with 24-50% reductions in crashes, while traffic speeds have increased 13-48% and capacity increased 8-22%.

Crash reductions of up to 62% have been reported with ramp metering the in US, with both rear-end and side-swipe crashes effected by these systems (Jernigan, 1998).

McKeever (1998) estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that a 2.3% reduction in fatalities and a 2.8% reduction in injuries could be expected with ramp metering.

Ramp metering in isolation is purported to reduce crashes by up to 10%, and up to 15% when part of an integrated traffic management system (Rumar, et al., 1999).

Ramp metering as an isolated traffic management strategy has been associated with crash reductions ranging 5-50%, and injury reductions of up to 71%, as well as resulting in significant reductions in delay, travel time, and increases in capacity (Turner, et al., 1998).

Various evaluations of the effects of ramp metering in the US have shown significant crash reduction rates, ranging between 15-50% (Apogee/Hagler Bailly, 1998). Other integrated traffic management and incident management systems have been associated with a 35% reduction in all crashes, a 15% reduction in injury crashes, and a 30% reduction in secondary crashes.

However, it has been suggested that ramp metering may only have significant safety effects on high-congestion roads (eSafety Forum, 2005).

4.1.7.6 Route Diversion

Route diversion strategies serve to encourage road users to find alternative, less congested routes. These may be mandatory, i.e., when the road is blocked due to a crash, or recommendations to road users. This information is presented via VMS or other ATIS, typically informing road users of the level of congestion and expected delays.

According to Kulmala (1997), this strategy is only effective when the alternative route reduces the exposure to crashes. Wendelboe (2003) found that drivers typically only diverted to a less congested route when the discrepancy in the estimated travel times between routes was high. Even when large differences were displayed, drivers only tended to divert 12-14% of the time.

Route diversion during congestion was associated with a 3.8% increase in vehicle diversion and an average time saving of around 10 minutes for road users. This time saving increased to up to 38 minutes during incidents (Abe, Shimizu & Daito, 1998).

4.1.7.7 Signal Control

Signal control systems are part of a wider integrated traffic management scheme. Adaptive traffic control systems allow for the modification of signal patterns and timing to improve the flow of traffic and reduce congestion. These systems depend on real-time traffic flow information, and may be integrated with other networks, such as public transport or weather management systems. Fixed signal control systems use patterns of traffic flow collected over time to coordinate traffic signal patterns. In these systems, signal timing cannot be modified to suit current traffic flow.

Signal control may effect the signal phases, signal length, coordination with other nearby traffic signals. Signal control may be limited to a single intersection, multiple signals on the same road, or an entire road network. Signal patterns may be coordinated in a number of ways (Pearson, 2001):

- **Pre-timed:** This involves the use of fixed, pre-set signal patterns. This pattern is based on historical traffic flow data.

- **Progressive:** Coordination of multiple signals that may be synchronised to show simultaneous or alternating signals, or coordinated to allow for varying distances between signals. Flexible patterns are changed to suit different traffic flows at various times of day.

- **Actuated:** Signals are triggered by vehicle demand. May be fully actuated or semi-actuated (actuated on the minor road only). The presence of vehicles is detected with inductive loop detectors or similar sensor technologies.

- **Traffic Responsive:** Signal patterns are modified to suit traffic conditions. These may be in response to detectors in the road network, predictive analysis of current traffic conditions, and pattern matching of previous traffic conditions.

- **Adaptive Control:** Use traffic sensors to detect traffic flow and demand, and creates a unique traffic control pattern to suit current conditions.

Maccubbin, et al. (2005) reported positive improvements in mobility, capacity and environmental benefits in the US with adaptive signal control. Signal synchronisation was associated with positive impacts on safety, with a 6.7% reduction in crashes in one location, attributed to fewer stops and increased speed.

Lind, et al. (2003) estimated that signal control systems, including emergency vehicle priority, have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 0.7%.

Pearson (2001) reported a 12% reduction in rear-end crashes with a traffic signal control system outside a major sporting arena, while another study showed a 89% reduction in all crashes and a 100% decrease in serious injury crashes at dangerous intersections.

Birst and Smadi (2000) simulated the combined effects of VMS and adaptive signal control, and found that an 18% reduction in travel time and 21% increase in average speed could be expected in a moderately sized freeway. The FHWA (1998) reported 8-25% improvements in travel time with signal control and traffic surveillance techniques.

In addition to traffic demand, traffic signals can be modified to suit weather conditions. During adverse weather (e.g., snow, storms), traffic tends to travel at slower speeds and have longer starting times (Maki, 1999). However, Maki found that road conditions were not consistently linked to weather conditions, making weather-related signal control systems difficult to create.

Lind (1998) estimated the long-term potential effects of various emerging ITS technologies in reducing crashes, using expert assessment of various areas of potential safety impact. It was estimated that at 100% implementation of intersection control systems, there would be an 8% increase in crashes. Why this was expected was not discussed.

Turner, et al. (1998) reported significant reductions in travel times, delays, fuel consumption, and up to 100% reductions in serious injuries at one site.

Signal control has been associated with an average decrease in injury crashes by 15% at t-intersections and 30% at x-intersections (Elvik, et al., 1997, cited in Rumar, et al., 1999).

Automated control of 719 signalised intersections in Japan resulted in a 75% reduction in crashes over a 5-year period (Saito, Yasui & Matsumoto, 1997, cited in McCormack & Legg, 2000).

While signal control systems have been shown to be effective at reducing crossing and turning collisions, they are often associated with an increase in rear-end crashes (Rumar, et al., 1997).

4.1.7.8 Traffic Monitoring

Traffic monitoring employs the use of infrastructure based sensors (i.e., loop detectors, CCTV) to monitor traffic speed, capacity and demand, as well as environmental information. These systems can be combined with floating car data and are used to inform traffic management centres, determine signal and ramp metering control patterns, and guide infrastructure planning.

Vehicle detection systems have been widely deployed in the USA with mixed degrees of success, depending on the type of technology used (FHWA, 2000).

No reported evidence of effectiveness or disbenefits found as yet.

4.1.7.9 Tunnel/Bridge Management

Traffic management systems can be applied to specific road segments where a crash may highly hazardous, such as a bridge or tunnel. These systems may incorporate additional speed warning signs, closed-circuit camera monitoring, fire alarms, emergency telephones, air quality monitoring and incident management systems linked to a monitoring centre (ERTICO, 2002). These systems allow traffic management centres to maintain a steady flow of traffic, safe speeds and quickly respond to and clear crashes.

No reported evidence of effectiveness or disbenefits found as yet.

4.1.8 Variable Message Signs

Description

Variable message signs can be used to convey a variety of information to road users, such as traffic congestion, road geometry warnings, estimated travel times, crashes ahead, upcoming construction work, weather conditions, and to vary the speed limit appropriate to these conditions. Other information, such as advertisements of local events, may also be displayed. VMS are used to present information to all road users. The sign may be a fixed or portable structure in the road environment that is linked to a traffic management network.

Variable message signs are often components of other infrastructure-based or cooperative ITS, such as variable speed limits, speed feedback indicators, incident management, route diversion systems and weather information systems. VMS may also be used with advanced traffic information systems, where road users are advised to listen to a specific radio channel for more information.

Bohren and Williams (1997) describe the use of VMS to display feedback to drivers about the state of their vehicle. The system involved infrared remote sensor that analysed the exhaust pipe emissions of vehicles. Road users are presented with a real-time analysis of their vehicles carbon monoxide level and provided feedback as to whether this was 'poor', 'fair', or 'good'.

Crash relevance

Crashes where speed, weather, poor visibility; poor road surface are factors.

Effectiveness

Other studies (OECD, 2003) estimated the crash reductions resulting from VMS to be 28% for injury related crashes in the UK, 35% for all crash types in Switzerland, and 10-30% for property damage and injury crashes in Germany (for an unusual condition VMS system only).

The use of VMS to convey information to motorists approaching a construction zone resulted in a 33% reduction in fatal crashes and a 7% reduction in rear-end crashes (Bushman, et al., 2003).

Lind, et al. (2003) estimated VMS have the potential to affect 30% of fatalities attributed to poor road surface in Sweden, and predicted that by the year 2015, these systems would reduce these fatalities by 21%.

Variable message signs that displayed slippery road condition symbols and recommended headways during adverse weather conditions were associated with an overall speed reduction of 1-2 km/h and a reduction in short headways between vehicles (Rämä, 2001). The systems showed greatest benefits under conditions when the poor weather conditions were more difficult to detect.

Dumke and Doyle (2001) found the use of VMS to alert road users of congestion and changed traffic conditions during incident management reduced the average incident clearance times by 20 minutes.

Significant reductions in vehicle delays, as well as small reductions in crashes when integrated into an incident management system were reported by Maccubbin, et al. (2005).

VMS have been deployed in some regions of the USA with varying degrees of success, due to variability in the operational quality of the technology (FHWA, 2000).

VMS that display speed regulation information have been estimated to reduce pedestrian crashes by 65%, injury crashes by 41% and rear-end injury crashes by 16% (Elvik, et al., 1997, cited in OECD, 2003).

Disbenefits

The FHWA (2000) regards the cost associated with VMS to be a limiting factor of this technology. Orrick (2003) noted that it is difficult to determine the exact effectiveness of VMS, as they are typically used in conjunction with a variety of other ITS. Orrick suggests the effects of VMS on an entire road network may be too small to distinguish.

4.1.9 Variable Speed Limits

Description

Variable speed limits alter the posted speed limit for a given area to suit changed traffic or weather conditions. The appropriate speed limit is presented on variable message signs on the roadside, typically using an illuminated LED sign to make the altered speed limit more noticeable. The method for determining the changed speed limit varies between systems. It may be manually set, where traffic management centres determine the speed limit based on an evaluation of the current traffic or road conditions, or the system may be automatically programmed to alter the speed limit under specific conditions, e.g., school start and finish times.

These are often weather related systems, controlled by weather stations, weather forecasts, cameras in the road environment and road maintenance personnel observations (Rämä & Schirokoff, 2004). Hazardous weather situations that affect the visibility and traction of the road environment, e.g., fog, rain, snow, ice, lead to reductions in the posted speed limit. A symbol or message denoting the hazardous conditions may also be displayed. During conditions when the speed limit has not been altered, the VMS can be used to display road and air temperatures. Variable speed limits may also be employed in construction zones, and may be combined with infrastructure-based ISA systems so that the altered speed limit is automatically communicated to the vehicle (Kulmala, 1997).

Crash relevance

Crashes where speed is a contributing factor.

