Automated Emergency Brake Systems: Technical requirements, costs and benefits

by C Grover, I Knight, F Okoro, I Simmons, G Couper, P Massie, and B Smith

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Executive summary

Vehicle technology has increased rapidly in recent years, particularly in relation to braking systems and sensing systems. The widespread introduction of anti-lock braking systems (ABS) has provided the building blocks for a wide variety of braking control systems. Additional hardware that allows brake pressure to be increased above pedal demand as well as to be reduced, combined with additional software control algorithms and sensors allow traction control (TC), electronic brake force distribution (EBD), brake assist (BA) and electronic stability control (ESC) functions to be added.

In parallel to the development of braking technologies, sensors have been developed that are capable of detecting physical obstacles, other vehicles or pedestrians around the vehicle. Many luxury, mid-size and small cars in Europe, and in Japan even very small cars (Daihatsu Move), are now fitted with an adaptive cruise control (ACC) system that is capable of measuring and maintaining a driver-preset headway to the vehicle ahead by automatic modulation of the engine control, and if required, automatically applying brakes up to a maximum deceleration of 0.3g (as per ISO standard). If no vehicle is ahead, the vehicle maintains the desired "set-speed". ACC can be ordered as an option for new vehicles. At least three heavy truck manufacturers offer this feature on their vehicles.

Theoretically, a vehicle equipped with modern braking technology and adaptive cruise control is equipped with the basic building blocks for a simple (braking only – no steering) collision avoidance system that would be capable of detecting when a collision is likely to occur and applying emergency braking to avoid it. More advanced and/or multiple sensors are likely to be required as well as considerable further development before full collision avoidance systems (other than low speed systems) are available in production. However, collision mitigation systems are already on the market, providing limited automated braking capability and some systems are available that can automatically avoid collisions in low speed traffic.

The focus of this project has been on the physical requirements of AEBS systems rather than any requirements or benefits relating to human factors issues, which although important were excluded from the project because of the limited scope of work available. Thus, the potential benefits of ACC and collision warning functions have been excluded from the cost benefit analysis. The project has also aimed to be independent of the technology (e.g., radar, lidar, infra red, video, etc.) used to achieve the requirements although brief reference to and/or short summaries of these other issues have been made.

The project has aimed to distinguish between systems currently in production and those future systems currently in development. However, the rapidly developing market for such systems has meant that some systems in development at the start of the project had reached production by the end. Where reference is made to current production systems it should be considered to mean current at the start of the project and not necessarily at the date of publication.

The scope of this project allowed for no test or simulation of the actual performance of current generation automatic emergency braking systems (AEBS). The project has aimed to assess systems based on:

- Review of scientific literature;
- Gathering information from industry;
- Analysis of accident data;
- Simulation of potential implications of reduced accident severity on congestion costs;
- Cost benefit analysis.

The main conclusions from the work are listed below:

1. Automatic emergency braking systems (AEBS) were in production on a number of current vehicles at the top end of the market in the early stages of this work and are capable of autonomously mitigating two-vehicle front to rear shunt accidents as well as some collisions

with fixed objects and motorcycles. Such systems were fitted alongside ACC and forward collision warning systems that shared the same hardware.

2. Systems are currently in various phases of development that will also act in pedestrian collisions and towards the end of the project at least one system offering some pedestrian functionality was released on a production vehicle. There is also a strong research base that aims to develop systems capable of acting in other vehicle to vehicle impact configurations.

3. Clear functional requirements for AEBS are in existence in Japan and appear to be appropriate to use as guidance for systems in Europe subject to modification of some limit values. An ISO standard is under development but was not yet available for study. There remains insufficient information available at this time to produce more rigorous standards that more closely define performance or to define methods of testing the effectiveness of the whole system and further research may be required in this area.

4. Further requirements are required to cover the integrity of the system. Some of these, such as reliability of the system and resistance to EMC issues are already embodied in regulation and are covered, at least to a minimum standard. There was however, evidence to suggest that further research was required to examine whether the safety critical nature of AEBS requires more stringent limits in these areas. Other areas such as environmental protection including immunity to electro-static discharge and particularly relating to the compatibility and reliability of similar and different systems when numerous modules are on the road are not covered and may need additional measures. In particular, the possibility that interference could occur when multiple sensing systems "meet" at a busy road section may require further investigation.

5. Substantial difficulties have been encountered in trying to define the benefits of an AEBS in terms of casualty reduction. These are related to fundamental limitations in terms of the detail available in accident databases and the reconstruction methods used to generate them and also related to the limited scope of the project which considered only the benefits of the automated braking and not the benefits of ACC, the collision warning and optimised restraint functions.

6. It was not possible to establish detailed and accurate estimates of the costs of systems because of commercial sensitivity and difficulties in separating the costs of different functions that shared the same hardware. Only current retail prices of optional systems, target costs for future systems and a broad range of generic cost estimates from industry were available.

7. Instead of a detailed analysis of the costs and benefits of current, first generation AEBS, a high level scoping analysis was carried out to indicate the potential benefits if certain levels of effectiveness could be achieved in a wide range of collision situations. This analysis reached the following conclusions.

    a. Immediate introduction of AEBS that approximated first generation system functions (front to rear collisions and collisions with rigid fixed objects located on the carriageway) to all light vehicles offered considerable casualty reduction potential but was unlikely to be cost effective unless substantial cost reductions could be achieved. The main reasons for this were the high frequency/low severity nature of light vehicle shunt accidents and the high number of vehicles that must be fitted with the technology to achieve the benefits.

    b. Immediately equipping all new heavy vehicles with such a system would yield a lower casualty reduction but a better benefit to cost ratio because of the much lower number of vehicles requiring fitment and the increased severity of front to rear collisions involving heavy vehicles.

    c. Introducing AEBS that was also effective in collisions with pedestrians and with fixed objects off the carriageway substantially changed the view of the systems. The casualty reduction potential in this situation was greatly increased and if fitted to all M and N vehicles it would be likely to have a fatality saving potential in the thousands if implemented across the EU vehicle fleet. The research suggests that at some point in the next three to eight years the technology to enable these functions will be readily available. The limited evidence available regarding the costs of the systems suggested alternative possibilities where either a combination of “low cost” sensors and increased production volumes decreased the cost or where increased technical complexity increased the costs. Achieving the considerable potential benefits with a substantially positive benefit to cost ratio is therefore strongly dependant on the system cost, although positive ratios are much more likely for fitment to M2, M3, N2 and N3 vehicles.

d. Further developments to allow function in head on and junction collisions also offer a substantial increase in both the casualty reduction potential and the benefit to cost ratio, although increased technical difficulty may increase costs or limit benefits.

e. Substantial technical difficulties are likely to be encountered when considering fitment of AEBS to motorcycles but if these can be overcome then substantial casualty savings are achievable with a high potential for a benefit to cost ratio in excess of one.

8. Overall, it was found that AEBS is highly likely to be a very effective safety measure in terms of both casualty reduction and benefit to cost ratio in the relatively near future, provided further technical development and cost reduction take place.

1 Introduction

Vehicle technology has increased rapidly in recent years, particularly in relation to braking systems and sensing systems. The widespread introduction of anti-lock braking systems (ABS) has provided the building blocks for a wide variety of braking control systems. Additional hardware that allows brake pressure to be increased above pedal demand as well as to be reduced, combined with additional software control algorithms and sensors allow traction control (TC), electronic brake force distribution (EBD), brake assist (BAS) and electronic stability control (ESC) functions to be added.

In parallel to the development of braking technologies, sensors have been developed that are capable of detecting physical obstacles, other vehicles or pedestrians around the vehicle. Many luxury, mid-size and small cars in Europe, and in Japan even very small cars (Daihatsu Move), are now fitted with an adaptive cruise control (ACC) system that is capable of measuring and maintaining a driver-preset headway to the vehicle ahead by automatic modulation of the engine control, and if required, automatically applying brakes up to a maximum deceleration of 0.3g (as per ISO standard). If no vehicle is ahead, the vehicle maintains the desired “set-speed”. ACC can be ordered as an option for new vehicles. At least three heavy truck manufacturers offer this feature on their vehicles.

Theoretically, a vehicle equipped with modern braking technology and adaptive cruise control is equipped with all of the necessary hardware to allow a simple (braking only – no steering) collision avoidance system that would be capable of detecting when a collision is likely to occur and applying emergency braking to avoid it. Collision mitigation systems are already on the market, providing limited braking capability.

Integrated safety systems based on these principles can be broadly divided into three categories:

- **Collision avoidance –** Sensors detect a potential collision and take action to avoid it entirely, taking control away from the driver. In the context of braking this is likely to include applying emergency braking sufficiently early that the vehicle can be brought to a standstill before a collision occurs. In future, this could also include steering actions independent of the driver. This category is likely to have the highest potential benefits but is the highest risk approach because a false activation of the system has the potential to increase the risk to other road users

- **Collision mitigation braking systems (CMBS)** – Sensors detect a potential collision but take no immediate action to avoid it. Once the sensing system has detected that the collision has become inevitable regardless of braking or steering actions then emergency braking is automatically applied (independent of driver action) to reduce the collision speed, and hence injury severity, of the collision. This type of system has lower potential benefits but is lower risk because it will not take control away from the driver until a point very close to a collision where the sensing system is likely to be more reliable. Such a system may also trigger actions related to secondary safety such as the pre-arming or optimisation of restraints.

- **Forward collision warning** – Sensors detect a potential collision and take action to warn the driver. This is the least risky option since false detection of a collision only has impacts on the driver’s reaction to, and perception of, the system. This type of system could also be used to optimise restraints. This type of system has been sold on some EU vehicles since 1999.

The original focus of this project was to assess the technical requirements, costs and benefits relating to collision mitigation braking systems in their current form, however, as the project has developed the scope has expanded to consider, the potential benefits that could arise from automatic emergency braking systems (AEBS) that include avoidance capabilities and offer protection in a wider range of collision mechanisms. The focus has also been on the physical requirements of the system, rather than any requirements or benefits relating to human factors issues. Thus, the potential benefits of ACC and collision warning functions have not been considered in any detail. The project has also aimed to be independent of the technology (e.g., radar, lidar, infra red, video, etc.) used to achieve the requirements although brief reference to and/or short summaries of these other issues have been made.

2 Research methods

The scope of this project allowed for no test or simulation of the actual performance of current generation automatic emergency braking systems (AEBS). The project has aimed to assess systems based on:

- Review of scientific literature;
- Gathering information from industry;
- Analysis of accident data;
- Simulation of potential implications of reduced accident severity on congestion costs;
- Cost benefit analysis.

An extensive review of literature was carried out. This included marketing and promotional information from manufacturers on AEBS and other active safety systems that they sold or were developing as well as scientific papers on the technical behaviour and development of such systems and technical standards, regulations and guidelines and research papers on the effectiveness of systems.

The project has been carried out in an open manner with industry involvement at several stages. Representatives of the automotive industry and other interested stakeholders were invited to the three main project meetings at inception, mid-point and final. In addition to input provided at these meetings, attendees were asked to complete two separate surveys. The first requested detailed information about the technical characteristics and performance of AEBS systems that were either in production or under development. The respondents included vehicle manufacturers and tier one suppliers and was widely distributed via the relevant trade bodies (e.g. ACEA, JAMA, CLEPA). The second survey was sent to the same respondents in a similar manner and asked for comments on a proposal for generic characteristics of systems to be tested against accident data to estimate benefits and to request information concerning the cost of the systems for use in the cost benefit analysis.

In addition to the scientific research identified that assessed AEBS in terms of effectiveness and accidents, specific studies of accident data were carried out. This involved the use of the UK STATS 19, On-the-Spot (OTS), and Heavy Vehicle Crash Injury Study (HVCIS) databases. The work was necessarily focussed on the use of UK databases for the in-depth analysis because these are the only data sources with sufficient level of detail for the assessment to which TRL has access. Estimates of the effect across Europe were, therefore, made via the assumption that the detailed effect in other countries would be the same as in the UK and that the high level differences in accident types and numbers would be accounted for by using the EU CARE database.

Most analyses of the costs and benefits of vehicle safety systems rely on accidents as the principal benefit. However, congestion is becoming an increasing problem and it is widely recognised that accidents contribute substantially to congestion problems and that this congestion also represents a cost to European business and society. For this reason, a preliminary investigation of the potential reduction in congestion that might arise from reducing the severity of accidents was carried out, based on the principle that accidents of lesser severity may, typically, have shorter durations in terms of road and lane closures and the obstruction of other traffic. This analysis was carried out based principally on UK data derived for separate research for the UK Highways Agency and the use of a congestion cost model known as INCA. In addition to this, the EC supplied TRL with information on the congestion costs from Germany which were also incorporated in the cost benefit analyses in order to provide a range of estimates of the effect.

3 Limitations of the study

The term Automated Emergency Braking Systems covers a very wide diversity of different systems from different manufacturers. Many of these systems share hardware and are integrated with other systems that do not involve automated emergency braking, such as adaptive cruise control, forward collision warning, and predictive brake assist systems. The scope of this project was, therefore, potentially very wide and it was not possible, within the available resources, to consider all aspects of all systems in detail. The research, therefore, focussed mainly on the parts of systems that involved automated emergency braking and within this, mainly on collision mitigation braking systems. The project was also limited to reviews of literature, consultation with stakeholders and analysis of accident data. It was not, therefore, possible to validate or extend any of the findings using simulation or testing. The HMI and driver behavioural aspects of systems were not considered in depth and the casualty effects of CMBS were considered in isolation. It is likely that the estimates of the benefits of CMBS will be an over-estimate because of this limitation. In reality, vehicles fitted with CMBS will first have been fitted with ACC and forward collision warnings. It is, therefore, highly likely that the warning aspects of these systems will have prevented a proportion of the accidents that CMBS would be likely to have mitigated, meaning that the automated braking function will be able to affect fewer accidents.

In addition to this, by the time that the use of CMBS or more advanced AEBS are in widespread use on vehicles, a number of other safety measures will have been implemented. These could include more widespread use of ESC and BAS, enhanced occupant protection, improved road designs, intelligent speed adaptation, alcolocks etc. Some of these other measures would also be expected to prevent some of the accidents that this analysis will assume AEBS can affect. However, such consideration of these wider changes in the transport safety field is extremely difficult and expensive to undertake and, as such, very few analyses of this type take them into account. So although this feature of this research means that in absolute terms estimates of casualty savings will be an over-estimate, in relative terms the predicted benefits will be comparable to those of most other studies.

Most of these systems involve very new technology and are either in research, development or early production phases. Although there is a reasonable amount of published research available studying the principles associated with this type of system, commercial sensitivities mean that there is very little scientific information available about the specific systems available on the market today and very little information on cost. For this reason, the project has had to rely heavily on information direct from a group of industry stakeholders asked to contribute to the project and marketing information from Manufacturers web-sites and marketing departments. In some cases, conflicting information on systems was identified from these different sources. Every effort has been made to avoid inconsistencies as a result of this problem but it is possible that some may remain.

