Review of Advanced Driver Assistance Systems

P.Thomas[1], J.Breen[2], G.Yannis[3], A.Laiou[4], K.Folla[5], A.Theofilatos[6]

[1] Professor, Loughborough University

[2] Road Safety expert, Jeanne Breen Consulting

[3] Professor, National Technical University of Athens

[4] Senior Researcher, National Technical University of Athens

[5] Researcher, National Technical University of Athens

[6] Senior Researcher, National Technical University of Athens

***Abstract*:** While vehicle safety is a key strategy to address ambitious long-term and interim goals and targets as part of an integrated safe system approach, advanced driver assistance systems (ADAS) are defined as vehicle-based intelligent safety systems which could improve road safety in terms of crash avoidance, crash severity mitigation and protection and post-crash phases. As the evaluation of ADAS is a young science and their road safety performance is of principal concern to road safety managers, the objective of the present research is to record and categorize advanced driver assistance systems as well as to discuss a variety of measures that are being promoted widely as ADAS, e-Safety or active safety measures, the knowledge about which is gradually evolving, including information on the costs and benefits of such measures. Results indicate a major categorization of ADAS regarding vehicle technologies and road casualty reduction. Furthermore, the known and unknown safety effect of specific systems is discussed including information such as the road safety problem they address, their effectiveness and benefit to cost.

Keywords: Advanced Driver Assistance Systems, Road safety, Vehicle technology.

1. INTRODUCTION

Vehicle safety is a key strategy to address ambitious long-term and interim goals and targets as part of an integrated Safe System approach. Secondary safety or crash protection technologies continue to deliver large savings in the last few years, while primary safety or crash avoidance technologies have started to contribute to casualty reduction and hold potentially large future promise. At the same time, new in-vehicle technologies under development have the potential to increase as well as decrease crash injury risk through introducing new driver distraction and inadvertent behavioural change that may solve one problem but create another. The safety effects of some of the technologies that are being promoted widely in the name of safety have yet to be demonstrated. More promising safety technologies that address large road safety problems and where benefits have been demonstrated are being promoted in only a few countries or are being taken up at a lesser rate across EU countries.

Advanced driver assistance systems (ADAS) are defined as vehicle-based intelligent safety systems which could improve road safety in terms of crash avoidance, crash severity mitigation, crash protection and post-crash phases. ADAS can, indeed, be defined as integrated in-vehicle or infrastructure based systems which contribute to more than one of these crash-phases. For example, intelligent speed adaptation and advanced braking systems have the potential to prevent the crash or mitigate the severity of a crash.

The objective of the present research is to record and categorize advanced driver assistance systems as well as to discuss a variety of measures mainly in the European Union and worldwide that are being promoted widely as ADAS, e-Safety or active safety measures, the knowledge about which is gradually evolving, including information on the costs and benefits of such measures. The findings of this paper are based on the Traffic Safety Synthesis on Advanced Driver Assistance Systems (European Commission, 2016), which updates the previous version of Traffic Safety Synthesis, entitled eSafety, produced within the EU co-funded research projects SafetyNet (2008) and DaCoTA (2012).

2. VEHICLES TECHNOLOGIES AND ROAD CASUALTY REDUCTION

Vehicle safety addresses the safety of all road users and currently comprises measures targeting at crash avoidance and injury prevention, which is called primary safety, measures targeting at the reduction of injury in the event of a crash, which is the crash protection or secondary safety and those which assist post-impact care, i.e. reduce the consequences of injury.

Concerning the crash avoidance systems, there is large future promise of casualty reduction from such technologies, as long as development is prioritised to provide maximum casualty reduction. Since driver behaviour can modify the performance of safety systems which aims for crash avoidance, assessment of the human-machine interface, while complex, is essential. The crash mitigation systems refer to active in-vehicle systems which aim to mitigate the severity of the crash. Examples of such systems are the intelligent speed adaptation and advanced braking systems. In addition, substantial and evidence-based improvements have been made in the last 20 years and research has identified continuing large scope for enhanced vehicle safety from improved crash protection, which aims to reduce injury severity during the impact phase. As far as post-crash response systems are concerned, a new development is the deployment of systems, such as eCall, which aim to alert and advance emergency medical system support in the event of crash. Finally, the potential for in-vehicle systems to integrate crash avoidance, crash protection and post-crash objectives is being increasingly understood, as shown in Figure 1, as are vehicle to vehicle and vehicle to network communications.