Effectiveness

In England, reductions of 25-30% in rear-end collisions on approaches to freeways, and have increase freeway capacity by up 5-10% have been observed (Maccubbin, et al., 2005).

Rämä and Schirokoff (2004) found that weather-related variable speed limits to be effective at reducing injury risk by 13% in winter and 2% in summer.

Wendelboe (2003) found the use of variable speed limits in a construction zone resulted an average speed reduction of less than 5 km/h and that traffic speeds was only more homogenous in heavy congestion.

Hautala and Nygård (2003) found significant reductions in headways during poor road conditions with variable speed limits.

Lind, et al. (2003) estimated that variable speed limits have the potential to affect 5% of speed related fatalities in Sweden, and predicted that by the year 2015, these systems would reduce speed related fatalities by 4%.

Variable speed limits linked to weather management systems have been shown to reduce injury crashes by 10-20% (Rämä, 2001; eSafety Forum, 2005).

Testing of variable speed limits in the USA has been regarded as promising by the FHWA (2000).

Rumar, et al. (1999) suggested variable speed limits may lead to reductions in injury crashes on rural roads by more than 10%.

Elvik, Mysen and Vaa (1997, cited in eSafety Forum, 2005) reported 20% reductions in crashes with variable speed limits applied near schools.

Kulmala (1997) cited evidence of crash reductions between 10-20% and average speed reductions of 3-10 km/ph for variable speed limits associated with weather warnings in Europe.

The use of a weather-related variable speed limit system estimated that the lowered speeds in poor driving conditions would result in a crash reduction of 8-25% (Pilla-Sihvola & Jukka, 1995).

Disbenefits

No reported evidence of disbenefits found as yet.

4.1.10 Weather Information and Maintenance Systems

Description

Weather information systems may involve a number of sensors that transmit information to a traffic management centre. These may include temperature, humidity, wind speed and rain gauges, floating car data, and video monitoring (CCTV) of visibility conditions. The road environment is continuously monitored for the early detection of rain, snow, ice and poor visibility (fog, dust/sand storms). Weather systems can be infrastructure-based, where information is communicated to the user via signs on the roadside, or cooperative, where weather detection beacons transmit information to on-board units in the road user's vehicle. Most commonly, these systems are only linked to VMS. Additionally, when weather management systems are linked to variable speed limit signs, the changes in speed limit can also be automatically sent to road authorities and police so that the lower speed limit is correctly enforced (Goodwin, 2003).

Such systems may provide either weather-related information to road users, or indicate to road maintenance authorities the need for appropriate winter maintenance (Kulmala, 1997). Early detection of changed weather conditions allows weather maintenance teams to apply preventative measures, e.g., salt to prevent roads icing over, rather than reactionary strategies (Todori, et al., 2004).

Goodwin (2003) suggests there are three types of weather management strategies and systems. Advisory systems inform road users and management centres of predicted or current weather conditions. Control systems alter the speed, flow or capacity of the roadway, or involve diversion of traffic. Treatment systems involve the coordination of resources (i.e., maintenance personnel, police, emergency services) in order to mitigate the effects of adverse weather on transport systems.

Some specific applications of weather management systems are described below. These strategies may be applied in isolation or as part of a coordinated traffic or weather management strategy.

4.1.10.1 Access Control

These systems restrict the use of freeways during extreme adverse weather conditions, such as heavy snowfalls or natural disasters (tornados, etc.), until the roadway is cleared. Access to freeway on-ramps is prevented via gate arms, and traffic is diverted to other roadways. The decision employ access control may depend on snow depth, visibility, weather severity, road condition, traffic demand, seasonal/daily travel patterns.

4.1.10.2 Anti-icing Systems

Anti-icing systems involve the application of anti-icing chemicals to roadways either pre-emptively or as soon as ice is detected on the roadway. Pre-emptive systems gather weather forecasts information from various sources (i.e., weather bureau, internet), while reactive systems involve temperature sensors on the roadway which indicate the presence of ice. Anti-icing agents are then applied to the road surface either via special vehicles or infrastructure-based sprayers.

4.1.10.3 Flood Warning Systems

These involve water level sensors, rain gauges, flood basin detectors, video monitoring and tide monitors (for coastal areas) to provide advanced warning of rising water levels to emergency management centres and activation of flood warning signs (Goodwin, 2003). These systems eliminate the need for manual inspections of waterways and drain systems, and allows emergency information to be made available to the public sooner.

4.1.10.4 Low Visibility Warning Systems

These systems employ video cameras at regular intervals along the roadside. When visibility drops below a certain threshold, variable messages signs and/or variable speed limit signs are activated. Different levels of warnings may be used, depending on the visibility level and other weather conditions. Instructions for headlight use and to keep trucks in a single lane, for example, may also be presented to motorists (Goodwin, 2003). The posted warnings and/or speed limit may be determined by the average speed of traffic, the level of visibility or wind speed. These sensors may also be linked to roadside lamps that provide additional delineation of the roadway.

4.1.10.5 Maintenance Vehicle Management Systems

These employ fleet management systems such as AVL and CAD to monitor and distribute the operations of weather maintenance vehicles (i.e., snowploughs, anti-icing trucks). In addition to navigation, AVL systems, and communication systems, the vehicles are also equipped with sensors that monitor the current operations of the vehicle. This allows management centres to continuously monitor which areas are or have been ploughed or applied with anti-icing agents, and at what rate (Goodwin, 2003).

4.1.10.6 Precipitation/Wind Warnings

These systems employ rain gauge, wind speed, and sometimes visibility detectors to detect potentially dangerous road conditions. When wind speed exceeds a certain threshold, or rain reduces traction or visibility, warnings are presented to road users via radio, VMS, or other ATIS systems. These may also be linked to variable speed limits or traffic management strategies (i.e. signal control, route diversion, lane control). Certain vehicles may be prohibited from using the roadway during extreme conditions.

4.1.10.7 Wet Condition Warning Systems

These systems may be useful in sites where crashes frequently occur when the pavement is wet, but not necessarily when it is raining. In-pavement sensors detect water on the road surface, and activate a VMS presenting an advised or mandatory speed limit. These systems have been effective in reducing maximum speeds, speed variability and crashes (Goodwin, 2003).

4.1.10.8 Weather-related Signal Timing

Adaptive signal control linked to weather management systems allow the rapid clearance of traffic from specific areas during poor weather. For example, in Florida, rain gauges and vehicle sensors have been linked to signal timing on the major roads leaving a popular beach (Goodwin, 2003). To accommodate the large numbers of traffic leaving the area when rainfall and large queues of vehicles are detected, the signal patterns are modified to minimise congestion and clear roads leaving the beaches more quickly.

Alternatively, signal timing may be used to reduce vehicle speeds during severe weather, where signal phases are increased in duration to slow the progression of traffic. With this strategy, vehicles are stopped at regular intervals, preventing them from reaching high speeds.

Crash relevance

Crashes where weather, poor visibility and poor road surface are factors.

Overall Effectiveness

The implementation of an automatic anti-icing system on a bridge in the US was associated with a 68% reduction in crashes compared to other winters of comparable weather conditions (Goodwin, 2003), while a pre-emptive anti-icing system in the US has been associated with an 83% reduction in crashes in winter, as well as improvements in maintenance efficiency. Goodwin also reported that multiple applications of low visibility warning devices in the US have been associated with reductions in fog-related crashes, speed variability and maximum speed.

Rämä, et al. (2003) estimated that injury crashes could be reduced by 8% on main roads an 5% of rural roads if drivers were provided with pre and during travel information regarding icy road conditions.

Pardillo (2003) concluded that the benefits of advanced weather warning systems (fog warnings) outweigh the costs of implementation, and a 43.8% reduction in injury crashes could be expected with their implementation.

A VMS system that incorporated fog warnings and advisory speeds was evaluated in the US (Perrin & Coleman, 2003). The system resulted in more uniform speeds during poor visibility conditions, fewer 'excessively slow' vehicles. No crash reduction data was available from this study.

The use of weather monitoring systems on a US highway enabled the application of preventative icing treatments to road surfaces resulted in an 83% reduction in crashes, as well as significant reductions in labour and quantities abrasive materials used (Breen, 2001).

Stowe (2001) estimated a benefit-cost ratio of 2.36, an 80% reduction in snow and ice related crashes with the introduction of an automated anti-icing system in the US.

A weather monitoring VMS system was estimated to reduce crashes by 30-40% in various European countries (PIARC, 2000, cited in OECD, 2003). Fatalities and injuries were conservatively estimated to reduce by 1.1% and 2.0% respectively.

The USDOT (1999) implemented a fog detection and warning system in December 1990. The system incorporated a VMS that alerted road users to the fog and slower traffic speeds, and a variable speed limit during foggy conditions. Following the introduction of this system, no fog-related crashes have been reported, compared with the 200 crashes that occurred between 1973 and 1990.

McKeever (1998) estimated crashes occurring in inclement weather (e.g., snowy or icy) could be reduced by 40%, and up to 85% in foggy conditions (for VMS systems linked to visibility sensors). McKeever also estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that a 0.9% reduction in fatalities and a 0.2% reduction in injuries could be expected with fog monitoring systems, and that a 1.1% reduction in fatalities and a 0.9% reduction in injuries could be expected with snow and ice monitoring systems.

Improved efficiency in de-icing activities as a result of weather monitoring systems could result in a 3-17% decrease in crashes, depending on location and weather severity (Pilli-Sihvola, Toivonen, & Kantonen, 1993). A cost-benefit ratio of 1:5 was estimated for this system.

Overall Disbenefits

No reported evidence of disbenefits found as yet.

4.2 Passive Systems

4.2.1 *Incident Management Systems*

Description

Incident management systems involve the continuous monitoring of road and traffic conditions in order to facilitate the rapid detection and clearance of crashes. The four main activities of incident management are detection, response, management and recovery (COMSIS, 1996). The technologies employed by incident management systems may differ, however all typically involve various roadside sensors, a processing centre, road user information displays, traffic management and incident clearance strategies (ERTICO, 2002; Kulmala, 1997; Archer, 2000).

For example, an incident management system may continuously monitor traffic flow with CCTV and floating car data. When an incident is detected, emergency services and clearance teams are deployed to the site, while other road users are informed of possible delays and hazards ahead via VMS and radio or cellular information services. To reduce delays and congestion, route diversion, adaptive signal timing and dynamic lane control systems may also be employed.

Incident management systems may only have a relatively small ITS component that may be limited to the one aspect of incident management, such as the detection phase, for example. Therefore evaluations of their effectiveness are also largely evaluations of the effectiveness of the management process (Turner, et al., 1998). The goal of incident management is faster emergency service response times to crashes, reduction of delays, avoidance of secondary crashes, and reduced exhaust emissions from congested traffic.