TRL were asked to consider the benefits of avoiding accidents and/or reducing their severity in terms of the effects on congestion as well as the effects on injury reduction. At present there are few standard valuations of the effect of accident reduction on congestion. The analysis of congestion effects has relied on one such valuation from Germany and a crude analysis of the effects on the UK. The latter analysis was based on investigation of accidents and delay times on one specific section of motorway in the UK and assuming that the results applied across the whole of the UK. Whilst this analysis involves very large assumptions, it was found to be fairly consistent with the German valuation and it appears that when the effects of accidents on congestion are considered in this way that the financial values assigned to the congestion effects are orders of magnitude lower than the values assigned to the injury prevention aspects of the same accidents. Thus, although the congestion estimates are crude, they have little effect on the overall estimates of financial benefits or break-even costs per vehicle.

It should be noted that the above limitation only applies to the estimate of congestion effects. The estimates of casualty effects were based on accident databases covering all different types of roads in either regionally or nationally representative samples. These UK estimates were then extrapolated to Europe via the CARE database, which accounts for different accident totals in different Member States but does not account for different distribution of accident types. The potential for different accident patterns in different member states was acknowledged by applying a tolerance of ±10% to each accident type in the extrapolation process.

The effectiveness of a first generation CMBS system fitted to trucks was derived based on two boundary conditions describing the characteristics of a generic system and applying this to detailed UK accident data. This produced a range of percentage effectiveness. However, it was not possible to derive such effectiveness measures for light vehicles or for systems that functioned in different types of conditions. For these different vehicle types and accident configurations, the *potential* benefits were approximated by assessing the size of the casualty group that could potentially be affected ***IF*** these other systems could also be made to have the same effectiveness as a first generation CMBS fitted to a truck. This is a very simplistic approach and really assesses the potential benefits of *ANY* safety feature that could achieve that level of effectiveness in that type of collision.

4 Results

4.1 Current production systems

This section identifies the range of active safety systems related to automated emergency braking that are currently fitted to production vehicles and describes the technical performance of these systems. It should be noted that this is a rapidly developing field and new systems are regularly entering production. Some systems reported in this section were not in production at the initial time of writing but were by the end of the project. This should not, therefore, be considered as a definitive list for the time at which the report was published. Where reference is made to a system either being under development or in production it should be considered in relation to the start of the project in June 2006, unless otherwise stated.

4.1.1 Forward collision warning/brake assist

Bosch has developed a suite of Predictive Safety Systems (PSS), the aim of which is to warn drivers of an impending emergency situation, support them and intervene to reduce the consequences of an accident (www.bosch.com.cn). The description provided in the manufacturer's literature states that the radar sensor used for Adaptive Cruise Control (ACC) monitors a distance of up to 200m ahead of the vehicle to detect vehicles in the same lane and calculate their distance and speed. When a dangerous situation is recognised in the area in front of the vehicle safety measures are introduced in three stages as soon as an accident is likely. If an accident risk is detected an emergency stop is considered by the system to be probable and the manufacturer then describes the following actions that can be taken:

- The first stage, the Predictive Brake Assistant (PBA), prepares the braking system for an emergency stop by pre-filling the circuit with fluid such that the linings are just in contact with the discs. The tripping threshold of the Hydraulic Brake Assist (HBA) system is also lowered. In this way Bosch claim that as soon as the driver initiates braking, full braking performance is available, around 30ms earlier than without the system, significantly shortening braking distances. Bosch suggest that this will offer substantial safety benefits because only one-third of drivers react to an emergency braking situation with a full brake application and also state that *"most drivers are so hesitant that hydraulic brake assist is not activated"*.
- Predictive Collision Warning (PCW) is the second module warning the driver of critical situations by applying a short burst of braking, a brief tug on the seatbelt and visual and acoustic signals to warn of imminent danger. Bosch claimed that a study by the Association of German Insurers shows that almost half of all drivers involved in accidents did not brake at all, prior to the crash. Early warning allows drivers to react faster to the danger of a collision by taking corrective action and/or braking to reduce the impact speed, significantly contributing to avoiding many accidents and reducing the severity of collisions.

The Nissan Brake Assist system with Preview Function (BAP) utilises information provided by Adaptive Cruise Control (ACC) sensors to judge when emergency braking application may be required based on the distance to the followed vehicle and the relative velocity (Tamura et al, 2001). Figure 1 is extracted from the paper by Tamura *et al* (2001) and shows that when an impending collision is detected a small braking force is applied to minimise the separation between the brake pad and rotor to reduce the brake response time. The small braking force is activated when the target deceleration for stopping without colliding with the vehicle ahead exceeds 5.88m/s² (0.6g).

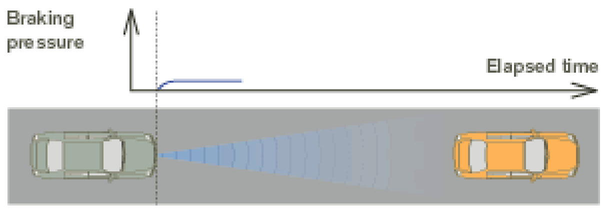

Figure 1: Nissan Brake Assist with a Preview Function (BAP) (Tamura *et al*, 2001)

Figure 2 shows the results of experiments conducted by Tamura *et al* (2001) with the prototype vehicle. It shows that the delay time from the operation of the brake pedal to the rise of the brake pressure was shortened by 100ms with BAP.

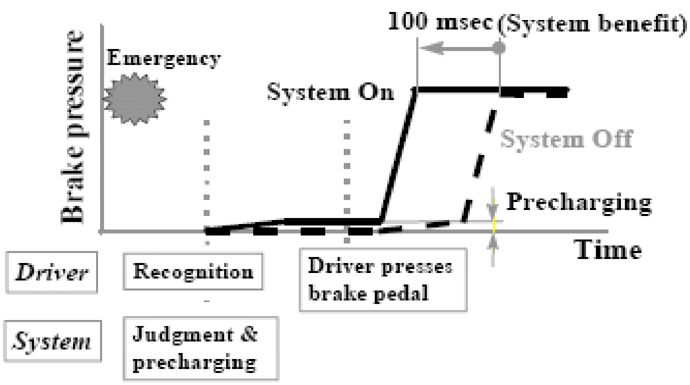

Figure 2: Brake system reaction (Tamura *et al*, 2001)

Tamura *et al* (2001) claim that the improved reaction time would translate into a 5km/h reduction in impact speed in a typical accident scenario where a driver travelling at 50km/h becomes aware of an obstacle at a forward distance of 20m. The impact speed of a BAP-equipped vehicle would be 17km/h, or 5km/h less than the 22km/h impact speed of a vehicle without this system.

4.1.2 Collision mitigation

A collision mitigation emergency braking system was fitted to the Toyota Harrier, launched in 2003 in Japan (www.denso.co.jp). Developed by DENSO with the Toyota Motor Corporation, the system identified inevitable obstacles a split second prior to collision, automatically tightened passenger seatbelts, and activated a pre-crash brake system to help reduce the impact speed.

Bosch has developed the Predictive Emergency Brake (PEB) as part of the suite of PSS (www.bosch.com.cn). The information on this system claims that should the driver fail to react to the warnings provided by PCW and an unavoidable accident is recognised due to the position and speed of the other vehicle the Predictive Emergency Brake (PEB) is activated. It intervenes in the driving process of the vehicle, taking control and automatically applying emergency braking at maximum force to respond to the imminent collision, reducing the impact speed in an attempt to minimise injuries. It is stated that in order that object recognition and accident risk assessment is reliable and robust the radar system must be supported by another measuring system such as video sensors.

The Honda Collision Mitigation Braking System (CMBS) entered production on the 2006 Legend saloon and the 2007 CR-V 4x4 (www.hondauk-media.co.uk). It is offered on several vehicle models in Japan and the USA it has been offered on the Acura (Legend). European Accords are expected to be offered with the system after the next model facelift. The aims of the system are to provide assistance in avoiding rear end collisions and to reduce the degree of occupant injury and vehicle damage in such accidents.

The available literature suggests that Adaptive Cruise Control (ACC) technology is used to monitor the road ahead, the millimetre-wave radar detects vehicles within a range of 4-100m in a horizontal detection area of 16° and a vertical detection area of 4°. The control ECU judges the risk of a collision approximately every 0.02s based on the location of the vehicle ahead and the relative speed between vehicles. When the closing rate to the vehicle in front increases to a point where a collision is likely to occur, CMBS operates in the following manner:

- A primary warning, comprising an audible warning and a visual 'BRAKE' warning on the dash display, is given when the space between the vehicles becomes closer than the set safety distance for 'normal avoidance' or 'normal cruising'. This warning is given at approximately three seconds time to collision. Depending on the situation at the time, a collision can be avoided with correct braking. At this stage brake assist will not be activated with light braking because the accident may be avoided with a normal brake application. Examples of when the collision may not be avoided at this stage include when the relative speed between vehicles is high, the grip available is low or if the driver's braking is insufficient.
- If the distance between the two vehicles continues to diminish, CMBS applies light braking and the driver's seatbelt pre-tensioner is activated by an electric motor which retracts the seatbelt gently two or three times, providing the driver with a tactile warning. The audible and visual warnings are also repeated. The secondary warning is given at approximately two seconds time to collision. At this stage the brake assist activation parameters are altered such that it is easily activated to provide maximum deceleration. Depending on the situation the collision may be avoided if the driver brakes appropriately, however in the case of high relative speed or low grip there are cases where the collision may not be avoided.
- If, after issuing the primary and secondary warnings, the system determines that a collision is unavoidable, the pre-tensioner retracts the driver's and front passenger's seatbelts and activates the brakes forcefully to reduce the speed of impact and mitigate the effects of the collision. At this stage, depending on the situation, it would be difficult for the driver to avoid the collision with last minute braking.

The literature claims that the Honda CMBS is effective at detecting, large vehicles, cars, larger motorcycles in the centre of the lane, parked vehicles, and roadside furniture. However, there are some limitations as described below:

- The sensor system is unable to accurately identify relative speeds less than 15km/h.
- Pedestrians cannot be detected
- Smaller motorcycles and two wheeled vehicles travelling in the edge of the road, diagonally parked vehicles and small objects such as fallen rocks may not be detected.
- The system will not function when the distance between vehicles is very short or when the conflict is very sudden such as at junctions
- The system may not function in adverse weather conditions

Nissan's Intelligent Brake Assist uses laser radar sensors to detect the distance to a preceding vehicle and the relative velocity (according to www.nissan-global.com). Figure 3 shows when there is a risk of a collision with the vehicle in front and the driver must take avoidance action immediately the system sounds a warning to prompt action by the driver to help avoid a rear-end collision. When a rear-end collision cannot be avoided by the driver's action the system activates the brakes to decelerate the vehicle at a maximum deceleration of 0.5g, thereby helping to reduce occupant injuries resulting from the collision.

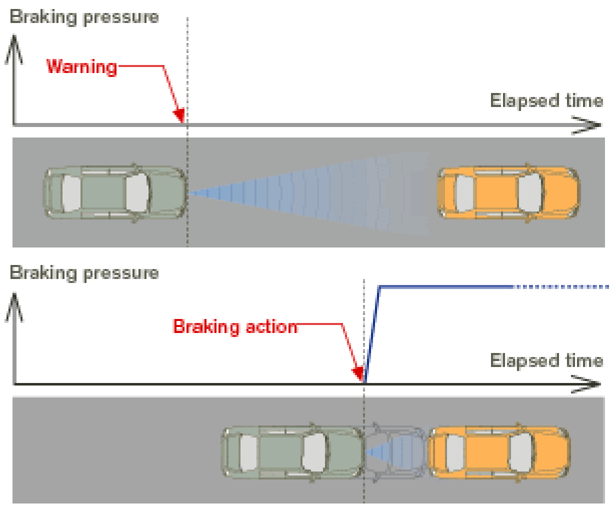

Figure 3: Nissan Intelligent Brake Assist (www.nissan-global.com)

The 2006 Mercedes-Benz S-Class is equipped with Brake Assist PLUS (BAS PLUS) and PRE-SAFE Brake (www.daimlerchrysler.com). The available information suggests that both systems utilize a single 77GHz radar sensor capable of monitoring a typical three lane motorway environment in front of the vehicle with a narrow field of view angle of nine degrees up to a distance of 150m. Two additional 24GHz radar sensors with an 80° field of view monitor the area immediately in front of the vehicle up to a distance of 30m. DISTRONIC PLUS is claimed to be an additional driver assistance system which also relies upon the radar sensors to provide adaptive cruise control at speeds between 0 and 200km/h, maintaining headway to the vehicle in front by automatically braking the vehicle to a standstill if required and then accelerating the vehicle as soon as the traffic situation allows. Depending on the speed, automatic deceleration of up to $4m/s^2$ is possible. Should heavier braking be required an audible warning is given telling the driver to watch the traffic situation and apply the brakes if necessary, and a warning light illuminates on the instrument cluster.

Daimler Chrysler claim that Brake Assist PLUS (BAS PLUS) expands BAS into an anticipatory system which registers the distance from the vehicle in front, provides an audible and visual warning to the driver when the gap is too small and calculates the deceleration necessary to avert a collision. The appropriate deceleration, which may not necessarily imply full ABS braking, will then be automatically applied as soon as the driver presses the brake. The fact that the system only provides the deceleration necessary to avoid a collision, rather than full ABS braking that might have been activated by a standard BAS, is claimed to give drivers behind the vehicle more time to react.

According to the manufacturers literature, PRE-SAFE Brake is a supplement to BAS PLUS. Should the driver fail to react to the warning proved by BAS PLUS, PRE-SAFE Brake intervenes by autonomously braking the vehicle with a deceleration of up to $4m/s^2$ if there is acute danger of an accident. Figure 4 shows a timeline representing a typical rear-end collision situation and the warnings provided.

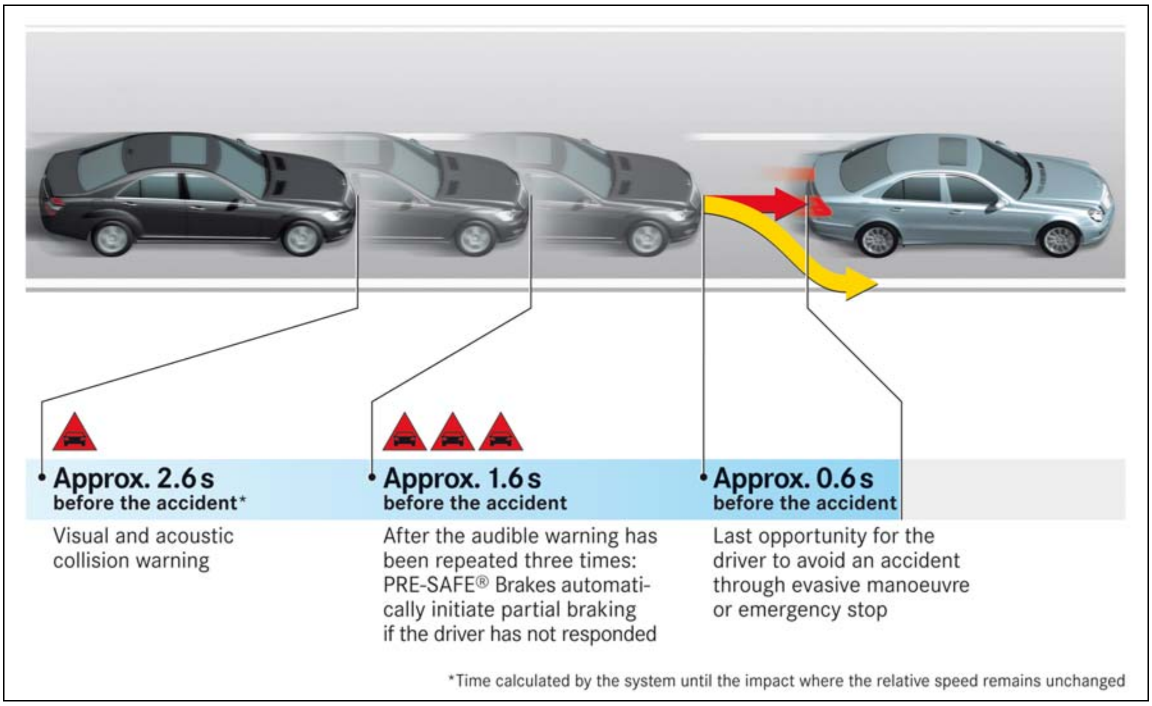

Figure 4: Warnings provided by PRE-SAFE Brake in typical rear-end collision situation (www.daimlerchrysler.com)

The system is active in the speed range between 10 and 180km/h where traffic is registered in front of the vehicle, and it also reacts when approaching a stationary queue of traffic providing the vehicle is not travelling at a speed in excess of 70km/h.