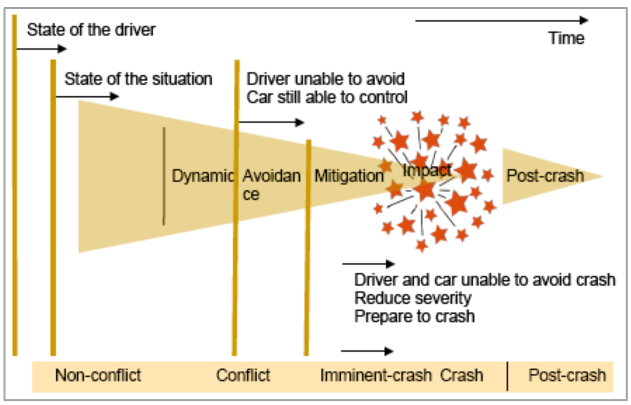

Figure 1: The Holistic View of Safety (Source: Swedish Transport Administration 2010)

New technologies for road safety have collectively been known as Intelligent Transport Systems (ITS) and transport telematics (although these cover a wide range of road and vehicle based systems), driver support technologies and, more recently, ADAS, to reflect increasing use of electronic and telecommunication technology within the road transport sector. While many predictive studies on ADAS effectiveness have been carried out, research on the casualty reduction effects of systems in practice is just starting. Although attempts have been made to classify the impacts of ADAS safety measures, it is acknowledged to be a young science (Golias et al., 2002; ADVISORS, 2003; SUPREME, 2007; Thomas, 2008). Based on current knowledge about safety impacts and feasibility, this paper accordingly discusses measures in two broad groups:

- Safety related ADAS - safety effects known
- Safety related ADAS – safety effects unknown

3. ADAS - SAFETY EFFECTS KNOWN

A wide variety of ADAS technologies are in use today, some of which are fitted to vehicles increasingly as standard equipment. Research on seat belt reminders, alcohol interlocks, intelligent speed adaptation (ISA) and electronic stability control (ESC) indicates that these measures offer significant safety potential. These technologies are, accordingly, being introduced increasingly into legislation into some national safety policies.

3.1. Intelligent Speed Adaptation (ISA)

Speed is considered as one of the major causes of accidents, and even more of fatal accidents. Studies show that small differences in speed can have a profound effect on the occurrence and severity of road accidents and injuries. More specifically, research indicates that a 1% decrease in average speed corresponds with a 2% decrease in injury accidents, a 3% decrease in serious injury accidents and a 4% decrease in fatal accidents and vice versa (Elvik, 2009; Nilsson, 2004).

ISA is a system which informs, warns and discourages the driver to exceed the statutory local speed limit or other desired speed thresholds below this limit at safety critical points. The in-vehicle speed limit is set automatically as a function of the speed limits indicated on the road. GPS allied to digital speed limit maps and speed traffic sign recognition allows ISA technology to continuously update the vehicle speed limit to the road speed limit.

An EU-funded project (PROSPER) calculated crash reductions due to the use of speed limitation related technology for six countries. Reductions in fatalities between 19-28%, depending on the country, were predicted in a market-driven scenario for voluntary systems. Even higher reductions (26-50%) were predicted for a regulated scenario. Benefits are generally larger on urban roads and are larger if more intervening forms of ISA are applied (Carsten & Tate, 2006). An earlier study in the Netherlands showed that ISA could reduce the number of hospital admissions by 15% and the number of deaths by 21% (Loon, van & Duynstee, 2001).

A study (Carsten & Tate, 2006) has calculated the costs based on the premise that by 2010 all new vehicles would be fitted with a satellite navigation system, as well as available and accurate speed limit maps. The benefit to costs ratios ranged from to 2,0 to 3,5 for the market driven scenario and from 3,5 to 4,8 for the regulation driven scenario. Additionally, other ISA benefits have been identified as fuel savings, CO_2 savings and the potential to reduce journey time (managed motorways; reduction in incidents).