Crash relevance

Secondary crashes. This strategy will also show benefits in the reduction of emergency service response times.

Effectiveness

Maccubbin, et al. (2005) found incident management systems to have shown positive impacts on mobility, productivity, environmental outputs and safety across various implementations in the US, including a 2.8% reduction in crashes.

Incident management systems are typically associated with reductions in incidents, particularly reductions in secondary crashes (eSafety Forum, 2005). It was also noted that many studies which report high crash reductions (i.e., up to 45%) may be statistically biased.

Lind, et al. (2003) estimated that incident management systems have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 3%.

Regan, et al. (2001) suggested incident management systems have the potential to reduce fatal and serious injury crashes by at least 10%.

PIARC (2000, cited in OECD, 2003) reported a benefit-cost ratio of 1.7-3.8 for incident detection technologies.

Numerous incident management ITS have been introduced throughout the USA, including automated incident detection algorithms, CCTV, cellular geolocation and motorist call boxes to varying degrees of success (FHWA, 2000). Systems which have been most successful include service patrols, common communication frequencies, motorist call boxes and CCTV.

Incident management systems have the potential to reduce injury and fatal crashes by more than 10-15% (Rumar, et al., 1999).

McKeever (1998) estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that a 1.7% reduction in fatalities and a 2.1% reduction in injuries could be expected with incident detection systems.

Lind (1998) estimated the long-term potential effects of various emerging ITS technologies in reducing crashes, using expert assessment of various areas of potential safety impact. It was estimated that at 20% implementation, there would be a 6% reduction in crashes. With 100% implementation, this was expected to be 28%.

Incident management systems in the US have been associated with up to 50% reductions in incident response times, 74% reductions in incident verification times, 66% reductions in total clearance times, and up to 65% reductions in vehicle delays (Turner, et al., 1998). Benefit-cost ratios were also reported to be 5:1 for some variants of these incident management systems.

Pearce and Subramaniam (1998) noted injury crash reductions of 15% associated within an incident response system, which was projected to reach up to 21%.

Systems which permit early detection and warning of incidents were estimated by McKeever (1998) to reduce crashes by 18% on urban freeways the USA.

Lind (1997, cited in Kulmala, 1997) reported that the incident management systems have been estimated to reduce crashes by 28%, although this benefit largely comes from a reduction in secondary crashes. Conversely, according to Archer (2000), the greatest safety benefits of these ITS can be seen in the reduction of severity of injuries and the prevention of crashes, resulting from more rapid emergency service responses.

An US combined traffic and incident management system has been highly effective since is inception in 1993 (Taylor, 1997). Upon detection of a crash, traffic is diverted. This has lead to 40% reduction in incidents and an 8% reduction in incident severity.

Taylor (1997) reported that the use of route diversion in an incident management system in the US has resulted in a 40% decrease in crashes and an 8% decrease in injury severity (as a result of emergency services being able to respond more quickly).

Disbenefits

A common limitation to incident management systems is the cost of implementation and maintenance (FHWA, 2000).

The use of incident management strategies (road user information, route diversion and so on) for minor and moderate incidents can actually decrease the efficiency of the road network (Science Applications International Corporation Systems, 2000). However, optimal use of the system resulted in a reduction in incidents of up to 4.4%, delay reductions of up to 20%. It was also concluded that the effects of the combination of incident management techniques (VMS, signal control, etc.) was far greater than the effects of any of these systems in isolation.

4.3 Combined active and passive systems

No infrastructure-based CAPS systems have yet been identified.

5 Co-operative systems

5.1 Active Systems

5.1.1 Advanced Traveller Information Systems

Also: *In-vehicle Information Systems (IVIS)*

Description

Advanced traveller information systems (ATIS) are a class of ITS that provide detailed and up to the minute travel information to road users. ATIS is a broad term for a number of pre-trip and en-route information systems that may be infrastructure-based or in-vehicle. While there are some variations in the type and manner of information provided by different ATIS, there is general overlap in their functional properties. An ATIS system typically provides users information about routes, landmarks, congestion, delays, weather, construction zones and expected travel times. In-vehicle signage systems present information that is presented on infrastructure-based signs (speed limits, route information, etc.) on an in-vehicle display. This information is gathered from various data collection points (video cameras, loop detectors, probe vehicles, etc.) and is collated by a traffic management centre. This information is then provided to users through personal communication devices, infrastructure-based data terminals and in-vehicle devices.

Examples of ATIS are:

- **Kiosks:** Fixed data terminals in public locations.
- **PDA's:** Travel information can be broadcast to personal handheld devices.
- **Digital watches:** Limited travel information, e.g., expected delays, can be broadcast to digital watches linked to an ATIS network.
- **Internet:** A wide variety of travel information can be accessed through the internet.
- **In-vehicle devices:** Navigation systems provide addition travel information as well as location via on-board displays. These are referred to as IVIS.
- **Phone:** Free or pay-per-use phone services.
- **Mobile phone:** Users receive a broadcast of travel information services through a hands-free in-vehicle mobile phone unit.
- **Radio:** Dedicated radio channels can be used to continuously provide travel information for a whole region or specific road network/highway (e.g., Highway Advisory Radio systems).
- **Television:** Dedicated television channels.
- **VMS:** Roadside displays.

Crash relevance

While these systems may not show direct safety benefits, their potential to reduce driver workload and travel times is expected to enhance user safety by reducing overall crash exposure.

Effectiveness

Estimations of the approximate reductions expected with real-time information systems (assuming 70% penetration of the German passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 25% of rear-end injury crashes would be affected, leading to a 12.5% reduction in these crashes, equating to a 0.2% reduction in all crashes.

Lind, et al. (2003) estimated that travel planning systems have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 0.5%.

Lind (1998) estimated the long-term potential effects of various emerging ITS technologies in reducing crashes, using expert assessment of various areas of potential safety impact. It was estimated that at 10% implementation of trip planning ATIS, there would be no reduction in crashes, although with 100% implementation, this was expected to be 3%. Public transport information system were not expected to have any reduction effects, even at 100% implementation, while parking systems (that aid motorists in finding available parking spots) were expected to show 1% and 13% reductions in crashes with 5% and 100% implementation rates, respectively.

A simulation study of an in-vehicle ATIS suggested that these systems can reduce overall crash risk by 4%, while crash risk may be reduced by as much as 10% when the vehicle is diverted to another route (Jernigan, 1998).

Numerous reports have shown that ATIS systems are effective in reducing travel times, travel distances and vehicle emissions (Noonan & Shearer, 1998).

An in-vehicle ATIS that utilised a mobile phone network was associated with a 2% reduction in crashes (FHWA, 1996).

Disbenefits

No reported evidence of disbenefits found as yet.

5.1.2 *Advanced Warning Device*

Description

Advanced warning devices (AWD) serve to provide advanced warning to road users of the presence of emergency vehicles. The device detects the presence of an on-call emergence vehicle within a given radius, and provides auditory or visual alerts to the user. This can be seen as a simplified version of inter-vehicle communication systems. They serve to alert other drivers of the presence of the approaching emergency vehicle, but do not provide the speed and position information that inter-vehicle communication does, nor do they transmit information about other vehicles to the emergency vehicle. The system detects the siren and flashing lights of the emergency vehicle before they become visible and audible to the user. This serves to enhance the conspicuity of emergency vehicles, and allow more time for other road users to move out of the way.

A variant of this technology is motorcycle detection systems. Such systems address motorcycle conspicuity crashes, where the driver fails to perceive the motorcycle. Rather than relying on the auditory and visual warnings from the emergency vehicle, the presence of the motorcycle emits a radio or infrared signal from a transmitter mounted on the vehicle. This signal is detected via receivers on the front and rear of the other vehicles, and the driver is informed of the motorcycles presence through auditory and visual displays.

Crash relevance

Multiple-vehicle crashes at intersections; rear-end crashes. Crashes where conspicuity is a factor. This system will also show benefits in the reduction of emergency service response times.

Effectiveness

In a simulator evaluation of the effects of AWD found that the advanced warning device was associated with greater reductions in speed than the approaching emergency vehicle without the AWD (Lenné, et al., 2004). With the AWD, speeds were reduced much earlier than without the device. As soon as the warning was activated speed was reduced, while without the device, speeds remained constant until the emergency vehicle was in the immediate vicinity. Also, participants tended to change lanes earlier with the AWD to clear the path for the emergency vehicle.

Disbenefits

No reported evidence of disbenefits found as yet.

5.1.3 Electronic Clearance

Also: *Electronic Screening; Electronic Data Interchange*

Description

Electronic clearance systems and strategies facilitate more accurate and more efficient inspection of commercial vehicles and reduce congestion around safety inspection points. Automated screening procedures reduce, but do not eliminate, the need to stop commercial vehicles at safety inspection points and border crossings. Fixed and portable inspection points are still used, however, vehicles with electronic screening equipment are allowed to pass through without stopping provided they meet safety standards, while vehicles that do not have electronic screening capabilities or those that fail to meet safety standards are stopped. Vehicles that are correctly weighted, legally compliant and have good safety records are allowed to pass.

The criteria for stopping vehicles are determined by state authorities. The vehicle is usually equipped with a transponder that passes information regarding registration, cargo, destination, and so on, to the safety inspectors, while weigh-in-motion scales measure the vehicles weight. This information is analysed and transmitted back to the vehicle along with the necessary permits and certificate of inspection. Electronic license plates may also be involved in these screening systems. The information collected from electronic clearance can be used for both enforcement and to better plan and manage transport networks to suit commercial vehicle traffic flows.

There are four general categories of electronic screening/clearance. A safety inspection point will most commonly employ all or a number of these systems.

5.1.3.1 Credential Checking

Automated credential checking can be regarded as electronic permit approval and fee charging. Heavy vehicle credentials typically include registration, location of operations, insurance, weight/size limitations, driver licences, and state/region fuel taxes (Cutchin, 2005). Electronic credential systems are regulated by a state authority.

5.1.3.2 Border Clearance

This is essentially credential checking at national border crossings. Border crossing declarations are electronically submitted prior to crossing, and border inspection facilities are therefore able to conduct automated safety screening and credential checking, speeding up the processes of border inspections (Cutchin, 2005).

5.1.3.3 Safety Screening/Automated Vehicle Safety Inspections

Automated safety screening procedures involve the use of in-vehicle telematics that transmit vehicle and cargo information to safety inspection points. This may be information regarding hours of service, cargo type and quantity, previous safety inspections, and the status of various vehicle systems. Other technologies may also be used to screen vehicles at inspection points. For example, Christiaen and Shaffer (2000) described an infrared brake screening technology. An infrared image of the vehicles tyres is taken as they brake in their approach to the safety inspection point. If the vehicles wheels appear white, they are warm and the brakes are functioning normally. Dark (cold) wheels indicate inoperative brakes. This is then verified by manual inspection.