Collision Mitigation by Braking (CMbB) is a joint development between Ford Motor Company's Research and Advanced Engineering group and the Volvo Safety Centre (http://media.ford.com). Previewed on the Mercury Meta One concept vehicle, the system uses radar and camera sensors to detect vehicles on the road ahead to determine whether a collision is imminent based on the position, speed and direction of other vehicles. Using estimates of collision threat and driver intent, the CMbB system provides driver warning and enhanced brake control when needed, amplifying the driver's braking and automatically applying full braking when it determines with certainty that a collision with another vehicle is unavoidable. It is claimed that depending on speed and road factors, the braking can automatically reduce vehicle speed by five mile/h or more before an impact.

The 2007 Volvo S80 and Ford S-Max and Galaxy are fitted with a Collision Warning with Brake Support system that continually monitors the area in front with a radar sensor (www.media.volvocars.co.uk). If the driver fails to react when approaching a vehicle in front an audible signal and warning light are triggered. The brake linings are automatically prepared such that they are just in contact with the discs and the system will boost the brake force if the driver fails to brake hard enough, as well as flashing the brake lights to warn drivers behind. If the driver does not react to these alerts or start braking and the risk of colliding with the car in front increases, effective braking is applied automatically.

In the 2007 LS saloon, Lexus have introduced additional features to the Pre-Crash Safety (PCS) system (pressroom.toyota.com). One such feature is an obstacle identification system that is claimed to pick up a wide range of obstacles on the road ahead, including pedestrians and animals, which depending on weather conditions will be effective in both daylight and darkness (www.lexus.co.uk). The system combines information gathered from a 25GHz millimetre-wave radar and a twin-lens infra-red stereo camera. The camera monitors near infra-red radiation, emitted from dedicated units built into the car's headlamp high-beam projectors, reflected by objects directly ahead up to 25m. The PCS system assesses the likelihood of a collision with an obstacle ahead based on its position, speed and trajectory. If the collision probability is judged as high a warning buzzer and 'brake' alert on the dashboard display are activated. Additionally, to help avoid an impact, at 1.5s before impact the parameters of the brake assist are altered to give maximum brake pressure the moment the driver presses the brake pedal. If the systems determine that a collision cannot be avoided the front seat belts are pre-tensioned and the brakes are automatically applied to reduce the vehicle speed at impact. Literature prescribing the maximum deceleration achieved during autonomous braking was not identified for the LS saloon but a maximum deceleration of 0.3g was identified for a similar system in the GS saloon (pressroom.toyota.com).

Volvo is implementing the Collision Warning with Auto Brake system on the 2008 models of the S80, V70 and XC70 (www.media.volvocars.co.uk). The systems operates using a fusion of data from a long range radar (range 155m ahead of the vehicle) and a camera (range 55m), which is claimed to provide more reliable and efficient object recognition. When a potential collision is detected a red light flashes on the head up display and an audible signal is provided. To shorten the reaction time the brakes are prepared by the brake pads being placed against the discs. The brake pressure is also reinforced hydraulically, ensuring effective braking even if the driver does not press the brake pedal particularly hard (similar to Daimler Chrysler's Brake Assist Plus system). If the driver doesn't brake and the sensor system determines that a collision is imminent, the brakes are activated. Auto Brake is designed to lower the impact speed as much as possible. Depending on the circumstances, it is also possible that the Auto Brake can help avoid the impact entirely. System availability depends on the number and quality of visible road markings. The lane markings must be clearly visible for the camera. Poor light, fog, snow and extreme weather conditions can make the system unavailable.

Hino Motors report on a collision mitigation braking system for trucks (Ezoe et al, 2006). The system comprises of a millimetre wave radar sensor, yaw rate sensor and steering wheel angle sensor, the outputs of which are processed to judge the likelihood of a collision occurring. Figure 5 shows that if the likelihood of a rear end collision with an obstacle ahead is judged as probable, audible and visual warnings are provided to alert the driver and an automatic braking impulse is triggered to provide further warning. Should the driver fail to react to the warnings when the collision likelihood is judged as being high the system applies full autonomous braking in order to reduce the impact speed via the vehicle EBS.

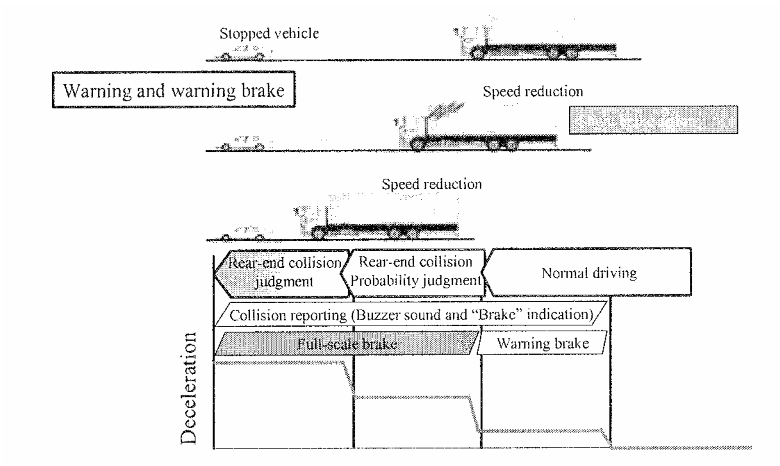

Figure 5: Hino Motors collision mitigation braking system intervention

A press release from Nikkei in Japan states that the Japanese Government will subsidise haulage companies that purchase trucks equipped with an AEBS for approximately half of the 550,000 Yen (c.€3,500) additional cost of the system.

Mercedes-Benz also has emergency braking systems in production for the Actros truck (http://media.daimlerchrysler.com). Proximity Control automatically ensures the road speed and headway to the vehicle in front are adapted to changing traffic conditions. A radar system similar to that on the S-Class monitors the traffic up to 150m in front of the vehicle, calculating the speed and distance between vehicles and evaluating any changes. To maintain headway the control system can decelerate the vehicle by means of the service and auxiliary brake and accelerate the vehicle using the cruise control function. Active Brake Assist builds on the function of the Proximity Control when there is an acute danger of a rear-end collision with a vehicle ahead. If the traffic situation does not change and an accident is likely, the driver first receives a visual and an audible warning. If the risk of a collision increases, partial braking (30% of braking power) is initiated to give the driver a further warning. If the driver still fails to react, the system automatically implements an emergency stop. Although the Active Brake Assist cannot actively prevent accidents, the application of the full braking power can reduce the collision speed and, therefore, the severity of the accident and its consequences.

Regarding future developments in truck safety, Volvo acknowledge Brake Assistance stating that *"it can help ensure that the truck is braked to the very maximum so as to minimise the collision speed"*, however there is no mention of a system currently fitted to production vehicles (www.volvo.com/trucks). ACC is available as an option on the Volvo FH and FM models (www.volvo.com/NR). The driver selects the time gap to the vehicle in front. The ACC system maintains this time by automatically controlling the throttle and brakes using the engine brake and auxiliary brakes. In situations when the auxiliary brakes are not able to maintain the distance, for example if the vehicle ahead brakes sharply, the driver is warned by an acoustic alarm and a light on the speedometer. The driver must then apply the normal wheel brakes. When a collision warning system is included, the system will also warn the driver of stationary vehicles and is activated if a large object appears within 30m of the front of the truck. The radar sensor system is operational over a range of approximately 150m with a horizontal and vertical field of view of 11°.

4.2 Potential future systems.

The scope and application of future AEBS could be influenced by the constraints of the 1968 Vienna Convention on Road Traffic. Article 8 (5) of the convention states that:

"Every driver shall at all times be able to control his vehicle…."

Article 13(1) further states that:

"Every driver of a vehicle shall in all circumstances have his vehicle under control so as to be able to exercise due and proper care and to be at all times in a position to perform all manoeuvres required of him…."

There is, therefore, a risk that any vehicle system that takes control away from the driver could be in contravention of the requirements of the Vienna Convention. However, opinion varies on the extent to which this constrains the design of active safety systems generally, and AEBS in particular, but it is clear that the systems already fitted to production vehicles, described in the preceding section, are not considered to be in contravention of the requirements. This issue has been studied extensively as part of the RESPONSE project and the requirements have been interpreted in a code of practice. The rationale of this interpretation is that controllability is the key factor in determining whether a system is in accordance with the Vienna convention. Schwarz (2007) suggests that wherever there is a chance that a driver could perform better than the automated system in terms of avoiding an accident then it must be possible to override the system so that the driver retains control. It was suggested, therefore, that an intelligent speed adaptation system that did not permit driver override would be in contravention of the Vienna Convention. However, the interpretation of the Response project (Scwarz, 2007) was that when the life and health of road users were directly threatened and the automated system could reduce the consequences this would not be in contravention of the Vienna convention because it was a situation that was beyond the control of the driver.

It can be seen that CMBS would be expected to fall under the latter category because it only acts when the collision has become unavoidable. However, as the technology develops towards full collision avoidance systems the Vienna Convention has the potential to become more of a constraint and it is possible that amendments may be required if future developments suggest that it is desirable.

4.2.1 *Forward collision warning and collision mitigation*

Although most of the forward collision warning and collision mitigation braking systems currently fitted to production vehicles mainly only function in front to rear shunt collisions and forward collisions with stationary objects, several research papers describing the development of the systems refer to function in other collision types. Jansson *et al* (2002) describe decision making algorithms and the results of computer simulations for systems intended to function in the following impact configurations:

- Front of host vehicle to rear of partner vehicle;
- Front of host vehicle to stationary object;
- Head on collision;
- Front to rear collision when the other vehicle suddenly changes lane to be in the path of the host vehicle;
- Head on collision when the other vehicle suddenly changes lane to be in the path of the host vehicle.

They also presented assessments of situations where collisions were not inevitable, for example, where a vehicle in the same lane brakes very hard causing a risk of a front to rear collision but then quickly turns out of the lane such that it clears the path of the host vehicle just in time. They predicted that the system and the detection algorithms they had developed would reduce collision speed substantially but that further development was required to ensure that the system suffered zero faulty detection events.

In COMPOSE, which is a sub-project of the EC 6th Framework Programme PReVENT integrated project, the development of a fully functional prototype application consisting of combined collision warning and collision mitigation functionalities, with full interface to the chassis, brake, safety and powertrain control systems, is underway for the Volvo Integrated Safety Truck (Sörensen et al, 2006).

Figure 6 shows collision scenarios have been principally structured according to four different phases, with corresponding reactions of the collision mitigation application.

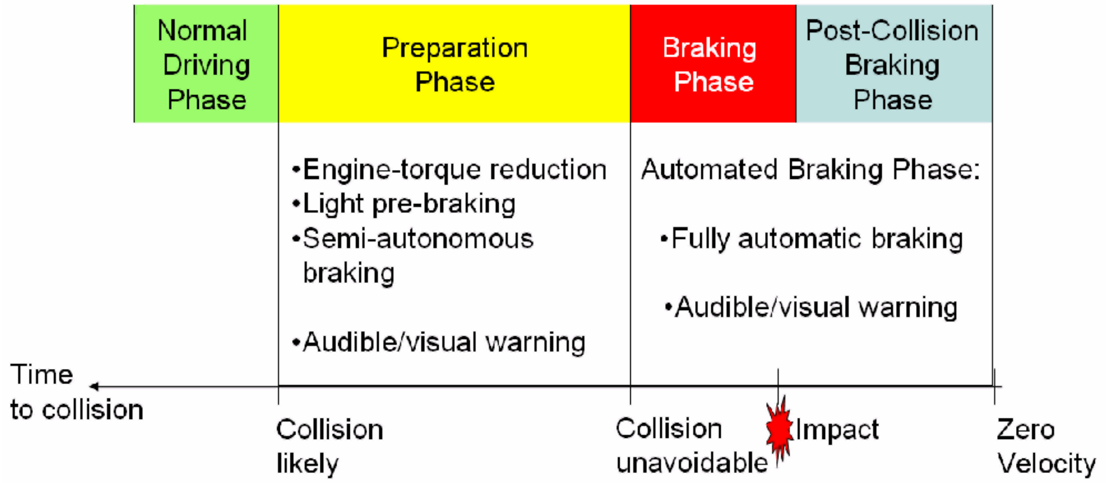

Figure 6: Collision mitigation phases and functionalities implemented in the Volvo Integrated Safety Truck (Sörensen et al, 2006)

The main focus for the application is mitigating collisions in non-urban situations (e.g. highways and rural roads) with moving objects larger than small animals, including oncoming vehicles as well as those travelling in the same direction, and large stationary objects (e.g. non-moving vehicles and other large obstacles). Single vehicle road departure accidents and truck front to car side impacts at junctions have not been considered within the scope.

Sensing is performed by a fusion of high performance laser scanner and far-infrared (FIR) camera technology. It is claimed these systems supplement one another ideally. The research states that cameras are known for their capability of measuring the angles to the outline of a target precisely, and for providing a classification of objects. On the other hand, range and speed measurements are less accurate, for which the laser compensates. The fusion module receives detections and tracks from the individual sensors and merges them to a consistent environment description. This includes classification of the observed objects (e.g. vulnerable road users and vehicles of different sizes) and their dynamics. The region covered by the perception system is shown in Figure 7.