3.2. Seat belt reminders

Research studies indicate that the risk of dying in a crash could be reduced by about 60% by using the seat belt and by more, when belts and air bags are combined (WHO/World Bank 2004). While most drivers in the EU countries wear seat belts in the front seats of cars, a significant proportion involved in crashes are unrestrained, even in countries with the highest seat belt use. Seat belt wearing levels in the rear seat are not high in most EU countries (ETSC, 2006 Seat Belt).

Seat belt reminders are intelligent, visual and audible devices that detect whether seat belts are in use in various seating positions and give out increasingly urgent warning signals until the belts are used. Based on the Swedish experience, the European Enhanced Vehicle- Safety Committee (EEVC) Working Group recommended in 2002 that seat belt reminders should (Kullgren et al., 2006):

- target part-time users, i.e. people who understand the value of a seat belt but sometimes do not use it
- not affect the driveability of the vehicle
- comprise a combination of visual and sound signals
- use a signal based on multiple steps, i.e. build up progressively
- be fitted to all seating positions

User trials and research in Sweden and the United States have shown that seat belt reminders with advanced reminder systems with visual and audible warnings were the most effective systems for increasing seat belt use (ETSC 2006, Seat Belt). A Swedish study examined differences in driver’s seat belt use in cars with or without different reminder systems and found that 99% of drivers used their seat belt in cars, with the most advanced reminders, 93% of drivers used their seat belt in cars equipped with “mild” reminders producing a visual and soft sound signal, 82% of drivers used their seat belt in cars without seat belt reminders. An observation study carried out in several EU countries in 2008 found a significant difference in seat belt wearing rate in cars with seat belt reminders. For all observations, the total seat belt wearing rate was 97,5% in cars with seat belt reminders, and 86% in cars without (Lie at al., 2008). Earlier US studies found a 7% increase in seat belt use among drivers of cars with seat belt reminders, compared with drivers of unequipped vehicles (Williams, 2002). A driver survey found that of the two thirds who activated the system, three quarters reported using their seat belt and nearly half of all respondents said their belt use had increased (Williams, 2003). It is also estimated in Sweden that reminders in all cars could contribute to a further reduction of 20% of car occupant deaths.

A cost-benefit analysis for the mandatory introduction of audible seat belt reminders for front seats in 2004 was undertaken by ETSC. It was based on the assumption that roughly 50% of fatally injured front seat car occupants in the EU did not wear seat belts and that audible seat belt reminders for the front seat could increase seat belt wearing among front seat occupants to 97%. After twelve years of introduction, the costs would amount to about 11 million Euros while the benefit would be 66 million Euros. The benefit to cost ratio of seat belt reminders was estimated at 6:1 (ETSC, 2004).

3.3. Electronic Stability Control (ESC)

Electronic stability control (ESC) is an active safety system which can be fitted to cars, buses, coaches and trucks. It is an extension of anti-lock braking technology, which has speed sensors and independent braking for each wheel. It aims to stabilise the vehicle and prevent skidding under all driving conditions and situations, within physical limits, especially on wet or icy roads or in rollovers. This is achieved by identifying a critical driving situation and applying specific brake pressure on one or more wheels, as required. (SUPREME).

Evaluation studies have shown that the fitment of ESC in cars has led to substantial reductions in crashes, deaths and serious injuries at the top end of the market. A Swedish study in 2003 showed that cars fitted with ESC were 22% less likely to be involved in crashes than those without. There were 32% and 38% fewer crashes in wet and snowy conditions respectively (Tingvall, 2003). In Japan, a study showed that electronic stability reduced crash involvement by 30-35% (Aga & Okada, 2003). In Germany, one study indicated a similar reduction while another showed a reduction in ‘loss-of-control’ crashes from 21% to 12% (Breuer, 2002). UK research indicates that equipping a vehicle with ESC reduces the risk of being involved in a fatal crash by 25%. The research also shows a particularly high effectiveness for reducing serious crashes involving other loss of control situations such as skidding (33%), and rollover (59%) (Frampton 2007). Research at the US Insurance Institute for Highway Safety (2006) found that ESC led to a reduction rate of 32% of the risk of fatal multiple vehicle crashes and a reduced risk of single vehicle crashes by more than 40% (of fatal ones: 56%). A recent US study indicated a 5% overall reduction in all impacts and a 23% reduction in fatalities in passenger car crashes reported to the police (Sivinski, 2011). The FIA Foundation estimated in 2007 that equipping all vehicles with an ESC system could save over 500 deaths and 2500 serious injuries per year in the European Union.