5.1.3.4 Weigh-in-motion

Weigh-in-motion provides a more efficient and objective means of ensuring commercial vehicles are within their weight limits. Weigh-in-motion allows vehicle weight to be determined without it stopping. The system measures the vehicle weight, axle weight and spacing, speed and vehicle height. Weigh-in-motion stations may be permanent, semi-permanent (when the sensor are fixed but the data collection system is portable) and portable. The system involves sensors in or across the road surface linked to a data collection point. The sensors may be bending bar plates, bar sensors, mat sensors or utilise existing bridge structures (ERTICO, 2002).

Crash relevance

Orban, et al. (2002) suggested commercial vehicle screening technologies will enhance safety in direct and indirect ways. Direct safety benefits will stem from the reduction of out of service vehicles on the roads, resulting from the increased enforcement of operating condition standards. Indirect benefits will be seen through more commercial vehicle operators improving their compliance with operating standards as a result of more strict enforcement standards.

Overall Effectiveness

Orban, et al. (2002) conducted a cost-benefit analysis of various implementation stages of electronic screening and credentialing strategies. These ratios ranges from 0.62 to 40.4 from the earliest to most advanced stages. Also, a localised 2% increase in out of service vehicles was observed with the use of combined electronic and manual inspections. If this effect was observed nation-wide in the US, Orban, et al. estimated that 84 commercial vehicle crashes would be avoided annually. If these effects also carried across indirectly, so that a 10% increase in compliance was achieved, 4332 fewer crashes would occur annually as a result of electronic screening.

The number of vehicles given Out-Of-Service orders increased by 32% with the implementation of infrared brake screening in four US states (Christiaen & Shaffer, 2000).

An estimated benefit-cost ratio of 7:1 for fleet management systems was reported by the FHWA (1998), largely due to labour cost savings. Automated credentialing was associated with an expected 4:1 ratio for medium fleets and 20:1 for large fleets. Automated safety screening increased the detection of unsafe commercial vehicles and drivers by 50%.

The benefits resulting from electronic clearance applications in the US were given by Turner, et al. (1998). Increases in operations efficiency, decreases in overweight loads, decreases in hazardous materials incidents, reduced operating costs for weigh stations, reduced tax evasion, and increases in the number of unsafe vehicles and drivers detected were reported. Benefit-cost ratios of up to 12:1 for governments were also reported.

Evanco (1997, cited in Lund, et al., 2003) suggested that widespread introduction of automated safety inspections could result in a reduction in commercial vehicle fatalities by up to 15%.

Electronic screening has been estimated to have cost-benefit ratios ranging between 3.3-6.5 for small commercial vehicle operators to 1.8-3.8 for large operators (Pritchard, 1996), and 4.8-12.1 ratios for state governments, depending on the level of implementation, where full implementation was associated with higher cost and therefore a lower ratio (Gillen & Haynes). It was also estimated that up to $8.6 million US could be saved in crash costs as a result of credentials checking.

Overall Disbenefits

No reported evidence of disbenefits found as yet.

5.1.4 *Fleet Management Systems*

Also: *Commercial Vehicle Operations (CVO)*

Description

Fleet management systems encompass a number of technologies specifically designed and implemented in commercial vehicles, including buses. These systems are designed to enhance the efficiency of commercial vehicle operations by tracking fleets, better route planning and monitoring of drivers, vehicles and cargo. The majority of these systems are cooperative, in that they involve communication between the vehicle and fleet management centre, or communication between multiple vehicles.

Other fleet management systems that have no foreseeable direct benefit to safety include automatic passenger counters, automatic annunciation systems, passenger information systems.

Crash relevance

While these systems may not show direct safety benefits, their potential to reduce driver workload and travel times is expected to enhance user safety by reducing overall crash exposure. These systems are relevant to any crashes involving commercial vehicles.

Overall Effectiveness

Fleet management systems in combination with electronic clearance has been estimated to reduce fatalities by 14-32% (FHWA, 1998), with an annual estimated benefit-cost ratio of 4:1 for medium fleets and 20:1 for larger fleets.

Lind, et al. (2003) estimated that freight and fleet management has the 'verified' potential (based on other studies) to reduce all road fatalities is less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is 0.7%. These benefits largely stem from the fact these systems result in shorter travel distances and durations.

Overall Disbenefits

No reported evidence of disbenefits found as yet.

Descriptions and Evaluations of System Variants

5.1.4.1 Automatic Vehicle Location; Computer Aided Dispatch

Automatic vehicle location (AVL) allows dispatchers to continuously monitor the location and activities of all vehicles in a fleet. This may involve a number of different technologies, such as GPS, roadside beacons (signposting) and dead-reckoning techniques. GPS based systems track the vehicle via satellite, allowing constant monitoring of the vehicles location. Roadside beacons are more typically used for public transport, where infrastructure-based sensors detect the proximity of a bus. The time, location and bus identification number is transmitted to the dispatcher, usually via fixed cable networks (Jones, 1995). Both these systems may be supplemented by dead-reckoning to provide additional location information when GPS is unavailable or between roadside beacons. Dead-reckoning estimates the position of the vehicle by measuring the direction and distance travelled from a known location. From this, it can be estimated when a vehicle has turned and how far they have travelled. AVL can be integrated with vehicle status monitoring systems, public transport information and signal pre-emption systems.

AVL systems may have passive safety benefits in reducing emergency response times by accurately locating vehicles in the event of a crash. Jones (1995) reported considerable reductions in emergency response times for several public transport networks in the US equipped with AVL attributable to the greater accuracy in locating the relevant vehicle. AVL systems been regarded as a success with widespread deployment in emergency vehicles and public transport systems in the US (FHWA, 2000). Various US public transport networks have found improvements in efficiency ranging between 7-28%, and small reductions in the number of vehicles required per fleet (Jones; USDOT, 2000; Maccubbin, et al., 2005).

5.1.4.2 Cargo Monitoring Systems

Cargo monitoring systems detect unsafe cargo movements and position, and alert the driver and fleet management to this hazard. These systems could reduce goods transport vehicle fatalities by up to 15% (Kulmala, 1997).

5.1.4.3 Digital Tachographs

Digital tachographs record vehicle and journey characteristics such as speed, distance, location, vehicle faults, time travelled and so on (ERTICO, 2002). These systems employ speedometer/odometer, an on-board recording unit, an intelligent senor connected to the transmission, smart card slots, and a printer. Digital tachographs must be tamper-resistant.

No reported evidence of effectiveness or disbenefits found as yet.

5.1.4.4 Electronic Towbar; Electronic Coupling

Electronic towbar systems allow the automation of a convey of commercial vehicles, so that only the lead vehicle requires manual control. The lead vehicle transmits information regarding all aspects of driving, e.g., acceleration, axle position, indicator use, to all subsequent vehicles via radio communications and infrared pattern detection (Bishop, 2005). This eliminates the disadvantages of a physical towbar, and reduces the number of drivers required per fleet (European Communities, 2000).

Electronic towbars have been estimated to reduce the number of injury and fatal crashes by 143-286 annually in Germany. European Communities (2000) also estimate a global economic benefit of €28.9 million.

According to Kulmala (1997) the safety-enhancing effects of towbar system depends on behavioural adaptation effects.

5.1.4.5 Hazardous Materials Systems/HAZMAT

These systems automatically inform emergency services the nature and quantity of hazardous materials that the vehicle is carrying. These are passive systems.

These systems have been estimated to save up to $85 million US in crash costs annually (FHWA, 1998).

5.1.4.6 Smart Cards

Smart cards are often incorporated into driver logging devices or tachographs. Smart cards allow driver identification and store vehicle and driver behaviour from in-vehicle recording devices.

Smart cards for public transport passengers are similar to personal debit or credit cards (Jones, 1995).

No reported evidence of effectiveness or disbenefits found as yet.

5.1.5 *Intelligent Speed Adaptation*

Also: *External Vehicle Speed Control; Intelligent speed control; Telematics Speed Control*

Description

ISA describes any system which either warns the driver or automatically limits the speed of the vehicle when it exceeds the legal speed limit of a given area. These systems establish the location of the vehicle and compare the current speed with what is the posted speed for that location. If the vehicle exceeds this speed, the system takes effect, either be in the form of a visual or auditory warning (informative system), or intervention (actively supporting systems). Actively supporting systems may provide haptic feedback to the driver through increased pressure or vibration in the accelerator pedal, but this can be overridden by the user.

In addition to these alerting systems, speed limiting systems also exist. These employ speed governors or retarders, which physically prevent the speed of the vehicle exceeding a predetermined limit, whether that is the speed limit or a manually set limit. These systems must be linked to some or all of the vehicles ignition, fuel, throttle or electrical systems. This limit can be set in one of two ways, for both alerting and limiting systems. The current speed limit may be communicated to the vehicle via roadside beacons or through GPS technology. GPS systems store a digital map on an on-board computer, and continuously determine the position of the vehicle in relation to this map with a GPS receiver.

Several types of ISA can be distinguished. This may be in terms of what level of intervention they take, or what type of speed limit is enforced by the system. In terms of intervention, ISA may be:

- **Advisory:** The system only alerts the user to the speed limit.
- **Voluntary/driver select:** The user can enable or disable the system.
- **Mandatory/limiting:** The speed limit cannot be overridden.

In terms of speed limit, ISA may be:

- **Fixed:** The posted speed limit is enforced by the system.
- **Variable:** The enforced speed may alter according to location, such as at pedestrian crossings, sharp curves, school zones.
- **Dynamic:** The enforced speed may alter according to current conditions, such as poor weather, construction work, traffic incidents.

The ISA system also varies in terms of how vehicle speed is controlled, though not for advisory systems (Carsten & Fowkes, 2000). This is often through haptic feedback (increasing resistance) in the accelerator pedal.

Crash relevance

Speed related crashes.

Carsten and Tate (2005) noted that almost all types of crashes, in all road conditions, may be reduced with ISA. Speed related crashes are considered to "comprise 20% of all single vehicle, head on, same direction, rear end, intersection and pedestrian crashes" (Regan, et al., 2002, p. 38).