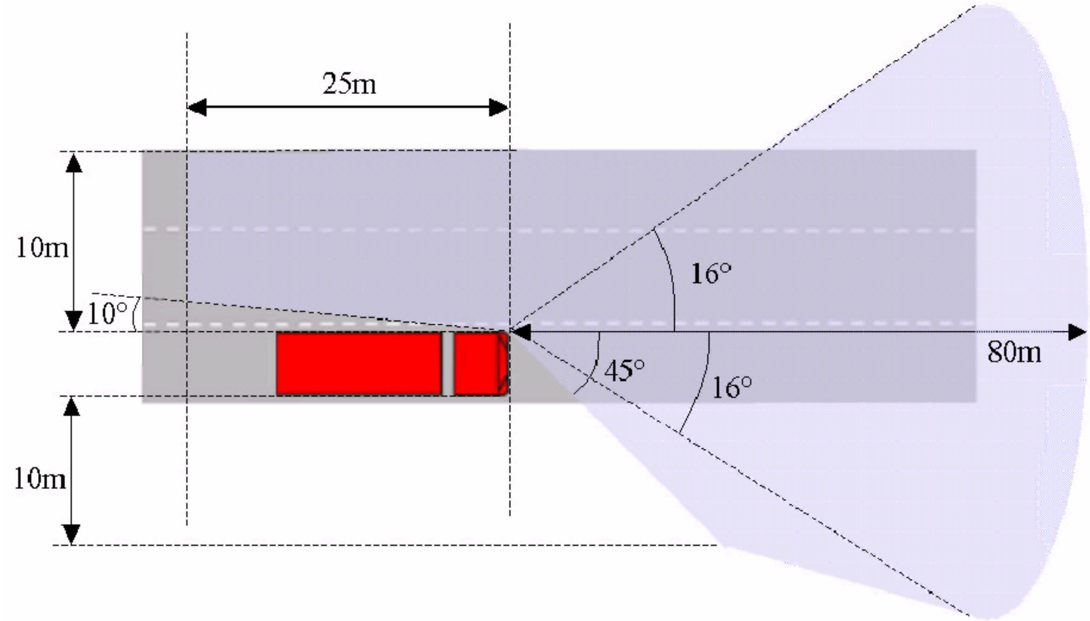

Figure 7: Region covered by laser scanner and FIR camera perception system (Sörensen et al, 2006)

The report (Sörensen et al, 2006) claims that the laser scanner monitors the traffic ahead and oncoming traffic as well as that on the left side adjacent of the truck (the system is installed in a left hand drive vehicle intended for operation in continental Europe where the vehicle will predominantly be driven in the rightmost lane). The laser scanner has a range of 0.3m to 80m over a 215° horizontal field of view, and an accuracy of ±0.05m. The FIR camera has a field of view of height 48° and width 37°, and is claimed to offer good performance both at night and in different weather conditions.

The research states that decision algorithms are based on evaluating the driving manoeuvres required for safely passing an obstacle, or alternatively to stop before the relevant object. For each object the required braking and steering parameters are calculated to avoid a collision with the object outline. When the risk of a collision is considered high the ‘preparation phase’ is initiated. This prepares the braking system for emergency braking (although the exact preparation is not specified) and warns the driver alerting them to manually intervene and avoid a collision. This decision is not only based on physical vehicle capability, but also on the current state of the vehicle and typical driver reactions. Therefore, some reaction time of both the truck and driver is allowed for. Assuming the driver is not able to perform a perfect escape manoeuvre by pushing the vehicle to its physical limits of handling, some safety margin must be available. Assuming typical driver reaction times, the preparation phase must be initiated approximately 2s before a collision becomes unavoidable, given a small safety margin.

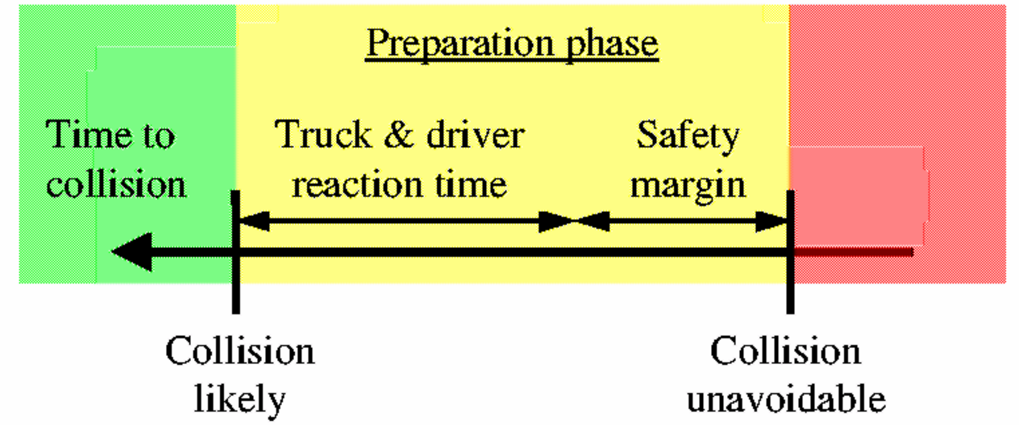

Figure 8: Collision warning 'preparation phase'

As long as the driver is capable of avoiding the collision by a braking and/or steering manoeuvre, mitigation braking is not activated. The steering and braking parameters are constantly compared to what the truck is physically capable of performing acknowledging a set of vehicle dynamics assumptions. Only if both steering and braking are considered not to be sufficient to avoid a collision, collision mitigation emergency braking is triggered. Assuming a given steering and braking capability, a risk zone can be derived solely depending on the truck velocity, load and load distribution.

At the time of writing simulations had verified fundamental system functionality in certain test scenarios, however tuning of the system, prior to and during vehicle test, was scheduled for completion during 2006.

Nitsche and Schulz (2004) discuss potential automotive applications of the ALASCA laser scanner with particular reference to warning and emergency brake systems. The authors claim that the device, coupled with appropriate analysis algorithms, is capable of detecting and separately classifying the following classes of road user:

- Trucks;
- Cars;
- Bicycles/motorcycles;
- Pedestrians.

The report separates automated emergency braking functions from pedestrian detection and protection functions, which are described as the activation of devices such as deployable bonnets. The report does not explicitly state whether pedestrians can be detected in time for the automated emergency brake system to be effective but it does state that the sensors can detect pedestrians earlier than is required for the activation of deployable devices, thus implying that it is possible.

McCarthy *et al* (2004) carried out research that successfully developed a proof of concept sensor system that was capable of detecting pedestrians in front of a vehicle. This project found that such a system could potentially be used to brake the vehicle and/or to implement active secondary safety features such as a pop-up bonnet and that this could offer substantial benefits in pedestrian accidents. The prototype system was developed by fusing a high resolution 24 GHz short range radar with a passive infra-red sensor. The basic functions were that the radar was used to identify distance and relative velocity accurately and the infra-red sensor was used to decide whether or not the object detected by the radar was a pedestrian or not.

McCarthy *et al* (2004) were developing a system capable of implementing pedestrian specific countermeasures, such as a pop-up bonnet or external airbag, so it was important to be able to specifically identify that an object was in fact a pedestrian. However, this distinction may not be necessary for a forward collision warning system or AEBS. This increases the likelihood that the AEBS is capable of mitigating or avoiding pedestrian accidents is feasible and likely to be developed in the near future. However, Lawrence *et* al (2006) noted that the nature of pedestrian accidents, where pedestrians sometimes step into the road immediately in front of a vehicle such that there is almost no time even for an advanced system to react, means that secondary safety is always likely to have a significant role to play in pedestrian protection. There are a range of factors, such as prediction of the path that a pedestrian will take and the influence of different clothing on detection capabilities that continue to make the development of a robust pedestrian sensing system technically more difficult that an equivalent car system.

Kalhammer *et al* (2006) also identified the possibility of developing systems capable of detecting pedestrians using a long-wave infra red camera. It was stated that this would be capable of forming part of an enhanced brake assist function and/or as part of an autonomously braking system. The authors concluded that it was feasible to develop such a system in time to meet the proposed requirements for complementary measures included in the second phase of the pedestrian protection Directive.

Walchshausl *et al* (2006) describe the development of a multi-sensor recognition system capable of detecting vehicles, objects and pedestrians. The system consisted of a far-infrared imaging device, a laser scanner and several radar sensors, integrated into a BMW passenger car. They state that the reason for developing a multi-sensor approach was that robust collision mitigation requires a perception performance of unprecedented reliability and that "current off-the-shelf single sensor approaches can hardly fulfil the challenging demands".

Elliott *et al* (2003) showed that a large proportion of killed and seriously injured motorcyclists resulted from a collision with a car. Some of the AEBS currently in production are claimed to be capable of detecting a large motorcycle in the centre of the lane and there is some evidence to suggest that further capabilities for detecting motorcycles may be developed in future (Nitsche and Schulz, 2004). Elliott *et al* (2003) report on a review of various studies of motorcycle accident data that give various estimates of the proportions of different motorcycle accident configurations that occur. There was evidence that the impact configurations varied with the engine size of the motorcycle with smaller vehicles more likely to be struck at the rear and sides and larger vehicles more likely to be struck at the front. Two of the papers reviewed found that more than 80% of impacts were in a direction within ±20% of the front of the motorcycle and one paper reviewed suggested that collisions to the rear of the motorcycle accounted for just 5% of motorcycle accidents. However a review of the most recent (at the time) analysis (Otte *et al*, 1998) suggested that 38% of the total 402 accidents analysed were single vehicle accidents and 24% involved the motorcycle colliding obliquely with the front or rear corner of another vehicle, 16% involved a head on collision and 5% involved the motorcycle front colliding with the side of the car. The proportion of cars colliding with the rear of motorcycles was not reported.

Although the data on collision configuration was highly variable, overall the data reported by Elliott *et* al (2003) suggests that fitting an AEBS capable of detecting motorcycles to cars and other four wheel vehicles could have some benefit but that a greater benefit may be obtained by fitting an AEBS to motorcycles that was capable of reacting to cars in head on collisions and front to side collisions.

An EC supported 6th Framework project entitled Powered two-wheeler Integrated Safety (PISA) began in 2006 to investigate the potential of integrated safety systems for motorcycle casualty reduction (www.pisa-project.eu). This project will be aiming to develop pre-crash sensing systems and advanced braking and stability systems for motorcycles that could act as enablers for a motorcycle AEBS. However, it is reported that the issues are more complex for motorcycles because of the greatly different dynamic characteristics of motorcycles, the adverse effect that braking can have on stability in some circumstance and the more complex HMI issues associated with autonomous braking on a motorcycle (i.e. the effect of braking on a rider not expecting it and insufficiently braced). All of these issues will be studied as part of the project.

There was relatively little research identified that proposed using a basic AEBS alone to mitigate the severity of accidents at junctions when one vehicle pulls out of a junction in front of another resulting in a front to side collision. This is typically quite a severe impact mechanism. The EC project INTERSAFE (Fuerstenberg, 2005) is aimed at avoiding or reducing the severity of such collisions using a combination of pre-crash sensing mounted with detailed feature-level digital maps of the intersection on the host vehicle as well as infrastructure sensors capable of locating vehicles within the intersection and vehicle to infrastructure and vehicle to vehicle communication. The project aimed to develop working prototypes of a system and to evaluate the potential of the system using computer simulation. Fuerstenberg (2005) reported that preliminary test results suggested the system worked well and further tests and evaluations were underway.

Huang *et al* (undated) stated that traditional vehicle collision warning and avoidance systems did not work well in the case of perpendicular path intersection accidents. One of the main reasons for this was that most vehicle based threat detection systems required line of sight to the hazard (the vehicle about to pull out of a junction) and that this was not always available at a junction. Huang *et al* proposed an alternative system for junction collisions based on vehicle to vehicle communications. They stated that this overcame the line of sight limitations of vehicle sensor based systems and did not require the infrastructure support of vehicle to infrastructure communication systems. However, they acknowledge that a drawback of this system was that its effectiveness was dependent on the number of vehicles using it. Research was underway to assess the critical mass of equipped vehicles that might be required before substantial benefits were observed.

4.2.2 Collision avoidance

There are no full collision avoidance systems that function at high speed fitted to production vehicles at present however such systems are under development and prototype systems are undergoing evaluation. Some new vehicles are equipped with systems that will fully avoid collisions but these only function in low speed circumstances.

Matsumoto et al (2001) describe the accident avoidance technologies on the Nissan Advanced Safety Vehicle (ASV) 2. Automatic braking decelerates the vehicle to a stop or reduces the collision speed as much as possible in the event the driver is slow to brake or does not brake sufficiently in relation to an obstacle ahead. Active brake control for emergency manoeuvring optimises the braking force at each wheel and comprehensively controls vehicle behaviour.

In a situation where there is an increased risk of a collision with an object in front of the host vehicle, such as a stopped vehicle, on account of human error due to the driver's inattention or misjudgement, the driver is alerted to the potential danger by audible and visual warnings. Should the driver fail to manoeuvre around the obstacle automatic braking is applied to reduce the impact speed. If the driver brakes to decelerate in this case, the driver's operation is given first priority. However the system continues to control the brakes if the driver's action does not decelerate the vehicle sufficiently to achieve maximum possible collision avoidance.

If the driver steers to avoid the obstacle, the system automatically brakes to reduce the speed of the host vehicle and simultaneously the system actively controls the braking force at each wheel in order to improve the steering response in line with the driver's steering action. The difference between this system and a conventional electronic stability control (ESC) system is an ESC system controls the braking force at each wheel to meet the target vehicle behaviour after a certain yaw rate or skidding has actually occurred. Active brake control actively controls the braking force at each wheel before such vehicle behaviour appears, based on the driver's steering action and the state of the obstacle detected by external environmental sensing devices such as a radar unit. The control system improves the vehicle's turning capability so as to avoid the object and continues optimum control of the braking force to stabilize vehicle behaviour.

Honda's prototype ASV 3 is equipped with advanced safety technologies including a head-on collision avoidance assistance system and a forward obstacle avoidance assistance system (http://world.honda.com/ASV).

Figure 9: Honda ASV 3

As shown in Figure 10, the head-on collision avoidance assistance system communicates with an oncoming vehicle to ascertain information such as its position, speed and steering wheel angle (http://world.honda.com/ASV). If the system detects the driver of the ASV 3 changing lanes into the path of the oncoming vehicle the accelerator pedal vibrates and torque is applied to the steering wheel (in the opposite direction to the driver) prompting the driver to return to their own lane.

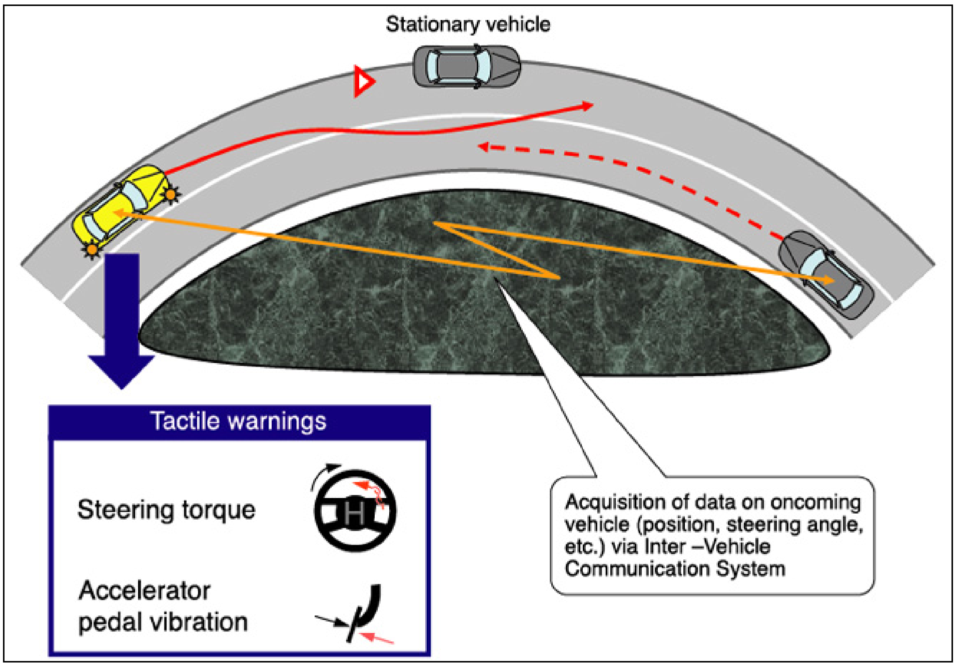

Figure 10: Head-on collision avoidance assistance system (http://world.honda.com/ASV)

Note that the figure depicts a Japanese traffic situation where vehicles drive on the left

The forward obstacle avoidance assistance system (http://world.honda.com/ASV) provides compensatory steering and braking assistance when a driver is slow to take evasive action when unexpectedly confronted with another vehicle or object in the vehicle's path (Figure 11). At the start of an evasive action, the system helps the driver steer to avoid the accident, it then reduces the steering input to help prevent the driver turning too sharply then, if the driver is slow to return the car to its original course, it provides more steering assistance whilst using the ESP system to help stabilise the vehicle.