A Norwegian benefit to cost analysis considered two scenarios for ESC fitment (Elvik, 2007). The first was that ESC continues to be fitted gradually through the vehicle fleet, but is not made mandatory. The benefit-cost ratio in this scenario was estimated to be 4. The second scenario was ESC retrofitted on all cars of whatever age producing a benefit-cost ratio of about 0,4.

3.4. Alcohol Interlock Systems

Excess alcohol contributes to about 25% of all road deaths in Europe. Alcohol ignition interlock systems are automatic control systems which are designed to prevent driving with excess alcohol by requiring the driver to blow into an in-car breathalyser before starting the ignition. The alcohol interlock can be set at different levels and limits. They aim to address excess alcohol in the general driving population and are being increasingly used in commercial and public transport operations, as well as in repeat offender schemes.

Large scale quantitative research on alcohol interlocks in use has shown that they are 40 to 95% more effective in preventing drink and driving recidivism than traditional measures such as licence withdrawal or fines (ICADTS, 2001; SUPREME, 2007). A literature review (UK Department for Transport, 2004) showed a recidivism reduction of about 28-65% in the period where the alcohol interlock is installed compared with the control groups who were not using the alcohol lock. Additionally, an EU study indicated that alcohol interlocks need to be fitted permanently to have an effect, for after removal of the lock recidivism increases again (Bax et al., 2001). While there has been no evaluation of the impact that alcohol interlocks used in commercial transport have on road safety, Swedish companies report that fitting alcohol interlocks prevented excess alcohol amongst fleet drivers. Some 23% of municipalities and 18% of county councils have stipulated the need for alcohol interlocks when purchasing new public and private transport vehicles. Some 70.000 alcohol interlocks are in use in Sweden in trucks, buses and taxis on a voluntary basis (Swedish Government Report).

The results of cost benefit analyses for implementing alcohol interlocks for drivers caught twice with a BAC between 0,5g/l and 1,3g/l and for drivers caught with a BAC above 1,3g/l vary between 0,7 and 4,5 in several European countries (Vlakveld et al., IMMORTAL, 2005).

3.5. In-vehicle event data recorders

These devices can be used in cars and commercial transport as a valuable research tool to monitor or validate new safety technology, to establish human tolerance limits and to record impact speeds. Even data recorders can also be used to influence driving behaviour and facilitate forms of automatic policing. Offenders can be tracked more easily and fined automatically by means of devices such as Electronic Vehicle Identification. Two types of in-vehicle data recorders are currently used, which can provide useful data for road safety purposes: crash data recorders and journey data recorders.

Crash data recorders collect data over a period before and after the crash and critical events. They are often based on the airbag control module and will cease to store information once the airbag has deployed (Langeveld & Schoon, 2004). Research indicates that data recorders fitted to trucks and vans lead to an average reduction of 20% on the number of crashes and damage (Wouters & Bos, 2000). The effect derives from the driver's knowledge that traffic law infringements can, in principle, be detected by examination of the driving records. On the other hand, journey data recorders collect data during driving, which can provide information regarding driving behaviour and any law infringements or be used to monitor driving in relation to insurance costs, while the information can be used for traffic management purposes as well. They can also be an important source of research data regarding the risks of normal driving and the nature of traffic conflicts. A study for the Netherlands (Langeveld & Schoon, 2004) has estimated the benefits and cost ratios of journey data recorders as 20:1.

3.6. Anti-lock braking systems in cars (ABS)

The main purpose of ABS is to prevent skidding where loss of steering and control result from locked wheels when braking hard. Such systems are now fitted to many new cars. This is intended to provide additional steering in an emergency situation, not to decrease stopping distances. A meta-analysis of research studies shows that ABS give a relatively small, but statistically significant reduction in the number of crashes, when all levels of severity and types of crashes are taken together. There are statistically significant increases in rollover, single-vehicle crashes and collisions with fixed objects. There are statistically significant decreases in collisions with pedestrians/ cyclists/ animals and collisions involving turning vehicles. ABS brakes do not appear to have any effect on rear-end collisions. However, while injury crashes decrease (-5%), fatal crashes increase (+6%) (Elvik et al., 2009). One study, however, indicates that anti-lock brakes may not contribute to crash prevention at all (Cummings & Grossman, 2007).