Effectiveness

A trial of ISA in Australia found that an actively supporting system was effective in reducing both average and maximum speeds, and the amount of time spent driving in excess of the speed limit. It was estimated that ISA would reduce the incidence of serious injury crashes by up to 6% and fatal crashes by up to 8% in 60 km/h zones. They also estimated that ISA would have the greatest safety benefits in 60 km/h zones, and is most effective when combined with a following distance warning system (Regan, et al., 2005).

Speed alerting systems are expected to reduce injury crashes by around 10% and fatalities by around 18%. It has also been expected that weather-related ISA would reduce injury crashes by 12% in both slippery and dark conditions (eSafety Forum, 2005).

Various studies, as cited by Regan, et al. (2005), have found alerting systems to reduce average speeds by approximately 5 km/h, and additionally reduce speed variance and violations. These changes should correspondingly result in a reduction in the total number of crashes.

Carsten and Tate (2005) estimated that the best possible outcome of ISA would be a 37% reduction in fatalities and 20% reduction in injuries with a mandatory system in all vehicles. A mandatory system that was integrated with weather and traffic management systems, so that speeds were further limited in poor driving conditions (a dynamic system), would reduce fatalities and injuries by 59% and 36%, respectively. A cost-benefit analysis revealed expected benefits as high as 15.4.

Regan, Young and Haworth (2003) estimated the following annual cost savings for speed-related crashes in all vehicle types and heavy vehicles (but not buses). These calculations, presented in Table 5-1, were based on an assumed 80% effectiveness and 50% acceptability:

Crash severity	All vehicles ($m AU)	Heavy vehicles ($m AU)
Fatal	105.1	16.6
Serious injury	232.8	26.5
Injury	-52.5	3.2
Property damage only	19.9	3.2
Total	304.4	49.4

Table 5-1: Expected reductions in crash costs associated with ISA for various crash severities.

Regan and colleagues also suggested that ISA will show benefits in reduced insurance premiums, reduced fuel consumptions and emissions, and improve road network efficiency.

Lind, et al. (2003) estimated that ISA has the potential to affect 20% of speed related fatalities in Sweden, and predicted that by the year 2015, ISA would reduce speed related fatalities by 10%. The 'verified' potential of this system (based on other studies) to reduce all road fatalities is 7%, while the 'full' potential (an optimistic estimate based on full deployment) is 17%.

A Swedish on-road trial involving up to 5000 vehicles equipped with various ISA system types was conducted (Biding & Lind, 2002). Reductions in overall speed were observed, and the following total crash risk reductions for ISA equipped vehicles were calculated and are presented in Table 5-2:

Speed zone	Informative system	Actively supporting system
30 km/h	10%	20%
50 km/k	12%	11-22%
70 km/h	15%	24%
90 km/h	11%	-

Table 5-2: Observed reductions in crash risk for informing and actively supporting ISA systems in various speed zones.

* For various types of traffic conditions

When considering the enhanced safety of pedestrians with ISA systems (both active and informative), an estimated crash risk reduction of 15-20% was estimated (Biding & Lind, 2002). It was also estimated that with full deployment of ISA, a 20% reduction in injury crashes could be expected, although this could be up to 25% in urban areas.

Regan, et al. (2002) estimated the potential effects of ISA in Australia. Depending on various levels of effectiveness and acceptability, it was estimated that ISA could lead to up to 40.5% of fatal crashes becoming serious injury and up to 40.5% of serious injury crashes becoming injury crashes. Reductions in other injury and minor injury crashes were predicted to be up to 16.2%. A reduction in the number of speed related crashes by 10-11% was predicted to result in an annual economic benefit of $155 million AU.

Carsten (2001, cited in OECD, 2003) estimated that ISA should result in a reduction in crashes in the magnitude of 18-24% for advisory systems, 19-32% for driver set systems (those which can be turned on and off by the user), and 37-59% for mandatory systems (those which cannot be overridden).

Besseling and van Boxtel (2001) estimated that ISA may reduce the number of injuries by 15% and fatalities by 21%.

Carsten and Fowkes (2000) and Carsten and Tate (2000) estimated the potential for the variants of ISA to enhance user safety in the UK. The best estimates of crash reductions are presented in Table 5-3:

System type	Speed limit type	Injury reduction	Fatality reduction	Fatal and serious injury reduction
Advisory	Fixed	10%	18%	14%
	Variable	10%	19%	14%
	Dynamic	13%	24%	18%
Voluntary	Fixed	10%	19%	15%
	Variable	11%	20%	16%
	Dynamic	18%	32%	26%
Mandatory	Fixed	20%	37%	29%
	Variable	22%	39%	31%
	Dynamic	36%	59%	48%

Table 5-3: Reductions in fatal and injury crashes expected with ISA system variants (Source: Carsten et al.)

Benefit-cost ratios for each these ISA variant were also estimated, accounting for both high and low economic growth. Driver select fixed systems were associated with the lowest ratio (3.7 for low GDP, 5.0 for high GDP), while dynamic mandatory systems were associated with the highest (12.2 and 16.7).

Harrison and Fitzgerald (1999) estimated that an ISA systems would result in the following reductions in speed related crash costs in Australia. These findings are presented in Table 5-4. This analysis assumed that 50% of the effects of the system would be the prevention of crashes, while the other 50% would be the reduction of crash severity (i.e., fatal becoming serious injury).

System	Effectiveness	Penetration	Cost reduction
Advisory	80%	100%	53%
	80%	10%	7%
	40%	10%	3.5%
Absolute	90%	100%	42%
	90%	10%	6%
Intervening*	90%	100%	59%
	90%	10%	7%

Table 5-4: Reductions in speed related crashes expected with ISA system variants.

* Note: In this instance, an intervening system limits the maximum speed of the vehicle but this can be overcome by the driver.

Harrison and Fitzgerald (1999) suggested that absolute ISA systems would become less acceptable as their penetration rate increased, resulting in this system being slightly smaller effect than alerting systems. The intervening system was deemed to be more acceptable as some control is retained by the user, and therefore showed the greatest effect.

Ekman and Hyden (1999) suggested that a cooperative speed limiting system that imposed a maximum speed limit of 30 km/h in areas with high pedestrian traffic would reduce the number of fatal vehicle collisions with pedestrians and bicyclists by 80%

Rumar, et al. (1999) suggested that ISA has the potential to reduce injury crashes on rural roads by up to 30%, and reduce fatal and injury crashes on motorways by about 10-15%.

McKeever (1998) estimated 20% of injury and fatal crashes on urban freeways in the USA could be avoided with an intervening ISA system. Also, the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US were reported by McKeever. It was predicted that a 0.7% reduction in fatalities and a 1.4% reduction in injuries could be expected with ISA systems.

The intervening variant of ISA has been estimated to reduce total crashes by 35% (Kulmala, 1997).

The NHTSA (National Highway Traffic Safety Administration) estimated that ISA systems may be able to reduce the related fatal accidents in a 27%, as well as another 20% in injury accidents (2001).

Disbenefits

ISA is associated with considerable acceptability issues. Limiting systems are particularly negatively viewed by road users (Regan, et al., 2002; Young, et al., 2003b).

According to Várhelyi (2002) advisory systems tend to be associated with lower crash reduction estimates than limiting systems.

5.1.6 Intersection Collision Avoidance

Description

Intersection collision avoidance systems rely on roadside sensors to detect the presence of vehicles approaching the intersection. The number of vehicles, and their speed and location relative to the intersection is communicated to the road users either via on-board displays within the vehicles (cooperative systems) or via roadside displays (infrastructure only systems).

Various intersection collision avoidance system concepts exist (Ferlis, 2001):

- **Traffic signal violation warnings and stop sign violation warnings:** Act to remind the violator of the traffic signal and warn other road users of the hazard. Roadside sensors detect that an approaching vehicle is unlikely to stop, and visual warnings are activated. These remind the (potentially) violating vehicle that there is a red signal/stop sign ahead, and alert other road users in adjacent roads that the intersection may not be clear. This may occur either through a VMS, warning lights or haptic feedback (an 'intelligent rumble strip', Ferlis, 2001).

- **Left turn assistance** (note: this is a US system, this would be right turn assistance in Australia, UK etc.): Vehicles performing turns across traffic are informed of the gap between oncoming vehicles. Roadside sensors monitor the distance between vehicles passing through the intersection, and advise the turning vehicle through VMS or a modified turning arrow when there is a safe gap.

- **Stop sign movement assistance systems:** Inform road users when it is safe to move on from a stop sign, that is, when there is a sufficient brake in traffic from adjacent directions. This is similar to left turn assistance, where the distance between vehicles is monitored by roadside beacons and the gap advisory information is presented on a VMS or other signal.

Another type of intersection collision avoidance involves the automatic detection of traffic signals (Bishop, 2005; eSafety Forum, 2005). Visual imaging techniques detect a stop signal or red light ahead and advise the user if they are not slowing sufficiently, or automatically alert the driver to other traffic signs.

Crash relevance

Multiple-vehicle crashes at intersections.

Effectiveness

Studies cited in OECD (2003) reported a 50% reduction in intersection crashes with the introduction of intersection collision avoidance systems in the USA, and a reduction in crashes involving vehicles from opposite directions by 46% in Japan.

An estimation of the expected reductions resulting from in-vehicle traffic signal recognition systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 50% of injury crashes at 'black spots' would be affected, leading to a 1.75% reduction in these crashes involving traffic sign violations, equating to a 0.2% reduction in all crashes.

The Invent project suggested that approximately 60% of city accidents and 29% of all accidents with severe injuries could benefit from this system.

Disbenefits

No reported evidence of disbenefits found as yet.

5.1.7 *Inter-Vehicle Communication Systems*

Also: *Vehicle-vehicle communication systems; V2V communication systems*

Description

Inter-vehicle communication systems provide real-time information to road users about the proximity of other vehicles. These systems give road users advanced knowledge of approaching vehicles outside their field of vision (i.e. on curves), or in complex driving situations. Information about other vehicles is detected and displayed on a heads-up display, navigation console or via auditory guidance.

Variants of inter-vehicle communication systems exist:

- **Vehicle-vehicle communication:** These systems allow vehicles to directly communicate their speed, position, course, and vehicle type to other vehicles. The system is two-way, in that vehicles both transmit and receive vehicle information so that all road users have an enhanced knowledge of the dynamic road environment.

- **Vehicle-infrastructure-vehicle communication:** Roadside beacons on the approach to an intersection or hazardous curve detect the presence, speed and size of oncoming vehicles. This information is then transmitted to other vehicles that are also approaching the area.

Crash relevance

Multiple-vehicle crashes at intersections, head-on crashes; rear-end crashes.

Crashes where conspicuity is a contributing factor.