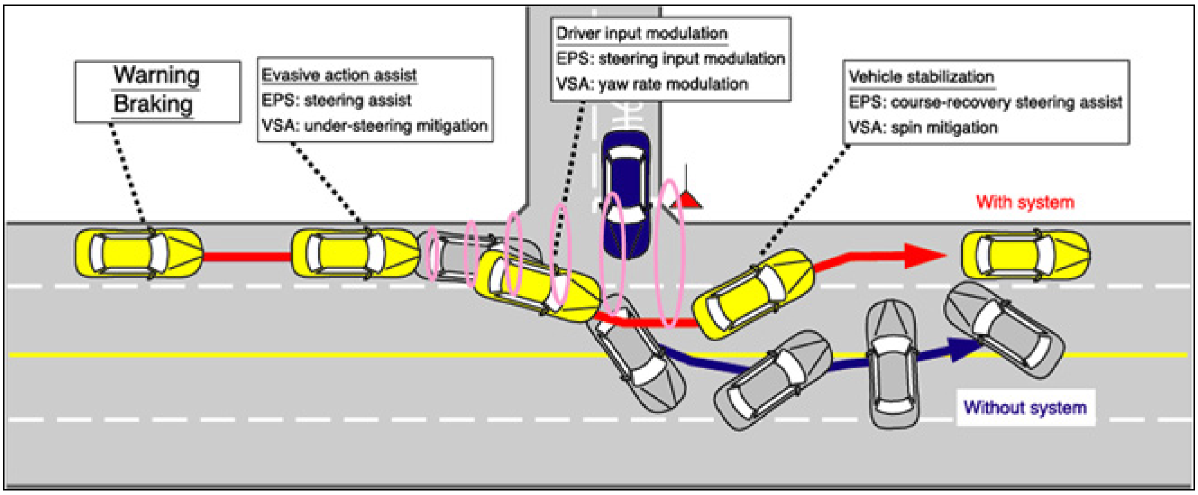

Figure 11: Forward obstacle avoidance assistance system (http://world.honda.com/ASV)

Note that the figure depicts a Japanese traffic situation where vehicles drive on the left

4.3 Information from industry survey

Further unpublished information yielded through consultation with vehicle manufacturers and tier-one suppliers to the automotive industry indicates that AEBS for trucks and buses/coaches, as well as passenger cars, are currently under development to mitigate and in some cases avoid collisions with other vehicles, vulnerable road users and other objects. A short questionnaire was distributed to industry through the relevant associations such as ACEA, JAMA, CLEPA etc. The response was not exhaustive but six manufacturers sent replies containing useful information, one truck manufacturer replied stating that they had no current plans to offer the system on their vehicle and JAMA replied stating that their system characteristics were in accordance with Japanese guidelines, of which they sent an unofficial English translation. A summary of the six manufacturer responses is given in Table 1, below.

Table 1: Summary of all industry survey responses

Respondent	Sensor technology	Current market/ future development	Operating conditions	Collisions sensed	Deceleration during autonomous braking
Car manufacturer 1	Radar	Current market production	Vehicle speed >15km/h, relative speed >15km/h. Ineffective at very short following distance and under sudden encounters. May not function in poor weather and when the sensor is impaired.	Front to rear shunts with moving vehicles (potentially including large motorcycles travelling centrally in lane, excluding small motorcycles travelling in edge of lane) on straight roads and curves (depending on geometry), and stationary vehicles and objects with appropriate material properties. No pedestrian detection capability.	>0.5g
Car manufacturer 2	Radar	Current market production	Vehicle speed 10-180km/h, <70km/h approaching stationary objects. May not function when the sensor is impaired.	Front to rear shunts with moving vehicles on straight roads and curves (depending on geometry), and stationary vehicles. No pedestrian detection capability.	0.2-0.4g depending on vehicle speed, typically applied 1.6s before collision whilst it is still avoidable to provide warning.
Car manufacturer 3	Radar	Future development	To be determined. Will be deactivated under certain speeds	Front to rear shunts with moving vehicles on straight roads and curves (depending on geometry), and stationary vehicles. No pedestrian detection capability.	Maximum achievable
Truck manufacturer 1	Radar	Current market production	Vehicle speed 10-90km/h. May not function when the sensor is impaired.	Front to rear shunts with moving vehicles on straight roads and curves (depending on geometry), and stationary vehicles. No pedestrian detection capability.	Maximum achievable

Respondent		Sensor technology	Current market/ future development	Operating conditions	Collisions sensed	Deceleration during autonomous braking
Tier one supplier 1	Sys 1	Radar	Future development	No limitations linked to sensor performance. Pedestrian protection potentially deactivated at <10km/h and >60km/h.	Head on and front to rear shunts with moving vehicles on straight roads and curves (depending on geometry), and stationary vehicles. Front to side collisions. Pedestrian detection capability.	Deceleration figures purely indicative. Deceleration levels confirmed with vehicle manufacturer strategy with regards to how to bias system.
	Sys 2	Radar & stereo vision	Future development	Partial deactivation may be for distances beyond 50m in poor weather conditions.		
	Sys 3	Stereo vision	Future development	Partial deactivation may be for distances beyond 50m in poor weather conditions.		
	Sys 4	Far infra-red	Future development	No limitations linked to sensor performance.		
Tier one supplier 2		Radar	Future development	No limitations specified, other than may be deactivated during snowfall	Front to rear shunts with moving vehicles on straight roads and curves (depending on geometry), and stationary vehicles. Potential pedestrian detection capability.	Braking generally applied to maximum possible deceleration.

Sensor technologies identified in the survey as being in use in current production or under development included radar, stereo vision and far infra-red (FIR), either individually or combined to complement one another. It was notable that although laser scanning/lidar had been identified as a potentially appropriate technology in the survey of published literature, none of the manufacturers that responded to the survey were using it, although anecdotally other manufacturers are understood to be using or considering using the technology.

The activation criteria for all collision mitigation emergency braking systems were based on time to collision (TTC) as well as other parameters not explicitly described. TTC is the time at which, taking the relative speed and vehicle overlap into account, a collision is deemed as being unavoidable when neither steering nor braking intervention would avoid the impact. In the absence of real-time friction measurement (typical for current or near-market systems) it is assumed that the vehicle is driving on a dry, smooth high friction surface. The estimate of the time at which neither braking nor steering intervention would not result in collision avoidance is typically derived from physical testing with the subject vehicle on such a surface. This data is then stored within control system.

Respondents stated that braking systems reactions times depend on the braking technology employed. For hydraulic systems found on passenger cars the rise time to achieve maximum braking effect is approximately 0.2 to 0.3s at room temperature. The rise time is dependent on the brake fluid temperature for a given system, and it was acknowledged that brake system pre-fill could improve system reaction times. Vehicle deceleration is modulated using a feedback control system, with automatically applied deceleration values quoted by different manufacturers as:

1. from 0.2 to 0.4g;
2. greater than 0.5g;
3. 0.6g;
4. 0.8g;
5. maximum deceleration achievable (i.e. full ABS braking), depending on the surface conditions.

One respondent noted that deceleration values were purely indicative. The control system offers the potential to apply any deceleration up to the maximum achievable depending on the how the system was configured and that configuration was specified by the OEM.

Systems may be deactivated when sensor impairment is detected (e.g. a build up of dirt or snow) or during poor weather conditions where the sensor system is blinded by precipitation (e.g. heavy rain, snow).

A question was asked concerning the possibility of a “false activation” of systems but only two respondents provided information on this subject, which contrasted notably. One respondent stated simply that in more than one million test kilometres in real road traffic no false activations had occurred. The second could not provide a quantitative answer because they stated that the level of false activations because it depended on how the characteristics of the system were calibrated for each different vehicle. However, they considered it likely that the calibration of each system would be biased towards achieving low levels of false activation and that the trade-off between missing or late valid activations and false activations would continue to be one of the main research areas.

When considering future developments of the technology, one respondent clearly indicated that a range of systems, using a variety of sensors and sensor fusion, were at varying stages in the development process and that it was intended that these would function in a much wider range of collision types including head on collision, front to side collisions and pedestrian collisions. Such systems would greatly expand the functionality and benefits of AEBS.

4.4 Summary of technical performance of AEBS

4.4.1 Systems in production vehicles

The following refers to the characteristics of systems that were identified as being in current production vehicles at the time the literature review and industry surveys were carried out. It is known that by the date of publication one or more systems under development at that time are likely to have been released on production vehicles but these are still defined as future developments in this section.

Information obtained describing the technical performance of the main components of current production collision mitigation emergency braking systems may be summarised as:

- Sensor system:
  - Sensor range ahead of vehicle (m): long range 100 to 200; short range c.30
  - Horizontal field of view (°):16, 9, ±3, 80 (short range sensor);
  - Vertical field of view (°):4, ±1.5;
  - Sensor scanning rate (Hz): 10 to 25.

- Analysis/processing system:
  - Collision scenarios identified:
    - Front to rear shunt collisions on straight roads;
    - Potentially front to rear shunt collisions on curves depending on geometry (line of sight required, dependent on roadside clutter).
  - Obstacles recognised:
    - All moving vehicles, including large motorcycles travelling centrally in lane, excluding smaller two wheeled vehicles (e.g. bicycles and mopeds) travelling in edge of lane;
    - Stationary vehicles (as above) if presented squarely in a similar fashion to normal driving;
    - Pedestrians not recognised.
  - Operative velocity range (km/h): either >10, >15, 10 to 180, or <70 if approaching stationary obstacle (depending on system);
  - Relative velocity between vehicle/obstacle for activation (km/h): >10, or >15;
  - Braking avoidance limit: calibrated for individual vehicles during braking trials performed on a smooth high friction dry surface at various relative speeds;
  - Steering avoidance limit: calibrated for individual vehicles during handling trials performed on a smooth high friction dry surface to investigate the maximum achievable steering and lateral displacement at various relative speeds;
  - Collision risk judgement algorithm update frequency (Hz): approximately 50;

- Autonomous braking:
  - Passenger car;
    - Deceleration (g): 0.2 to 0.4, >0.5, >0.6, >0.8g, or maximum achievable (full ABS braking) depending on surface conditions;

        - Brake system reaction time (s): 0.2, 0.2 to 0.3, 0.12 to 0.20 with pre-filled circuit.
    - Heavy vehicle deceleration (g): maximum achievable (full ABS braking) depending on surface conditions.

- System deactivated when:
    - The sensor view is 'blinded' during periods of heavy precipitation (heavy rain, snow etc.);
    - The sensor head is impaired because of debris build-up (road grime, dirt, snow etc.);
    - When a system fault is detected.

- System ineffective when:
    - There is a sudden encounter such as a vehicle cutting immediately in front or a emerging at a junction;
    - Sudden acceleration is applied and the vehicle ahead is becoming too close;
    - The distance between vehicles is extremely short;
    - The overlap with obstacle ahead is small.

It can be seen from the above list that the circumstances in which these first generation systems are expected to be effective is quite limited. Effectively, the systems will only function fully in front to rear shunt collisions where both vehicles are travelling within the same lane on reasonably straight roads in good weather conditions. This represents a relatively small sub-section of the serious or fatal accident population.

Industry stakeholders expressed the view in general terms that avoiding "false positive" detections was one of the most important objectives of development and quite difficult to achieve. This was considered by those stakeholders to be one of the most significant barriers to developing the system to be active in more accident configurations and to the development of full avoidance systems. However, little or no information was available, either in publications or in response to the industry survey, to quantify the rates of false positive detections that might be expected from either current or future systems.

4.4.2 Future developments

Systems that had increased functionality were identified that, at the time of the literature review and industry survey, were under development and, in some, cases close to production. These included systems capable of functioning effectively in a wider range of collision circumstances, including head on and front to side collisions on straight roads and curves and pedestrian collisions. This was achieved using a range of different sensors (radar, camera image technology, infra red, far infra red, laser etc) and sensor fusion. However, there was a substantial quantity of research that suggested AEBS alone would have limited abilities in collisions at junctions because of restricted line of sight and more complex situations. These researchers recommended adding vehicle to vehicle communications and/or vehicle to vehicle communication to develop the functions in this collision type. Some full automated collision avoidance systems were also identified using both vehicle sensors and vehicle to vehicle communication. It is likely that some of these systems may have been brought into production by the time of publication of this report.

4.5 Analysis of brake system requirements

4.5.1 Light vehicles

Information gathered from the industry survey revealed that for a typical hydraulic system found on a passenger car the rise time from the signal for an autonomous brake application to maximum brake pressure being achieved at the calliper is approximately 0.2 to 0.3s with the system and fluid at room temperature. The rise time is highly dependent on the brake fluid temperature for a given system. Maximum deceleration may not be achieved until 0.5 to 1.0s after the initial signal because of the effects of weight transfer and vehicle chassis and tyre dynamics.

Research completed previously by TRL has also been drawn upon to quantify typical braking system performance. Figure 12 shows a typical hydraulic braking system response to a rapid driver-applied brake application (pedal force rise time of 10 to 500N less than 0.09s) for a medium sized passenger car equipped with disc brakes at all wheels and ABS, travelling in steady state linear motion at 100km/h on a uniform high friction surface. The origin is placed at the time when the brake application was initiated.