3.7. Autonomous emergency braking (AEB) systems

AEB systems detect approaching vehicles or other road users and apply braking to either prevent a collision occurring or to reduce the impact severity. Early systems were relatively slow in analysing the information from the camera or LIDAR sensors and these systems were therefore only able to brake sufficiently to avoid a collision with a relative velocity of around 15 kph. More recent systems can operate faster and can therefore detect obstacles at greater travel speeds. In addition, early systems were only able to detect cars, however, object recognition of more recent systems now includes PTWs, pedestrians and cyclists although to a lower level of precision.

A meta-analysis (Fildes et al, 2015) based on accident data from six countries identified that vehicles equipped with City-AEB systems were effective in preventing 38% of front to rear collisions. A further analysis of collision claims (IIHS 2013) examined two Volvo models and found reduced collision claim frequencies of 9%-20%. More recently it was observed that AEB in conjunction with forward collision warning systems reduced rear end collisions with injury by 44% (Ciccino, 2016), however the reduction from FCW systems alone was not significant.

3.8. Anti-lock braking for motorcycles

Anti-lock braking systems are in-vehicle devices which aim to prevent the locking of wheels during braking when under emergency conditions, so preventing the motorcyclist from falling off their vehicles.

A German study concludes that in 93% of cases where the motorcyclist fell of the vehicles, ABS would have avoided the crash or at least reduced the severity of the accident. This provides an estimated reduction in fatal and severe injuries to motorcycle drivers by 8 to 10% in Germany (Winkelbauer, 2006). Another prospective estimate also suggests that ABS might reduce the number of crash victims by at least 10% (Sporner & Kramlich, 2000). A Swedish study (Rizzi, 2009) has evaluated the effectiveness of antilock brake system (ABS) technology on motorcycles in reducing real life injury crashes and to mitigate injury severity. Moreover, induced exposure analysis showed that the overall effectiveness of ABS was 38% for all injury crashes and 48% for severe and fatal crashes, with a minimum effectiveness of 11% and 17% respectively. Since the launch of the Swedish Transport Administration’s study results in June 2009, Swedish importers have increased the number of motorcycle models with ABS as standard and the share of new motorcycles with ABS has gone from 15% in 2009 to 60% in 2010 (Swedish Roads Administration, 2011).

4. UNKNOWN SAFETY EFFECTS OF ADAS

This section discusses a range of new technologies that are being promoted currently by the European car industry and EU institutions amongst others as promising safety measures. These either are being fitted widely, ready for implementation or are under development. While safety benefits have been predicted for such measures, their effects and/or feasibility have still to be scientifically demonstrated. Such technologies may even lead to disbenefits where some vehicles are equipped but not others.

4.1. Emergency Brake Assist

Emergency Brake Assist in emergency situations is a technology which comes as standard on new cars forms part of an EU legislative package on pedestrian protection. Emergency Brake Assist aims to address the problem of insufficient pressure being applied to the brake by drivers in emergency situations, so increasing stopping distances. Car manufacturing trials have shown that brake assistance systems could help by providing full braking effect, where the driver does not press hard enough on the pedal. In marketing material, Daimler Chrysler indicate that for a car braking at 100km/h, Emergency Brake Assist can reduce the normal stopping distance by 45%.

In general most of the devices described for improvement of braking and handling interfere with driver behaviour, as well as the matter of driver acceptance, risk compensation and driver reaction, when the system is activated, are important (especially for old drivers). There is no standard method to assess the safety performance of these devices, which makes it difficult to estimate their potential benefits. Moreover, under the same name very different systems can be found, as each manufacturer has its own specification.

While a prospective estimate has been made for Emergency Brake Assist to reduce fatal and serious injuries among pedestrians by 10%, the same study noted that the casualty reduction effect of Emergency Brake Assist has yet to be scientifically established (Hardy & Lawrence, 2005). A Swedish study of real-world pedestrian crashes found that the isolated effects of Emergency Brake Assist on pedestrian safety were not significant enough (Strandroth et al., 2011).