Effectiveness

Estimations of the approximate reductions expected with inter-vehicle 'hazard' warnings in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). These systems communicate information regarding road environment hazards to other vehicles. It was expected that 25% of injury crashes in slippery conditions would be affected, leading to a 12.5% reduction in these crashes, equating to a 0.7% reduction in all crashes.

Disbenefits

No reported evidence of disbenefits found as yet.

5.1.8 Navigation Systems

Also: *Route Guidance Systems*

Description

Navigation systems provide dynamic and personalised travel information to the user, as well as the ability to plan and share travel routes. These systems may be either in-vehicle or employ a mobile device such as a PDA. On-board systems tend to be better integrated into the HMI, however, they are limited by the inflexibility of the data stored within the unit. Mobile device systems allow access to a wider range of information but do not have the same usability benefits as on-board systems (Mitterreiter, Schlagmann & Stocker 2005). Hybrid systems, which are integrated into the vehicle in a similar way to on-board systems and allow regular updating of information, may serve to improve the safety of these units considerably.

Navigation systems are typically designed to find the shortest or fastest route to the given destination. However, they also may incorporate safety information. This involves the programming of crash statistics into digital maps (Rumar, et al., 1999).

Crash relevance

While these systems may not show direct safety benefits, their potential to reduce driver workload and travel times is expected to enhance user safety by reducing overall crash exposure.

Effectiveness

Lind, et al. (2003) estimated that route guidance systems that show a preference for safer alternative routes have the 'verified' potential (based on other studies) to reduce all road fatalities by less than 0.5%, while the 'full' potential (an optimistic estimate based on full deployment) is also less than 0.5%. This was expected to be a result of increased distraction due to the in-vehicle unit.

McKeever (1998) estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that a 0.2% reduction in fatalities and a 0.3% reduction in injuries could be expected with in-vehicle navigation systems. McKeever further reported an estimated 1% reduction in crashes in urban areas with navigation systems in the USA.

Disbenefits

Kulmala (1997) noted that is has been argued that these systems encourage drivers to take unfamiliar routes, thereby increasing their exposure to risk.

Navigations systems are potential sources of distraction for users. In a review of driver distraction literature, Young, et al., (2003a) found that in-vehicle navigation systems are more distracting in the destination input phase than the presentation of navigation instructions. However, the level of distraction depends on the mode of input and presentation. Voice recognition and vocal instructions tend to be less distracting than visual displays (Young, et al.).

Elvik (1997, cited in OCED, 2003) described two studies that showed conflicting results regarding the safety of navigation systems. While one study reported that these systems would not prevent crash occurrence, there would be a 1.5% reduction in crash costs, another indicated that there would be an increase in crashes resulting from the more widespread distribution of traffic throughout the road network.

Abdulhai and Look (2003) employed a simulation model to determine the effects of dynamic route guidance systems at various levels of market penetration. It was found that while re-routing created more crashes, due to vehicles performing more turns and greater activity in the road network, the shorter travel time and more efficient use of the road network also lead to an overall decrease in crashes. Crashes at non-intersections steadily increased by 6% at 100% penetration, while at 60% penetration, the maximum level of intersection crashes was observed. However, with route-guidance systems that are designed to find the route with the lowest crash route as well as shorter travel time, intersection collision risk decreased as the fleet penetration rate increased (after a small initial increase).

Lind (1998) estimated the long-term potential effects of various emerging ITS technologies in reducing crashes, using expert assessment of various areas of potential safety impact. It was estimated that at 20% implementation, there would be a 1% increase in crashes. At 100% implementation, this increase was expected to be 3%.

5.1.9 Pay-As-You-Drive Insurance

Description

Pay-as-you-drive insurance systems record the distance, time, location and frequency of travel using in-vehicle telematics and GPS tracking. This information is then assessed by insurance companies to calculate a monthly/annual payment. These systems allow a user-pays approach to insurance, and can be used to discourage particular driving patterns. For example, drivers may be charged higher rates for driving in high alcohol times, or for driving for excessively long journeys where fatigue may become a factor.

The system involves an in-vehicle unit that records and calculates driving behaviour, much like an electronic logging device in commercial vehicles. A GPS system monitors vehicle location, and the information is sent via a mobile network to the insurance company. Other versions of pay-as-you-drive insurance records only mileage (from odometer readings), and does not track the time, location or pattern of driving behaviour.

Crash relevance

Crashes where speed, fatigue, intoxication are contributing factors. Indirect benefits may also be seen from reduced crash exposure.

Effectiveness

No reported evidence of effectiveness found as yet.

Disbenefits

No reported evidence of disbenefits found as yet.

5.1.10 Railway Crossing Systems

Description

Railway crossing systems serve to enhance the safety of road users at signalised railway crossings. They are cooperative systems, in that the infrastructure-based signals require coordination with the rail network or approaching trains. Numerous systems may be applied to railway crossings in order to better coordinate signals, enhance warnings to road users, or enforce crossing laws.

Methods for detecting the presence of trains include tag readers (with tags located in each carriage of the train), acoustic detectors, lidar and radar. Railway crossing signals may also be integrated with nearby traffic signals to better facilitate the flow of traffic and prevent congestion around railway crossings (Lee, et al., 2004). Other techniques to improve the efficiency and safety of railway crossings include consistent warning times for crossing signals, leaving crossing gates open when trains are stopped at stations near the crossing, minimising transient gate openings (when the gates open for a brief period, i.e., less than 15 seconds, before closing again), and railway crossing cameras.

Crash relevance

Crashes between trains and pedestrians and vehicles.

Overall Effectiveness

Hellman (2005) found that a four-quadrant crossing gate combined with an indicative loop vehicle detection system resulted in a significant reduction in vehicle entering the crossing after the crossing signal lights were activated, and a 100% reduction in vehicles entering the crossing after the gates were deployed.

Overall Disbenefits

No reported evidence of disbenefits found as yet.

Descriptions and Evaluations of System Variants

5.1.10.1 Advanced Warning for Railroad Delays

Sensors along railway lines on the approach to crossings detect the speed, length and proximity of approaching trains. This information is used to calculate the expected time delay caused by the train at the crossing, and this information is passed onto road users via variable message signs. The aim of such systems is to encourage road users to take detours to prevent congestion around railway crossings.

An estimation of the effectiveness of advanced warning systems predicted an 8.7% reduction in crashes with even only 20% of drivers responding to VMS delay warnings (Carter, Luttrell & Hicks, 2000). If this compliance increased to 45%, time savings of 19% were also expected.

5.1.10.2 Automated Horn Warning

The provide additional warnings to road users that a train is approaching but eliminate the noise pollution typically associated with train horns. Rather than a horn located on the train itself, which has to be sounded from a considerable distance to give road users sufficient warning, the horn is part of the crossing infrastructure. The same mechanisms that activate the crossing signals also activate the horn. This localises the sound to the area of the crossing only. Activation of the horn is indicated by a display in the train cabin. If this fails to activate, the driver is alerted and can manually sound the train horn.

Gent, Logan and Evans (2000) found an automated horn warning system to significantly reduce the negative noise effects of traditional train horns without compromising crossing safety. However, no reported evidence of effectiveness or disbenefits found as yet.

5.1.10.3 In-vehicle Warning System; Vehicle Proximity Alert

The system provides an in-vehicle visual and/or auditory alert to road users that an active railway signal crossing is ahead. Activation of the crossing signals also causes a radio signal to be transmitted from the crossing. Vehicles equipped with transmitters in the vicinity detect this signal, and the in-vehicle alert is activated. Information such as the distance of the vehicle to the crossing may also be provided, as well as whether there is a train present. This system has been implemented in school buses in the US, where the system automatically adapts the auditory warning so that it can be heard over the ambient noise in the bus (SRF Consulting Group, 1998). Other applications include emergency vehicles, commercial vehicles and vehicles carrying hazardous materials (Carroll, Passera & Tingos, 2001). In order to minimise false alarms, the system is only activated when the vehicle is travelling toward, not away from, the crossing.

No reported evidence of effectiveness or disbenefits found as yet.

5.1.10.4 Obstacle Detection Systems

Radar, laser, lidar or inductive loop sensors obstacle detection systems may be used to detect the presence of road users or objects in the crossing area. Traditional systems are only able to detect objects as large as cars, leaving pedestrians, bicyclists and motorcyclists vulnerable. However, more advanced systems have been developed. The presence of a vehicle or pedestrian in the crossing is detected by the system, and this information is provided to the driver of the oncoming train.

Lee, et al. (2004) estimated the economic benefits of full and incremental deployment of various railway crossing technologies. Savings of around $81,000 and $320,000 US in collision costs could be expected with full deployment of a VMS warning system and stationary vehicle detection systems, respectively. With incremental deployment of the stalled vehicle detection system, savings of $26,000 US were expected.

5.1.10.5 Railway Crossing Cameras

Automated enforcement strategy to prevent road users disobeying crossing signals. See Automated Enforcement Systems.

McKeever (1998) estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that a 0.8% reduction in fatalities and a 0.2% reduction in injuries could be expected with rail crossing enforcement technologies.

5.1.10.6 Second Train Warning

Instances where a second train immediately passes through a crossing following another train may cause confusion and danger among road users who assume there will be only one train. Second train warnings detect the second train and activate visual and/or auditory warnings that indicates to pedestrians and motorists that another train is approaching. These systems are particularly relevant to pedestrian safety.

Second train warnings were found to significantly reduce the number of pedestrians engaging in risky behaviour (still in the crossing 4 seconds before the train entered the crossing) by 73% in a US trial (TRB, 2002).

Bousquet and Peck (2004) stated that there may be some confusion that the absence of the second train warning when only one train crosses means that it is safe to enter the crossing.

5.1.11 Road Geometry Warnings

Incorporates *Curve Speed Warnings* and *Downhill Speed Warning*

Description

Vehicle warning systems provide feedback to road users on potentially hazardous sections of road, such as corners, steep descents and curved ramps. These systems may involve in-vehicle units or infrastructure-based warnings and signals. Essentially, speed warnings based on upcoming changes in the road geometry are communicated to the driver, either through an on-board display or via message signs on the roadside. This advice may be in the form of a recommended speed, a warning that the vehicles current speed is too fast, or information regarding the angle and camber of the road ahead.

- **Infrastructure-based:** Roadside speed sensors detect the speed of vehicles approaching a curve. If the speed of the vehicle is deemed too fast, VMS display warnings or advisory speeds. Variants of this system resemble speed feedback indicators, where the vehicles actual speed is presented next to the suggested speed.