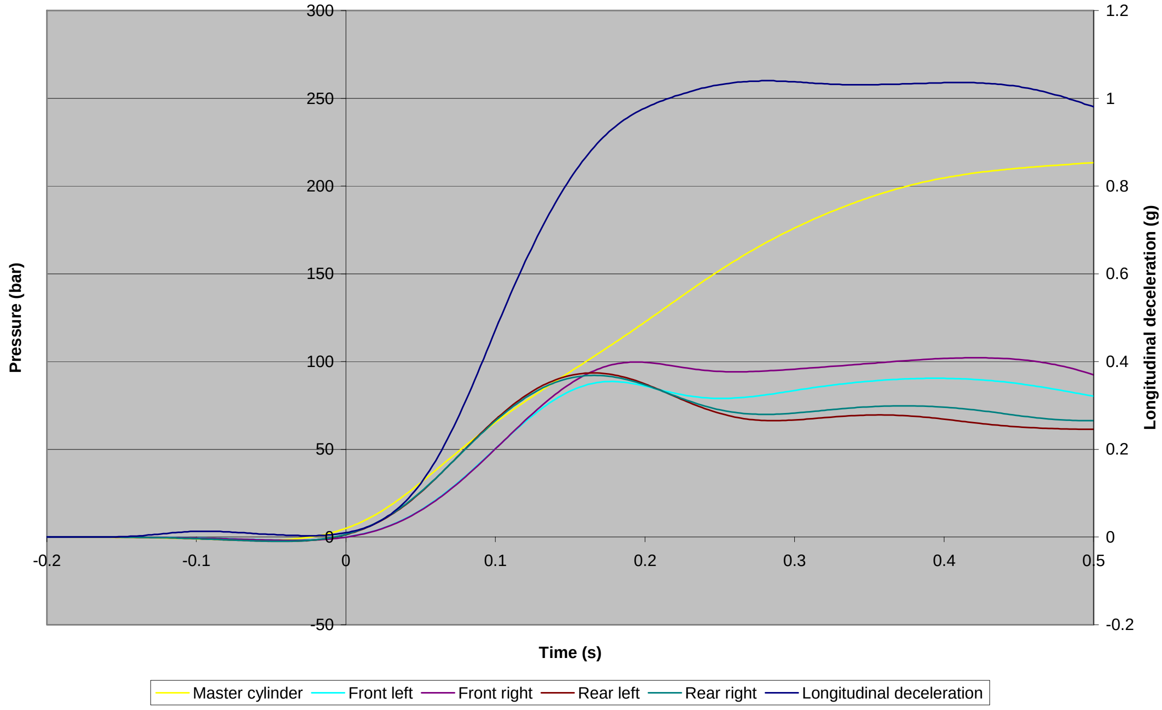

Figure 12: Hydraulic braking system response to rapid brake application

The hydraulic pressure at the master cylinder rises rapidly in response to the brake pedal application. The pressure measured at individual callipers also increases rapidly, the rear almost simultaneously with the master cylinder whilst the front lags slightly behind for this particular vehicle. Regulation of the pressure applied at each individual calliper by the ABS initiates after approximately 0.11 to 0.14s at all wheels, indicating maximum tyre/pavement friction utilisation. Until ABS regulation, pressure rise rates at the front and rear axles are in excess of 550 and 650bar/s respectively. Typical pressures maintained under ABS regulation range from 60 to 100bar. Maximum longitudinal deceleration of 1.04g is achieved at approximately 0.26s after the initial pedal application and approximately 0.13s after initial ABS control is initiated.

Figure 13 shows electronic stability control (ESC) intervention in the braking system for a medium sized passenger car undergoing a harsh steering only evasive manoeuvre (no braking applied by the driver) on a uniform high friction surface. The origin is placed at the time when intervention at the rear right brake calliper initiated.

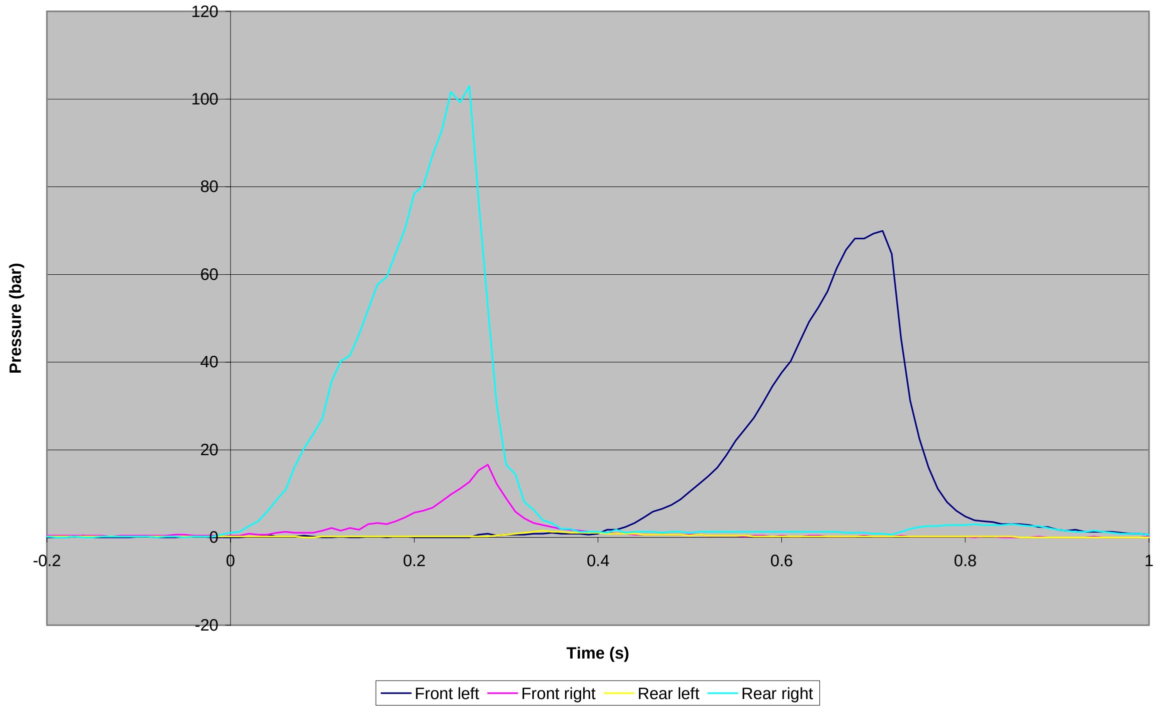

Figure 13: ESC intervention during harsh evasive manoeuvre

A pressure of approximately 100bar is achieved autonomously by the ESC system at the rear right wheel within a time of 0.24s, indicating a pressure rise rate in excess of 400bar/s. This is slightly slower than that of the driver applied braking shown in Figure 12.

Assuming the braking system has sufficient capacity to simultaneously raise the pressure at all wheels to that required to fully utilise the maximum tyre/pavement friction, it may be inferred from the above examples that under autonomous braking, maximum deceleration may be achieved 0.37s after the initial signal to increase brake pressure. This figure compares favourably with that cited by industry stakeholders (0.5 to 1 second).

When a potential collision scenario has been identified, the braking system reaction time may be reduced by pre-filling the circuit with fluid such that the linings are just in contact with the discs. The pressure required is of the order of 3 to 5bar. By pre-filling and lowering the tripping threshold for the hydraulic brake assist (HBA) such that full braking performance is available as soon as the pedal is depressed, Bosch claim that for a driver brake application, full braking performance is available 30ms earlier (www.bosch.com.cn).

One industry stakeholder responding to the survey claimed that with a pre-filled brake system under autonomous braking, maximum system pressure may be achieved in 0.12 to 0.20s. This is faster than the example shown in Figure 13 (0.24s) for ESC intervention where the brake system is not pre-filled, and indicates a comparable or better time saving to that claimed by Bosch for a pre-filled circuit.

Stakeholders also noted that the braking system reaction time depends on the braking technology employed. electro-hydraulic braking (EHB) systems, developed by a number of tier-one component suppliers, and currently in production on a number of Mercedes-Benz passenger cars named Sensotronic Brake Control (SBC), utilise a central hydraulic brake unit which replaces the conventional brake booster, and an electric pump and high-pressure accumulator are added. It is claimed that electronically adjustable valves facilitate the application of maximum braking pressure much more quickly than in a conventional servo-assisted hydraulic braking system. Under normal braking, sensors on the brake pedal detect the driver braking demand and convert this to a braking command, applying the appropriate braking force at each wheel. A typical performance specification for an EHB system is to raise the brake pressure at the calliper to 80bar within 0.12s, a rise rate in excess of 650bar/s (Delphi, 2003). Pure electro-mechanical braking (EMB), where the physical link between the brake pedal and wheel actuator is removed, is said to offer the potential to further improve braking system response. Although this has been demonstrated as being feasible in prototypes, such systems have not yet entered series production.

From studying the literature published by manufacturers and via information from the industry survey the deceleration rates for current production and future near market light vehicle collision mitigation emergency braking systems ranged from 0.2 to 0.4g, greater than 0.5, 0.6 and 0.8g or the maximum deceleration achievable (i.e. full ABS braking) depending on the surface conditions. One respondent noted that deceleration values were purely indicative, the control system offers the potential to apply any deceleration up to the maximum achievable depending on the how the system was configured.

The literature review and industry survey also highlighted that one key element of the decision algorithm responsible for autonomous braking was to assess whether the collision was avoidable by steering action. Previous research completed by TRL also investigated vehicle handling response to various steering inputs. Figure 14 shows a typical light vehicle response to a rapid driver-applied step steering input (steering rate in excess of 250°/s) for a medium sized passenger car equipped travelling in steady state linear motion at 80km/h on a uniform high friction surface. The steering input was of sufficient magnitude to fully utilise the available tyre/pavement friction. The origin is placed at the time when the steering input is initiated.

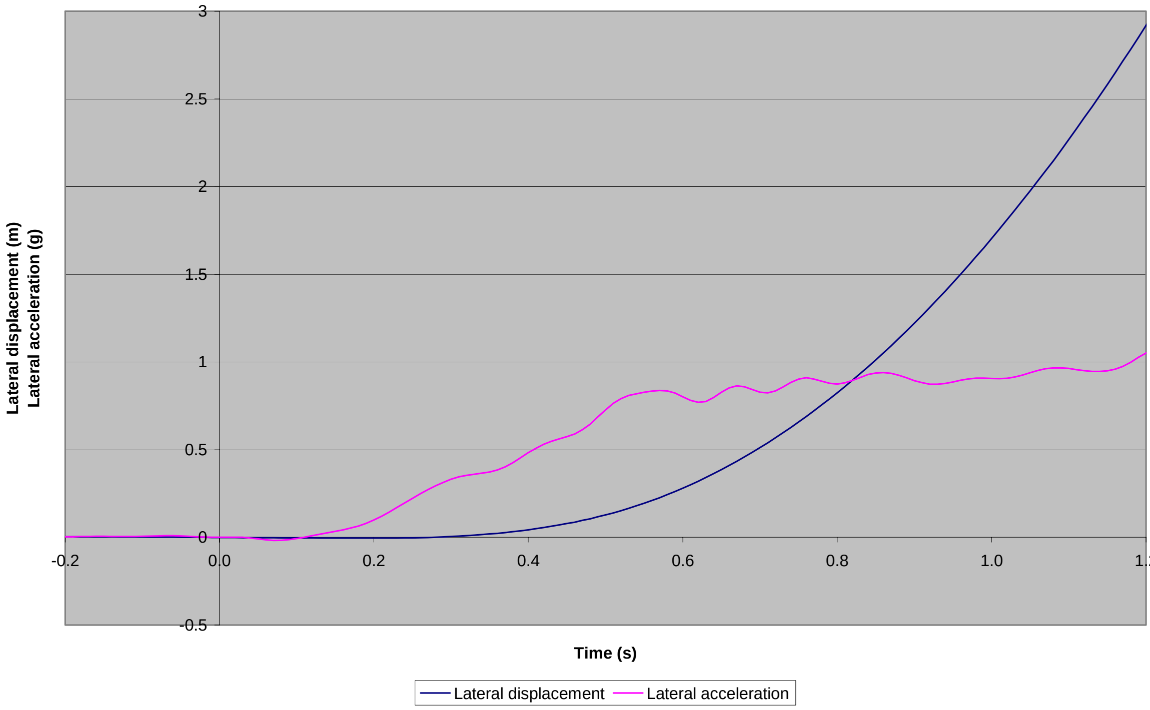

Figure 14: Light vehicle response to step steer input

The lateral acceleration increases approximately linearly soon after the initiation of the steering input, with this particular vehicle achieving an ultimate value in excess of 0.9g. At the test speed, a lateral displacement equivalent to a typical passenger car half and full width (0.9 and 1.8m) is achieved 0.82s and 1.02s respectively after the initiation of the steering input. A displacement equivalent to an LGV/PCV half and full width (1.25m and 2.5m) is achieved after 0.91s and 1.14s respectively.

4.5.2 Heavy vehicles

The operating performance and characteristics of heavy vehicle braking systems are substantially different to those of light vehicles. Current heavy vehicle braking systems are typically either fully pneumatic or electronically controlled pneumatic, known as electronic braking systems (EBS). The reason for this is that it is a power-brake system where all of the energy required is generated by an extraneous source (compressed air). In this type of system, none of the energy used to apply the brakes is supplied by the muscular force of the driver, whose application of the pedal merely acts as a control function. Fully electronic (brake by wire) systems, where the air system is completely replaced and electrical actuators that provide the physical force, have been demonstrated as being feasible in prototypes, however such systems have not entered series production.

In a collation of data from the Society of Automotive Engineers (SAE), Economic Commission for Europe, Group of Rapporteurs on Brakes and Running Gear (ECE-GRRF) and by the International Organisation for Standardisation (ISO/TC22/SC9), Neilson (1987) listed, without prejudice, the safety impairing characteristics of HGVs with air brakes. Many of these factors related to the compressed air system. It was noted that air brakes have substantially longer response times than hydraulic brakes, due to the compressibility and comparatively low wave propagation velocity of air. In addition to this, HGVs use long expandable air hoses and the distance from the control valve at the brake pedal to the farthest wheel brake chamber is considerable. The increase of air pressure at the foot brake valve that signals brake demand will, therefore, take a finite amount of time to travel via the various relay and control valves to each brake chamber and begin generating a braking torque. This is known as the brake response time.

The response time and minimum deceleration rates for motor vehicles undergoing braking are governed by UNECE Regulation 13. For an actuating time of 0.2s, the time elapsing from the initiation of the braking system control actuation to the moment when the pressure in the brake cylinder reaches 75% of its asymptotic value shall not exceed 0.6s. For trailers, a simulator is used to apply the pressure and the pressure in the brake chamber must reach 75% of asymptotic value in 0.4s. For tractor units the pressure at the coupling head must also reach 75% of asymptotic value in 0.4s. For a passenger car the minimum required deceleration rate is 5.8m/s^2, whereas for a commercial vehicle it is only 5.0m/s^2.

A major advantage of the EBS localised air system over a typical fully pneumatic system is the response times are quicker than those stipulated in Regulation 13. Tests on an early EBS system showed an improvement in pressure increase of approximately 0.2s, and a pressure release of approximately 0.6s (Göhring & Glasner, 1990). This results in a system that is more responsive to the dynamics of the vehicle, for example in the use of antilock or reacting to load transfer under emergency braking. It is claimed an EBS system achieved 75% of asymptotic value in 0.15s (Sowman, 1995a). A manufacturer claims that the reaction time of the brakes can be reduced to 0.15s, compared with a typical air brake of 0.4s, regardless of the length of the vehicle (Blakemore and Clancy, 1995). During a review of EBS technology, it is claimed that on an 18m long vehicle, EBS can cut the response time of the actuators on the rearmost axle by up to 0.3s, reducing the stopping distance by 13m for a vehicle travelling at 80km/h (Bunting, 1996).

Another advantage is the ability to achieve balanced braking between the tractive unit and trailer (Göhring & Glasner, 1990) by incorporating coupling force control (CFC). The forces between the tractor and trailer can be indicative of the amount of braking each unit is undertaking. By monitoring the coupling forces, the braking effort can be adjusted so that balanced braking is achieved. EBS could also be used to balance incompatibilities between the tractor and semi-trailer (Blakemore & Clancy, 1995). This would be achieved by measuring the horizontal and vertical forces at the fifth wheel and then adjusting the brake pressure accordingly to bring about balanced braking. Drawbar combinations may also benefit substantially from EBS because of the more extreme compatibility problems resulting from a laden truck towing an empty trailer or an empty truck towing a laden trailer (Dickson-Simpson, 1996).