4.2. Collision avoidance systems

Much work is being carried out on technologies such as collision avoidance systems but their usefulness in addressing high-risk crash scenarios typical of most European roads as well as their feasibility has yet to be determined. Research on collision warning and collision avoidance systems is taking place in Japan, the United States and in the European Union within the European Commission's H2020 research programme. Very large estimates of the safety potential of such systems have been claimed following laboratory studies, but the range of technical and behavioural issues involved in many of the concepts require full on-road assessment. To be practical, most of the proposed systems require a well-controlled traffic situation, such as that found on motorways where the casualty reduction potential is relatively low.

4.3. eCall

eCall is a system that provides an automated message to the emergency services following a road crash which includes the precise crash location. The in-vehicle eCall is an emergency call (an E112 wireless call) generated either manually by the vehicle occupants by pushing a button or automatically via activation of in-vehicle sensors after a crash. When activated, the in-vehicle eCall device will establish an emergency call carrying both voice and data directly to the nearest emergency services. The voice call enables vehicle occupants to communicate with the trained eCall operator. At the same time, a minimum set of data will be sent to the eCall operator receiving the voice call, which contains information about the incident time, precise location, vehicle identification, eCall status and information about a possible service provider (CEC, 2005).

These systems aim to reduce the time between the occurrence of the crash and the provision of medical services, and thus, to reduce the consequences of injury in order to prevent death and disability, particularly in single vehicle crashes. A prospective Finnish study has estimated that such a system might reduce between 4-8% of road deaths and 5-10% of motor vehicle occupant deaths in Finland (Virtanen et al., 2006). The study assumed that all vehicles were equipped with the eCall terminal and that each terminal would function properly. The study was unable to evaluate the impact of the precise location information given by eCall on the swifter arrival of rescue units at the crash site in the evaluation of decrease in road traffic deaths. The overall impact of the system which involves additional players has not been evaluated. The Finnish study noted that through "the comparison of the 4–8% decrease in traffic accident fatalities arrived at in this study with the figures of other European studies, one can see that the results are similar to the German (5%) and Dutch (7%) estimations. The estimations in Sweden (2–4%) and Great Britain (2%) are smaller and the estimate for the whole EU area (5–15%) greater than the estimate in this study. The American estimation for the decrease in traffic accident fatalities based on field studies was smaller (2–3%) than in this study. The estimate made by the doctors was, however, greater (9–11%)". The European Commission believes that a pan-European eCall is estimated to have the potential to save up to 2.500 fatalities annually in the EU when fully deployed (Bouler, 2005).

The benefits to cost ratio (BCR) of eCall in Finland have been found to be in the range of 0,5 (minimum estimate) to 2:3 (maximum estimate). A UK benefit to cost analysis concluded that universal fitment of eCall would result in more costs than benefits (McClure & Graham, 2006).

5. CONCLUSIONS

Vehicle safety plays a key role in the protection of all road user and in the achievement of long term goals and targets of road safety strategies. Vehicle safety is distinguished in following types of safety: the primary safety, which comprises measures targeting at crash avoidance and injury prevention and the secondary safety, which comprises measures targeting at the reduction of the injury in the event of crash and those which assist the post-impact care. While new in-vehicle technologies have the potential to decrease crash injury risk, they may also increase it through introducing new driver distraction and inadvertent behavioural change which may solve one problem but create another.

This paper presents the most recent findings of the literature and research project concerning the advanced driver assistance systems, the measures taken, their effects on road safety as well as information on their costs and benefits. Based on current knowledge about safety impacts and feasibility, the measures discussed are divided in two broad groups, those with safety effects known and those with safety effects unknown.

While research has attempted to record and classify ADAS by their impacts, various problems need to be addressed in the assessment of both existing and new systems. No systematic methods currently exist to evaluate new systems. While systems are under development, they are not yet mature. It is not possible to predict eventual casualty reduction on the basis of experimental studies, field trials or simulators for most new systems. Further naturalistic driving studies and the establishment of a European in-depth crash injury database are urgently required to evaluate current measures as well as identify future problems and solutions. In addition, the implications of retrofit of nomadic devices could be problematic since the response of the vehicle to the technology in question might not be predictable. There needs to be a clear policy for handling nomadic devices so that no gross assumptions are made to the effect that any single device will offer the same benefit to all vehicle types and make/models and that they will not interfere with vehicle systems or add to the load of the driver.

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