- **In-vehicle:** Upcoming curves are detected through on-board navigation units (GPS, etc.) or a roadside beacon transmits the warning to an in-vehicle unit. The current speed of the vehicle relative to the geometry of the curve is assessed, and the driver is warned if vehicle speed should be reduced (Bishop, 2005). Variants of this system may only advise that a curve is ahead, without the speed warning function. A system described by Sayer, Sayer and Devonshire (2005) incorporated a two-stage alert. The first stage involved haptic feedback (seat vibration), while the second stage elicited an auditory warning. Another variant, NAVTEQ's Electronic Horizon, monitors the speed and position leading traffic in relation to a digital map and indicates to the driver when it is safe or unsafe to overtake the leading vehicle (Telematics Journal, 2006).

Crash relevance

Off-path on curve crashes; off-path on straight crashes. Crashes where speed is a contributing factor.

Effectiveness

Estimations of the approximate reductions expected with speed alerts for 'black spots' in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 50% of crashes on black spots would be affected, leading to a 1.75% reduction in these crashes equating to a 1.75% reduction in all crashes.

Infrastructure-based systems which provide warnings to road users about downhill and curve speed, and rollover warnings have been deployed to a limited degree in the USA, and have been regarded as a success (FHWA, 2000).

Significant reductions in average heavy vehicle speed was observed in a trial in the US (Tribbett, McGowen & Mounce, 2000).

Lind (1998) estimated the long-term potential effects of various emerging ITS technologies in reducing crashes, using expert assessment of various areas of potential safety impact. It was estimated that at 23% implementation of 'regional' warning systems, there would be a 3% reduction in crashes. With 100% implementation, this was expected to be 13%.

A similar system using weigh-in-motion and VMS preceding a steep decline was associated with a 13% reduction in speed-related heavy vehicle crashes, and 24% fewer trucks used the runaway ramps in this area (Inside ITS, 1997).

Disbenefits

Tribbett, et al. (2000) observed lesser speed reductions over time with heavy vehicles, indicating road users tended to habituate to the speed warnings as they became more familiar with them.

5.1.12 Rollover Warning Systems

Description

Rollover warning systems provide feedback to heavy vehicle drivers on potentially dangerous curved sections of road, such as highway ramps. Similar to curve speed warnings, the system assesses the approaching vehicles speed and advises the driver through a VMS or other such visual warning if their speed is too great. However, rollover warning systems also involve additional sensors that determine whether the heavy vehicle is likely to rollover. The critical threshold for a given vehicle to rollover is determined by sensing the vehicles speed, height and weight (with weigh-in-motion sensors), compared with the curvature and camber of the road.

Crash relevance

Rollover crashes; off-path on curve crashes involving heavy vehicles.

Effectiveness

Strickland and McGee (1998) reported significant average speed reductions (8.3 mp/h) with the use of a rollover warning system for heavy vehicles. No rollover collisions occurred in the 3-year evaluation period following instillation of the system, compared to 10 rollover crashes in the preceding 5 years.

A similar system using weigh-in-motion and VMS preceding a steep decline was associated with a 13% reduction in speed-related heavy vehicle crashes, and 24% fewer trucks used the runaway ramps in this area (Taylor & Bergan, 1997).

Prime Inc. announces the implementation of "Roll Stability Control (RSC)" on every additional truck to their fleet, and estimates a reduction of 60% of rollover related accidents (2004).

A study of the Cambridge University Engineering Department, suggests a reduction of 29% of rollover related accidents for semi-trailers (Sampson & Cebon, 2001).

At the same time, another study of the Cambridge University Engineering Department estimates a reduction of 20% to 30% of rollover related accidents for trailers (Sampson & Cebon, 2001).

Disbenefits

No reported evidence of disbenefits found as yet.

5.1.13 Vehicle Pre-Emption Systems

Also: *Signal Priority Systems*

Description

Vehicle pre-emption systems involve cooperation between the infrastructure and certain vehicles. Emergency vehicles, buses or trains are given priority signals at intersections. Signal pre-emption systems facilitate the movement of emergency service and public transport vehicles through signalised intersections. Traffic signals may not automatically change to green for buses, but they may experience shortened red signals. Rather than skipping signals, the system speeds up signals that conflict with the priority vehicles needs. Also, the system may only be used when the bus is already delayed.

Awar and Collura (n.d.) distinguish between priority and pre-emption systems. Priority systems serve to reduce delay, but not eliminate it. That is, the adaptation of traffic signals will be to the benefit of the priority vehicle, but not at the expense of significantly interrupting other traffic. These are typically used for public transport vehicles. Pre-emptive systems alter the pattern of traffic signals to allow a particular vehicle through, typically emergency service vehicles.

These systems may function in one of two ways:

- **Vehicle-signal communication:** They may involve in-vehicle transmitters and roadside receivers which detect approaching vehicles and maintain or change to a green signal until the vehicle has passed through the intersection. This may involve an infrared signal or radio transmitter to communicate vehicle location with infrastructure. Sensors within traffic signals detect an approaching emergency vehicle or bus, either via visual imaging, sound or light detectors (which recognise the siren and/or flashing lights of the vehicle), infrared or radio communication. The traffic signal pattern can be interrupted so that the priority vehicle has a green signal until they pass through the intersection.

- **Management centre-signal communication:** Other forms of vehicle pre-emption utilise automatic vehicle location and remote control of traffic signals. Of course, the accuracy of the AVL is very important in these systems (Jones, 1995). Traffic signals are managed through coordination between fleet management centres and traffic control centres. Information from automatic vehicle location systems is used to alter the traffic signal, without the use of vehicle sensors located at each intersection.

Crash relevance

Multiple- vehicle crashes at intersections. These systems are also expected to show benefits in reduced emergency service response times.

Effectiveness

Maccubbin, et al. (2005) regards signal priority for public transport vehicles to have had positive impacts on mobility, productivity and efficiency. Emergency vehicle pre-emption was deemed to have had significant positive impacts, reducing response times by up to 23%.

Lee, et al. (2004) estimated that approximately $26,000 US could be saved annually as a result of emergency vehicle pre-emption systems at railway crossings. However, if the system is installed incrementally, savings of around $65,000 were expected.

PIARC (2000, cited in OECD, 2003) reported a benefit-cost ratio of 4.8 for emergency vehicle pre-emption.

Applications have shown bus journey time reductions of between 10-27% (Chada & Newland, 2002). The use of signal pre-emption for passenger vehicle services can reduce travel time variability, reduce the number of signal stops and create a smoother ride.

Have been regarded as a success with widespread deployment in emergency vehicles in the USA (FHWA, 2000), while public transport pre-emptive systems may be beneficial in reducing fleet size and travel times.

It has been reported that no bus crashes in the year following the introduction passenger vehicle pre-emption system in the US, compared with 32 crashes in the 5 years prior to its inception (Fors, 1998).

Perrett and Stevens (1996, cited in Lind, et al., 2003) estimated that emergency vehicle priority systems will result in 2% of crashes will reduce in severity (i.e., fatal crashes will become serious injury, serious injury will become minor injury).

Use of signal pre-emption for emergency vehicles has been shown to reduce incidence response times by 16-23% (Traffic Engineers Inc., 1991).

Disbenefits

An evaluation of bus signal pre-emption in Michigan showed that the 6% time savings experienced by passenger vehicles was not enough to outweigh the significant delays that other road users experienced (Chada & Newland, 2002). The FHWA (2000) expressed concern about the effects of these systems on traffic flow.

5.2 Passive Systems

5.2.1 *Automatic Crash Notification*

Also: *Mayday Systems; Emergency Notification Systems*

Description

Automatic crash notification (ACN) systems aim to reduce critical incident response times to crashes by automatically informing emergency services when and where a crash has occurred. Automatic crash notification uses input from the vehicles ignition, acceleration, tilt and shock sensors to determine if the vehicle has crashed. Often ACN is linked to the vehicles airbag system, so that any crash severe enough to result in the airbag being deployed will also activate the ACN. Emergency services are automatically contacted through a mobile telephone network and the location of the vehicle is provided by a GPS systems. More advanced systems are able to inform the emergency services of the severity and nature of the crash, and may have speakers so that the driver can communicate with the emergency services operator. The system can usually be overridden by simply pressing a button.

According to Campbell, et al. (1998) ACN should perform several important functions. The system should be able to inform the user that emergency services have been contacted and when they are due to arrive through auditory and/or visual displays, the system should provide information to the user from the emergency services operators, and the system should update this information in real-time.

Crash relevance

All crash types. These systems are expected to show benefits in reduced emergency service response times.

Effectiveness

According to Abele, et al. (2005), at maximum potential effectives, ACN systems have the potential to reduce the severity (i.e., reduce fatal crashes to serious injury, serious injury to minor injury) of 15% of all crashes, and reduce incident related congestion by 20%. Even if ACN only has minor effectiveness, it is still expected to reduce fatal crash severity by 5% and serious injury severity by 10%, while reducing congestion by 10%.

Various European studies have estimated that 5-15% of all fatalities could be reduced to serious injury and 10-15% of serious injuries could be reduced to minor injuries with ACN. No effect on minor injuries is expected (eSafety Forum, 2005).

Estimations of the approximate reductions expected with ACN in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 12% of fatalities in rural areas and 7% of fatalities in rural areas would be prevented, with an overall reduction in fatalities of 11%.

Lind, et al. (2003) estimated that ACN has the potential to affect 40% of remote fatalities in Sweden, and predicted that by the year 2015, these systems would these fatalities by 30%. It was also estimated that ACN has the 'verified' potential (based on other studies) to reduce all road fatalities by 0.8%, while the 'full' potential (an optimistic estimate based on full deployment) is 1%.

Regan, et al. (2002) estimated that ACN systems could result in reduction of approximately 5% of fatal crashes (which became serious injury crashes), with an estimated annual saving of $21 million (AU). This analysis assumed that ACN would have no effect on serious or minor injury crashes.

Widespread deployment of these systems has been regarded as a success in the USA (FHWA, 2000).

ACN has been has the potential to reduce rural emergency service response times from 9.6 to 1 minute (FHWA, 1998).

It has been estimated that a reducing emergency service response times from 5.2 to 2.0 minutes would result in an annual 15% reduction in fatalities in the US (Apogee/ Hagler Bailly, 1998).

McKeever (1998) estimated the predicted system-wide effects of the full deployment of numerous ITS on all fatal and injury crashes in the US. It was predicted that a 3.4% reduction in fatalities could be expected with ACN systems. It was also estimated that a reduction of 7% of crashes on rural roads in the US as a result of ACN.

The eImpact project suggested that the introduction of the "e-Call" system will allow a reduction of 5 % to 15 % of road fatalities to severe injuries and 10% to 15 % of severe injuries to slight injuries (2005).