The brake response time can have a substantial effect on overall stopping distance, as measured from initiation of the braking system control actuation. However, it has no effect on the MFDD measured because, by definition, that is the deceleration from 80% of the initial speed to 10%, so the response time has already elapsed before the calculation is applied. Previous research completed by TRL investigated the braking performance of commercial vehicles. Figure 15 shows the deceleration profiles obtained in response to rapid, nominally identical driver-applied brake applications for a fully pneumatically braked tractor unit and an EBS equipped tractor unit drawing a semi-trailer equipped with a fully pneumatic brake system, travelling in steady state linear motion at 90km/h on a uniform high friction surface. Both tractor units were fitted with identical tyres. The origin is placed at the time when the brake application was initiated. It should be noted that response time is measured in a different way to that prescribed by the Regulation; the onset of deceleration is compared with the onset of pedal application. The time required for the air pressure in the chamber to be converted to push rod movement and torque generation is included.

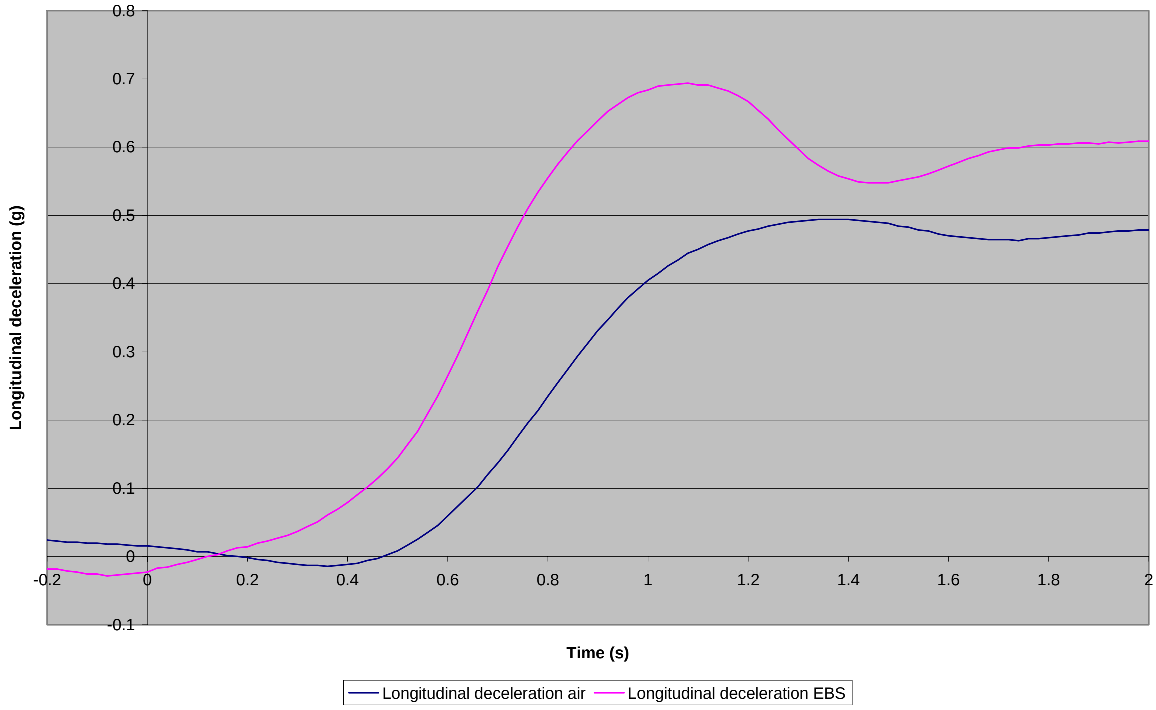

Figure 15: Heavy vehicle deceleration profiles in response to rapid brake application

In relation to the onset of pedal application, the deceleration is generated sooner for the EBS equipped tractor. The EBS unit has a response time of 0.40s compared with 0.75s for the fully pneumatic unit. These results support the claims that EBS greatly improves response times, although only two vehicles were compared and other variables may also affect the response. As the deceleration builds, air lags EBS by approximately 0.2 to 0.3s in terms of deceleration build up. This time difference is similar to that estimated by vehicle manufacturers for the difference between pressure build up times of air and EBS systems.

The difference in initial response time of 0.35s may not appear to be very substantial. However, when travelling at a constant 90km/h for 0.35s a distance of 8.75m is travelled. The EBS combination stopped in 61 metres from 90km/h. If it is assumed that this vehicle just avoided an accident, then a vehicle that is identical, apart from a response time increased by 0.35s, would be expected to collide with the object at an impact speed of 34km/h (21mile/h). This collision speed could be sufficient to kill a pedestrian and to kill or seriously injure the HGV driver, depending on the collision object and whether the driver was wearing a seat belt.

The difference found between a 2+2 non-EBS articulated combination with drum brakes and the 3+3 combination with disc brakes throughout and EBS on the tractor was 22m. It is, therefore, likely that approximately 40% of the difference between the two vehicles was because of the different response time. If the 3-axle trailer had been equipped with an EBS then the response time may have been even shorter with a corresponding beneficial reduction in stopping distance.

The integration of a collision mitigation emergency braking system on a vehicle equipped with EBS should be straightforward because all brake applications are controlled electronically, whether driver or autonomously applied. The trigger signal for autonomous emergency braking system may be forwarded to the braking control system in the same manner as demand signal from the foot pedal, leaving the braking control system to operate and apportion braking as deemed appropriate in the normal manner. The collision mitigation emergency braking system available on Mercedes-Benz heavy vehicles operates in conjunction with EBS demonstrating the feasibility of the technology. Similarly, the integration on a vehicle equipped with a full brake by wire system should not pose any additional difficulties beyond those associated with normal driver applied braking because all braking demands would also be controlled electronically.

In a fully pneumatic heavy vehicle braking system application of the service brake operates a valve increasing the pressure in the signal line. This signal operates a relay valve at each air tank that in turn sends air to the brake chambers, applying the brakes. Autonomous braking could be achieved by automatic control of a valve regulating the signal pressure, with the braking control system operating in the normal manner. However it is unlikely that a fully pneumatic brake system would be used on a vehicle equipped with advanced technology such as an emergency braking collision mitigation braking system.

The specification of this project included a concern about braking compatibility of heavy vehicle combinations. Brake performance compatibility of such vehicles is controlled by EC Directive 71/320 and UNECE Regulation 13. Despite this, research has shown that vehicles can still suffer from compatibility problems in service. These arise where the brake system of one of the component vehicles (tractor or trailer) has a brake system with characteristics that do not closely match the other. This could be either that the threshold pressure at which the brakes first begin to work are different or that the ultimate high pressure brake performance is different. At the extremes of the corridors of values permitted by the regulations this can mean that one of the components of the vehicle suffers excessive brake wear while the other can suffer from glazed brake linings and consequently reduced performance, the combination can suffer from an increased stopping distance and in some circumstances the potential for instability under braking can be increased.

It is, therefore, important to consider whether there are any circumstances where the use of an autonomous braking application could interact with existing problems of incompatibility to present a safety risk. No scientific literature could be identified that considered this problem. In the absence of such literature the problem has been considered hypothetically. If, in the worst case, a tractive unit equipped with an AEBS was towing an older trailer with a simple pneumatic braking system without ABS then it is clear that there would be several potential effects. Firstly, the increased reaction time of the pneumatic brake system would reduce the effectiveness of the AEBS in terms of the speed reduction obtained before collision. For the period between the tractor unit with its quicker response time reaching full braking and the slower responding trailer reaching full braking, the braking forces may potentially be substantially unbalanced and incompatible, leading to a greater risk of braking instability. Any tendency toward becoming unstable could be made considerably worse by the fact that the trailer is not equipped with ABS and wheel lock would be likely to occur.

However, analysis of the test data described above has suggested that a rapid driver-applied brake application can be notably faster than the autonomous braking supplied by ESC and faster than the response times suggested in the industry survey responses for AEBS. This suggests that although this situation does represent a risk of at least reduced effectiveness and at worst vehicle instability (jacknife/trailer swing) this risk is no greater, and possibly less, when the braking is applied autonomously than it is when applied in an emergency by a skilled driver.

4.5.3 Discussion of the brake system requirements

The review of brake system requirements has shown that there is currently a wide range of capabilities and, particularly philosophies, regarding the implementation of AEBS. There are also differences in how it is applied to light and heavy vehicles.

One key difference is the level of braking applied by the autonomous brake system. This ranges from the lowest level where braking of 0.2 to 0.4g is applied, depending on circumstances to full ABS braking. This choice of braking strategy obviously has a substantial affect on the magnitude of speed reduction that is possible in a given time. The different strategies adopted in this area appear to be the result of different approaches to dealing with some of the compromises inherent in the system. The longer the time to collision at the point of activation of the brake system, the more potential there is for a "false alarm", that is an autonomous brake application where the possibility of a driver avoiding the collision by steering still exists. The systems that have lower levels of autonomous braking also tend to activate earlier in the sequence of events leading to a collision, thus potentially offering comparable benefits, while mitigating the increased risks associated with earlier activation by only braking at lower levels.

Limiting the maximum deceleration applied to a level below the maximum available means that the tyre grip available is not fully utilised by braking, offering some residual amount which may be used to generate a directional change, offering the driver increased directional control during autonomous braking.

It should also be noted that there was an obvious difference in this strategy between light and heavy vehicles. All references to systems for heavy vehicles that were either identified in the literature or from the industry survey suggested that full ABS braking would be applied by the system. This is consistent with the arguments presented above. It can be considered that any severe steering avoidance manoeuvre carried out in a heavy vehicle, particularly in a laden truck, represents a very high risk of vehicle rollover. Heavy vehicles are also very large and in many accident situations there may not be the available road space to successfully manoeuvre around a hazard. Thus, there is considerably less advantage in offering the driver increased steering ability during the braking application. In addition to this, heavy vehicles are typically capable of lower levels of deceleration than light vehicles and have increased response times. The approach of maximising the speed reduction at the expense of offering less steering capability during the brake application to the driver, therefore, appears to be an appropriate strategy,

At this time, no research could be identified to assess which approach to AEBS was actually more effective when both the magnitude of speed reduction and the consequences of possible false alarms were considered. Therefore, it is not possible at this time to develop a technical requirement that rigidly specifies a minimum or maximum value for the deceleration, or related parameters, for such systems.

4.6 Analysis of sensing system requirements

The objective of this task was to provide a brief review of sensor technology and to assess the high level technical requirements of the complete sensing system, independent of the technology employed to achieve those requirements.

4.6.1 Review of sensor technology

AEBS are a new automotive technology so there is relatively little published literature describing the technical details of the sensing systems used and data processing algorithms. The majority of this information remains confidential as manufacturers' intellectual property. However, there is a substantial body of literature describing general system characteristics and the advantages and disadvantages of different approaches at a relatively high level. A compendium of sensors has been produced within the EC PReVENT project (www.prevent-ip.org), sub-project PRoFusion. Typical sensor technologies for this type of application are described below.

4.6.1.1 Radar sensors

Radar is currently the most widely adopted sensing technology for automotive ranging applications but careful design and optimisation are needed for a particular sensing task (e.g. frequency, antenna type and size, range, power limitations etc.) and frequency band availability is limited. It is suitable for both short and long range applications (typically <1 to 200m) and is superior to many other technologies for vector analysis. Radar sensors are also known to have sufficient robustness to function reliably under harsh environmental conditions for extended periods of time. Their performance is affected by atmospheric attenuation (particularly molecular oxygen and water droplets and precipitation will increase attenuation, especially at higher frequencies. Radar sensors are of medium to high cost and offer poor recognition of lane markings. They rely on objects reflecting the radar waves so objects with poor reflectivity are not easily detected.

The simplest type of radar system is a basic rangefinder that measures the time of flight of the transmitted radar beam from its reflection. This provides the distance between the sensor and the obstacle. Another type of radar uses the Doppler effect where the reflected beam undergoes a frequency shift proportional to the relative speed of the transmitter/receiver and the obstacle. Pulsed radar is frequently used in automotive applications to continuously update the position and closing speed etc. of the obstacles in the radar field of view. Other techniques include frequency modulation and frequency shift keying. Combinations of several radar beams can be used to accurately triangulate the positions of objects within the vehicle foreground up to several hundred metres.

4.6.1.2 Passive infrared sensors

Infrared radiation, more commonly identified as thermal radiation, is emitted by all objects having a temperature above absolute zero. A passive infrared sensor detects this naturally emitted radiation. Infrared radiation sits between the visible and microwave region of the electromagnetic spectrum and has a wavelength range of approximately 750nm to 1mm. Infrared sensors have numerous applications in object detection. Sensor functionality varies dramatically; high resolution (10 to 100,000 element) arrays with high sensitivity have been developed for military use, whilst volume manufactured one or two element detectors are found in intruder systems and simple light sensor applications. The pyroelectric detectors respond to changes in thermal characteristics – objects that are moving relative to the sensor are detected by the thermal contrast between the object and its background.

In practical terms a passive infrared sensor can be as simple as a single semiconductor detector peaked to respond in the infrared band. Arrays of these types of sensor can be put together to form a crude infrared “camera”. Traditional cameras are also available designed to work at infrared wavelengths. Such designs are used by the military and police for surveillance applications. These systems allow the detection of humans at night and provide a complete night vision scenario.

Passive infrared sensors are compact, provide good object detection and are suitable for pedestrian detection, however low resolution sensors may prove inadequate at reliably identifying obstacles, whilst the increased cost of high resolution sensors may prohibit their use. They are typically poor at differentiating between multiple hot bodies in close proximity and detection can be influenced by the presence of thermal insulation. For example, a pedestrian wearing a thick coat may appear to be relatively cold. Performance is also affected by the emissivity of the detected object and environmental conditions; the emitted radiation being absorbed by particles in the air. The effective distance at which sensors can reliably identify obstacles in automotive applications has yet to be established.

4.6.1.3 Active infrared sensors

The receiver in an active infrared sensor performs in a similar manner to that of a passive device, albeit the sensed area is either flooded with infrared radiation or a scanning laser beam may be used. Advantages of active infrared sensors over passive devices include improved range and sharp directivity. They provide a high data transmission rate and good immunity to electromagnetic disturbances. They are typically poor at differentiating between multiple hot bodies. Performance is also affected by the reflectivity of the detected object and environmental conditions.

4.6.1.4 Laser sensors

Laser or lidar (light detection and ranging) sensors are effectively range finders that calculate the distance to an object by measuring the time of flight of the emitted and reflected signal. In this respect, their principle of operation is similar to radar. Varying the direction of the emitted beam facilitates scanning over a wide area at high frequency to build up a map of points describing the environment and any potential obstacles. Frequently updating the map enables the determination of the relative position and speed of obstacles.

Laser scanner systems are capable of up to 100% detection accuracy in fair weather and 95% classification accuracy (Nuttall & Myers, 1996), overcoming many of the problems associated with radar sensors. However their performance is affected by output power, reflection, refraction, absorption and scattering. They provide good lateral resolution but are poor at recognising lane markings and require complex shape and motion recognition algorithms to be able to differentiate between different types of obstacles.