Disbenefits

There is concern that the frequent false alarms from ACN systems may lead to their alerts being ignored (Rumar, et al., 1999).

5.3 Combined Active and Passive Systems

No cooperative CAPS systems have been identified at this stage.

6 Conclusions

The collection of all these results regarding the effectiveness of existing safety systems , as well as the upcoming ones, has allowed identifying the most promising ITS that will have to be considered in the following steps of TRACE (that is, WP6).

This study reveals the relevance of those systems in terms of crash avoidance/reduction, as well as in derived injuries. Some of the systems have been found to be especially effective *(ESC, e-Call, ACC*), while the effectiveness of some other systems is not proved to be so relevant. Nevertheless, most of them act simultaneously or have a similar function (e.g. *Lane Changing Assistant or Lane Departure Warning*), or even they interact between the car/user and the road (e.g. Traffic Sign Recognition), what makes them more efficient.

The importance of passive safety systems in the future has been found to be related to active systems, which are called “combined active and passive systems”. In that field, the most relevant systems are the ones that act just before a crash occurs.

Some of those *Pre-Crash* systems use some forward-facing sensors, such as in the case of collision avoidance systems, to determine the eminent crash and prepare the vehicle to minimise the effects of the crash. For example, passive safety systems like the seatbelt pre-tensioners have the objective of diminishing the consequences of a crash in case it occurs.

Some other systems consist on the detection of elements on the road that can interfere in the trajectory of the vehicle (e.g. the *Automatic Pedestrian Detection* or the *Animal Detection System*), which derives also in an important reduction of crashes and injuries.

Finding all the collected information has been a difficult task (especially for some of the systems), and in many cases the information provided was contradictory. Nevertheless, it is undeniable that ITS will become one of the most effective way to reduce the amount of injury accidents regarding all types of vehicles in our roads, under any circumstance or crash condition. As a consequence, the number of victims and injured people is expected to decrease considerably.

This is one of the TRACE objectives to verify this expectation, at least for a selection of the systems already evaluated or not evaluated yet. WP6 has selected a list of safety functions to be evaluated in WP tasks 4.1 and 4.2. Deliverable D6.1 presents this list. Deliverables D4.1.4 and D.4.2.2 will present the results of such evaluation whereas Deliverables D.4.1.3 and D.4.2.1 will have presented beforehand the relevant methodologies to be used.

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List of Abbreviations

ABS: Anti-lock brakes

ACC: Adaptive Cruise Control

ADAS: Advanced Driver Assistance System

AFS: Active Front Steering

APTS: Advanced Public Transport System

ARP: Active Rollover Protection

ARTS: Advanced Rural Transportation Systems

ATIS: Advanced Traveller Information Systems

ATMS: Advanced Traffic Management Systems

AVI: Automatic Vehicle Identification

AVL: Automatic Vehicle Location

AWD: Advanced Warning Device

CAD: Computer-Aided Dispatch

CAPS: Combined Active and Passive Systems

CCTV: Closed-Circuit Television

CVO: Commercial Vehicle Operations

DRL: Daytime Running Lights

ESC: Electronic Stability Control

FHWA: Federal Highway Administration

GPS: Global Positioning System

HDD: Heads-Down Display

HMI: Human Machine Interface

HUD: Heads-Up Display

IIHS: Insurance Institute of Highway Safety

ISA: Intelligent Transport Systems

ITS: Intelligent Transport Systems

IVIS: In-vehicle Information System

NHTSA: National Highway Traffic Safety Administration

OCED: Organisation for Economic Co-operation and Development

PDA: Personal Digital Assistant

SUV: Sport Utility Vehicle

VMS: Variable Message Sign

European Projects

Within the in-vehicle intelligent systems, the European project **CHAUFFEUR** has been carried out with the following technical goals as develop system that allows following of any other vehicle at a safe following distance in order to reduce driver's workload, develop lane keeping function for the trucks and obstacle detection and collision avoidance features, develop a suitable safety concept, realize truck platooning function, develop communication concept for platoon inter vehicle communication, develop safety concept for platoon operation, demonstrate truck platoon on test truck, demonstrate / evaluate systems functions in a test truck environment and real life situations.

While there are still some ways for entering the commercial market, the CHAUFFEUR project has achieved a new level of capability in truck automation. The Chauffeur Assistant can be seen as a relatively near-term offering, as truckers adopt mature Adaptive Cruise Control technology and marry that with new products in lane keeping assist. Implementation of truck platoons, however, is expected to take quite some time – many experts believe that this type of trucking operation would only be allowed on dedicated truck lanes, which have not yet been constructed although studies are underway.

A further multi-year demonstration project titled **CHAUFFEUR 2** has also been conducted. This Project, co-ordinated by DaimlerChrysler, is aimed at developing the future of automated road transport through the implementation of smart adaptive cruise control and vision-based lane keeping. Three-truck platoons were demonstrated using trucks from DaimlerChrysler, IVECO and Renault, where the first trucks only were driven by human drivers. Electronic control was used to completely control the remaining vehicles, following the leading vehicle at safe but close distances.

Within the **PROTECTOR** (Preventative Safety for Unprotected Road User, 2000-2002) project, the first ever large-scale field tests with the aim of developing and validating sensors for detection and classification of vulnerable road users (pedestrian, cyclist, etc.) in order to reduce accidents involving pedestrians and allow smart passive safety devices. Results showed that some systems (Daimler Chrysler) were quite reliable at detecting pedestrian as objects but that more work was generally needed for the classification of the detected objects.

The successor project **SAVE-U** (Sensors and System Architecture for Vulnerable road User protection) was then introduced to improve the (Daimler Chrysler) system performance by an order of magnitude in terms of reduction of false classifications, compared to PROTECTOR. Automatic braking capabilities were also added to the system.

SAVE-U announces good improvements but acknowledges inadequate system performance for real world deployment, too relaxed system operating conditions, not suitable sensor packaging and processor hardware, rudimentary collision risk assessment, driver warning and vehicle control.

Now the research on improving the recognition performance by video sensing system continues through the current **WATCH-OVER** project that started in January 2006.

Within this project, Co-operative approaches based on vehicle-vulnerable road user communication are explored in addition to the sensor systems.

Other companies also conducted similar projects (e.g. APALACI) with the same main aim to find ways of distinguishing between the different forms of vulnerable-road-users.

Also in the field of detection systems, the **CHAMELEON** project was carried out with the purpose of developing and validating an advanced sensorial platform, able to detect an imminent crash and provide relevant data to passive safety systems as smart restraint system.

The European project **RESPONSE** (1998-2000) is an integrated approaching of user, system, and legal perspective. The introduction of new automobile technologies always holds both opportunities and risks. This applies particularly every kind of innovative support for the drivers, which has been developed in recent years under the name of Advanced Drive Assistance System.

This project lead to the definition of the safety key concepts needed for the development of integrated ADA Systems, stating the need for a code of practice for development and testing of ADAS. This movement from the product liability argumentation to the market introduction scenarios based on a code of practice has been the general guideline of the **RESPONSE 2** project, carried out between 2002 and 2004. The obtained Code of Practice describes all technical reliability and system safety issues, a human factors design process and the methods for HMI specification and validation. The **RESPONSE 3** project kept on developing this European Code of Practice between 2004 and November 2006 to provide manufacturers the necessary tool for ADAS development and validation.

LACOS, "Lateral Control Support", aims to validate the autonomous systems capable of providing driver assistance for Anti-collision purposes along the lateral axis of the vehicle. It integrates two main functions of vehicle lateral control "Lane Warning Support" and "Lane Change Support".

A microwave radar from Agricultural Digital Camera and Charged Coupled Device cameras was installed for the Lane Change Support. A CCD camera or microwave radar was applied for Lane Warning Support. The information provided by the sensor systems was then processed by an electronic control unit, adopting sensor fusion algorithms to guarantee detection reliability and robustness.

LACOS made an analysis to figure out the consumer needs used to derive the system function together with the architecture and the Human Machine Interface requirements. These adaptations have been carried out to lane change support sensors that had been already developed.

European **ALCOLOCK** project assessed acceptance, practicability and usability of Alcolocks (device that prevents the engine from starting in case of alcohol detection) as a general preventive measure. Both commercial and non-commercial field trials showed good results in terms of acceptance even though some technical problems were considered an obstacle to daily work by truck drivers. Also the cost-benefits analysis is an obstacle to the wide use of this system (ALCOLOCK, September 2006).

ROSETTA project also takes into account the infrastructure based technology. With the aim from a network operator's perspective of improving highway efficiency at a system level through systems that collect information about traffic, those that provide information to drivers, and devices that exert control on traffic. Now the infrastructure based technology focuses on improvement highway efficiency and safety system level, systems that collect about traffic, providing information on drivers as well as devices that exert control on traffic.

Anther project related with Infrastructure-based system is **SAFESPOT** which is an integrated research European Project whose objective is to under-stand how intelligent vehicles and intelligent roads can cooperate to produce a break- through for road safety. With the aim of preventing road accidents, SAFESPOT develops a Safety Margin Assistant that can detect in advance potentially dangerous situations and is also able to extend in space and time driver's awareness off the surrounding environment. SAFESPOT looks for the "combination" of the information from vehicles and from the infrastructure, making use of sensor technologies to enable the possibility to have in real time a picture of the vehicle surroundings, thus improving road safety by avoiding an important number of accidents, or at least reducing their effects.

The **COOPERS** (CO-Operative systEms for intelligent Road Safety) is an ongoing European research and development project focusing on the development of innovative telematics applications on the road infrastructure with the long term goal of a Co-operative Traffic Management" management between vehicles and infrastructure, to reduce the self opening of the development of telematics applications between car industry and infrastructure operator.

The goal of the project is the enhancement of road safety by direct and up to date traffic information communication between the infrastructure and motorised vehicle on motorway sections.

With the same main objective, projects as **CIVS** (Cooperative Infrastructure Vehicle Systems) and **I-WAY** are also focusing on the development of multi sensorial systems to be implemented on the motorways for monitoring and signalizing special drivers or environment situations.

As a post-crash system, **AIDER** focuses on the reduction of accident aftermath by an optimised rescue chain. To achieve this purpose, On-board System for Automatic Incident Detection detects reliable information (e.g. vehicle's GPS position, number of passengers) and Bio-Medical data of the passengers (e.g. heart- and respiration rate) and videos from the passenger compartment are sent to the control centre. AIDER is based on an on-board-system for automatic accident recognition, a communication system including a back-up satellite channel and an advanced control-centre. This should lead to an effective reduction of the time of intervention and optimisation of the rescue procedures, so it can be possible to consequently reduce mortality in road accidents.