It is important that laser based systems are operated correctly because exposure to high power laser light can seriously damage human eyesight. This can be achieved by limiting the power and restricting the wavelength. Since laser systems require a clear line of sight they are usually mounted behind the windscreen whereas radar sensors can effectively ‘see through’ non-metallic structures.

4.6.1.5 Ultrasonic sensors

Like radar, lidar and active infrared systems, ultrasound can be used in detection and ranging applications using the time of flight principle to estimate the distance to an object. Ultrasonic emissions are effectively sounds waves with frequencies higher than that audible to the human ear, suitable for short to medium range applications at low speed. A scanning sonar sensor based on a phased array of ultrasonic sensors facilitates gathering information on the distance, angular position, velocity and nature of surrounding obstacles. Ultrasonic sensors provide a good indication of vehicle to obstacle distances, are less susceptible to being affected by a build up of debris, have good response times and are low cost. However their performance is only suitable for short and medium range applications, fluctuations in operating voltage reduces performance and the accuracy of object detection is sometimes affected by reflected signals.

4.6.1.6 Imaging systems

Cheap video cameras are now readily available and provide a low cost solution to image detection. However, the fundamental problem when using cameras is the need to distinguish particular objects within the image requiring complex software. Much research is going on in this field, for example the EC PReVENT project.

In their basic single camera configuration video imagers cannot provide ranging information. However, using the principle of triangulation coupled to obstacle recognition routines, the images viewed by camera systems may be processed to facilitate identification of obstacles and their range. Such systems provide good obstacle and environmental recognition using non-intrusive means. Their performance can be affected by contamination of the external optical surface of the viewer and by air-borne emissions affecting vision (e.g. precipitation, fog, smoke etc.). The ability to process environmental data in real time is based upon a large number of image simplifying assumptions, which may prove to be insufficiently robust for identifying complex urban road environment and obstacle movements reliably. Imaging technology provides the most complete environmental information.

A particular type of camera is the 3D imager. These devices include a laser emitter built into the camera that illuminates the scene. In effect, each pixel of the camera sensor acts as a simple 'Lidar like' range finder. Further details of this type of system are provided in the EC PReVENT project, sub-project UseRCams.

4.6.1.7 Passive mmWave sensors

Millimetre waves (mm-waves) are electromagnetic waves similar to light and radio waves. The name "mm-waves" is given to the region of the electromagnetic spectrum between frequencies of 30GHz and 300GHz, which correspond to wavelengths of 10 to 1mm. Mm-waves can be regarded either as very high frequency radio waves or as very long wavelength infrared. They should not be confused with the shorter wavelength terahertz (THz) waves though the terms are often interchanged.

All objects which are above absolute zero in temperature (-273 degrees C approximately) emit thermal radiation according to Planck's law and according to the emissivity of their surfaces. Human skin is highly emissive and its emission peaks in the infrared range at a wavelength of about 10µm. Infrared emissions are normally blocked by clothing which is worn with the express purpose of preventing heat loss. However, this clothing is largely transparent to millimetre-wave radiation. This offers the possibility of detecting human presence by their mm-wave emissions, a technique which is already in use by the military and security forces to detect the presence of enemy or undesirable personnel in buildings or vehicles.

There are two types of passive mmWave detectors that may be suitable for vehicle applications. These are imagers that behave like a camera except that they are tuned to a different part of the electromagnetic spectrum and discrete detectors that behave like a simple photo-cell, known as bolometers. These types of detector are being examined within the EC PreVENT project, sub-projects ProFusion and COMPOSE.

4.6.1.8 Sensor fusion

Sensor fusion involves combining multiple sensing technologies to supplement, enhance and improve the reliability of sensing system. Using one sensor technology to compensate for the drawbacks of another is a common practice in sensor fusion applications. A common fusion application involves the combination of radar or laser scanner and image sensing system. Sensor fusion offers the potential to gather additional information describing the vehicle operational environment and any obstacles but complex algorithms are necessary to interpret the data gathered.

4.6.2 Reliability of the sensing system

The reliability of a system is the ability to provide optimum performance within a range of operating conditions and over specified time duration. The reliability of an automotive sensing system will depend on a number of factors, including the reliability of components and subcomponents, the nature of interface between components and subcomponents, operational conditions and environmental interference, integrity of the software for data processing etc. There are many approaches to estimating systems reliability and different methods often yield varying estimates of reliability.

System reliability is a key factor in determining testing requirements for vehicle systems and particularly for those used in safety critical applications. In the late eighties, the IEC set up WG 10 to examine risk and reliability issues in the generic domain. This work has led to the almost worldwide adoption of IEC 61508 (International Electrotechnical Commission, 2005) as the methodology for the functional safety of electrical/electronic/programmable electronic systems (International Electrotechnical Commission, 2002). This document is currently being adapted for specific application areas, for example automotive, nuclear and medical sectors (Schoitsch and Althammer, 2006). Work within the AUTOSAR consortium project is developing a set of functional safety objectives and approach (Furst, 2006) specifically for the automotive sector. The work is based upon the ISO CD 26262 document which is itself based upon IEC 61508.

The approach used takes into account the full life cycle of the equipment from design and development to implementation and maintenance. The method introduces concepts such as hazard analysis and risk assessment and these are fundamental to the use of safety-related systems. Key to the process is the use of system integrity levels based upon the application. This has four basic levels of integrity split into two groups, safety-related continuous control systems and safety-related protection systems. These range from one in 100,000 to one in one billion failures per hour for the former and one in ten to one in 100,000 for the latter. There are also those systems with a zero rating which have no apparent safety function.

One such method (Holding and McCarthy, 1999), used to estimate the reliability of several automotive sensing systems, involved considering how the system would integrate with other safety devices in the vehicle, and the individual components and sub components that a base level sensing system will be comprised of. A failure mode and effect analysis (FMEA) was conducted and each fault was then examined and allocated an impairment factor (IF) ranging from 0 to 1, representing how serious an effect each fault would have on the system as a whole. The sum of the impairment factors and the total number of faults may be summed for system components, and the reliability factor (RF) calculated for each component as the ratio between these values. An RF for the system is then simply the sum of those for the individual components. The RF is a normalising term giving a value for each component that indicates the likely impact on the whole system for any one particular fault. The reliability factor facilitates a rapid analysis of system components, identifying areas for concern where improvements are required.

Currently, Annex 18 to UNECE Regulation 13 specifies general requirements for complex electronic systems that are used to apply higher level control to the braking system. This annex fundamentally specifies that systems must be designed according to processes that take functional reliability into account but does not specify those processes in any detail. The principles involved are comparable to those of the IEC document. This means that all AEBS in production that are approved to Regulation 13 will have to demonstrate some level of reliability. However, given the safety critical nature of autonomous braking systems it may be beneficial to require a more specific regulation of reliability, likely to be based on the IEC approach as amended by ISO for specifically automotive applications.

4.6.3 Environmental protection

Generic environmental requirements for a wide range of equipment are provide in IEC EN 60068, (International Electrotechnical Commission, 2005). This covers a wide range of test measures of which many are appropriate to motor vehicles and sensing systems in particular. The key areas of concern for motor vehicle applications include:

- Climatic sequencing;
- Damp and vapour;
- Vibration;
- Shock;
- Corrosion;
- Soldering;
- Sealing;
- Sand and dust;
- Chemical attack;
- Biological attack;

- Water ingress.

Similar requirements are listed by the SAE in the USA but these are too numerous to describe in this report. Although these requirements may vary from standard to standard in terms of detail they are reasonably uniformly applied in automotive electronics and must also be applied to AEBS.

4.6.4 Electromagnetic compatibility

Tests to examine the immunity of electromagnetic equipment to electromagnetic radiation and similar emissions have been used by the military since the mid fifties. Most of the early work was carried out in the USA. These techniques have been developed and now form the basis of international standards in both the military and commercial fields. In an attempt to produce harmonised standards and test methods within the European Community for the automotive sector, the Commission produced a Directive, 72/245/EEC, in the early seventies (Commission of the European Communities, 1972). This Directive received a major change in 1995 with the introduction of the new Directive, 95/54/EC, that came into force in 1996 (Commission of the European Communities. 1995). This Directive included, for the first time, specific test methods and levels for both emissions and immunity. This Directive was further revised in 2004 to take account of changes in technology, 2004/104/EC (Commission of the European communities, 2004). This revised the frequency range for immunity testing with a new upper frequency limit of 2GHz.

Specific requirements for transient disturbances, based upon ISO 7637 (International Standards Organisation, 2004) were also included. In fact, many of the test methods throughout the Directive are based upon International Standards from both the International Electrotechnical Commission (IEC) and the International Standards Organisation (ISO). The emissions tests are based upon the well established CISPR documents CISPR12, 16 and 25 (International Electrotechnical Commission, 2001, 2002 and 2002 respectively) that are produced by a special group within the IEC. Many of the immunity tests follow the procedures specified in ISO 11451 (International Standards Organisation, 2004) and ISO 11452 (International Standards Organisation, 2005) covering whole vehicles and component test methods. The 800mm stripline test has been included from IEC procedures, originally described in IEC 801 and now replaced by IEC 61000 (International Electrotechnical Commission, 1990 onwards). The IEC documents are more generic in nature and are applicable to a wide range of industrial and commercial equipment rather than specifically targeted at automotive equipment as is the case with ISO 11451 and 11452.

A summary of the immunity tests is shown in Table 2:

Table 2: Summary of EMC immunity tests prescribed in 2004/104/EC

Test method	Level
Full-scale chamber radiated	30V/m
Component radiated	30V/m
Bulk current injection	60mA
800mm stripline	15V/m
ISO 150mm stripline	60V/m
TEM cell	75V/m

With the implementation of 2004/104/EC, the frequency range for immunity testing was increased to cover 20MHz to 2 GHz. However, not all of the test methods can achieve the full frequency range.

In the USA, similar test methods are used and are summarized in Table 3:

Table 3: Summary of EMC immunity tests used in the USA

Test method	Frequency range	Test level
Chamber radiated	10kHz to 18GHz	200V/m
Direct injection	250kHz to 500MHz	0.5W
Bulk current injection	1MHz to 400MHz	350mA
Stripline	10kHz to 200MHz	200V/m
TEM cell	10kHz to 200MHz	200V/m
Tri-plate	10kHz to 200MHz	200V/m
Reverberation chamber	500MHz to 2GHz	200V/m
Power line magnetic	10kHz to 200MHz	15kV/m
Power line electric	60Hz to 30KHz	160dBpT
Conducted susceptibility	30Hz to 250kHz	3V p-p

It can be seen that the tests used in the US standards do differ to some extent but where direct comparison is possible the test levels appear to be considerably higher in the US. Given the safety critical nature of AEBS it may be appropriate to consider increasing the requirements for EMC immunity. The procedures used in the US are described in SAE J 1113 (Society of Automotive Engineers, 2005). Other relevant standards used in the USA and Japan are:

- SAE J 551 – Performance levels and methods of measurement of electromagnetic compatibility of vehicles, boats and machines (Society of Automotive Engineers, 2002);
- SAE J 1742 – Connections for high voltage on-board road vehicle electrical wiring harness – test methods and general performance requirements (Society of Automotive Engineers, 2005);
- SAE J 1812 – Function performance status classification for EMC immunity testing (Society of Automotive Engineers, 2003).

In Japan, the test methods for immunity follow the American SAE procedures summarized above.

Whilst the test methods for immunity are varied in nature, the requirements for emissions are much simpler and are based upon a particular test method as specified by the CISPR, part of the IEC. American, Japanese and European methods are similar although the American requirements, defined in SAE J 1113, cover the frequency range of 150kHz to 1GHz whilst European tests cover the range 30MHz to 1GHz. The particular emission limits vary with frequency. The American SAE also includes other tests for conducted emissions and conducted transient emissions.

Another important Directive is the Radio Equipment and Telecommunications Terminal Equipment Directive, 1999/5/EC (Commission of the European communities, 1999). This covers the emissions and immunity of all types of radio transmitting equipment. However, it does not cover the level of the wanted transmission which is governed by the appropriate ETSI (European Telecommunications Standards Institute) standards for the particular device. A particular area for concern is where transmitters are fitted to road vehicles because the two Directives are not harmonized. Work by TRL (Higgins, 1991) and, more recently by Nokia (Terronen, 2000), has demonstrated that mobile radio transmitters can generate electromagnetic disturbances significantly higher than the current EU immunity test level requirements prescribed in 2004/104/EC. This situation is under review by the Commission. In practice, it is well known that vehicle manufacturers test to levels considerably higher that the requirements prescribed in the Directive; many manufacturers test to levels of at least 100V/m.

The safety of telecommunications equipment is being specifically addressed within the SAFETEL project. This work is looking at the different types of system, risk and recommending future testing requirements. It is expected that deliverables from this project will become available during 2007.

Of particular relevance to automated emergency braking systems are the new requirements for radar systems fitted to vehicles. Commission Directive 2006/28/EC now includes the use of short range radar systems fitted to road vehicles. Furthermore, there has been debate about whether radar systems should be part of the RTTE Directive 1999/5/EC, (EUROPA website, 2006). The Directive provides the following definition of radio equipment;

'radio equipment' means product, or relevant component thereof, capable of communication by means of the emission and/or reception of radio waves utilizing spectrum allocated to terrestrial/space radiocommunication.

The EUROPA web site describes the issues and has concluded that radar systems should be included in 1999/5/EC. TRL suggests that this sets a precedent for sensors that generate electromagnetic waves and receive them. Other sensors that meet these requirements should also be included in both the automotive Directive, 2004/104/EC, and the RTTE Directive, 1999/5/EC. Examples of other sensors include laser ranging devices and passive mmWave detectors.

Underpinning the requirements for electromagnetic compatibility is the framework to limit the exposure of the general public to electromagnetic fields, Council Recommendation 1999/519/EC (Commission of the European Communities, 1999). This covers the frequency range of 0Hz to 300GHz.

4.6.5 Performance testing and evaluation

There are currently no generally accepted methods for testing and demonstrating that the performance and function of AEBS actually meeting minimum standards as a whole vehicle. An ISO standard relating to collision avoidance assistance systems is under development but its content remains confidential within the relevant working group. Once complete it may contain requirements related to the performance testing and evaluation of systems but this remains unknown at this time.

Within the EC PReVENT project, sub-project RESPONSE 3, considerable research has been completed to develop a code of practice for the design and evaluation of advanced driver assist systems (ADAS). A detailed check list has been compiled providing a step-by-step approach to this complex subject. Much of the work is based upon the practices recommended by IEC 61508. The concepts include:

- Hazard and risk;
- Techniques such as FMEA and FTA;
- System integrity;
- Controllability;
- HMI;
- Testing methods;
- Simulation techniques.

One of the most important, if not the most important, issue is that of controllability, which is defined as the ability of the driver to maintain control of the vehicle. This is relevant to situations where the driver needs to adequately control the vehicle when:

- An appropriate hazard is present, with the driver possibly aided by an electronic device;
- When an electronic device returns control to the driver;
- When an electronic aid develops a fault.

The APROSYS project (McCarthy & DeLange, 2007) has carried out related research. This aimed to define a generic method for gaining approval for active safety systems according to the flow chart shown in Figure 16. However, this approach has yet to be tested against the performance of a specific system and still relies on test methods defined by manufacturers on a case by case basis to assess the detailed performance aspects of the system.

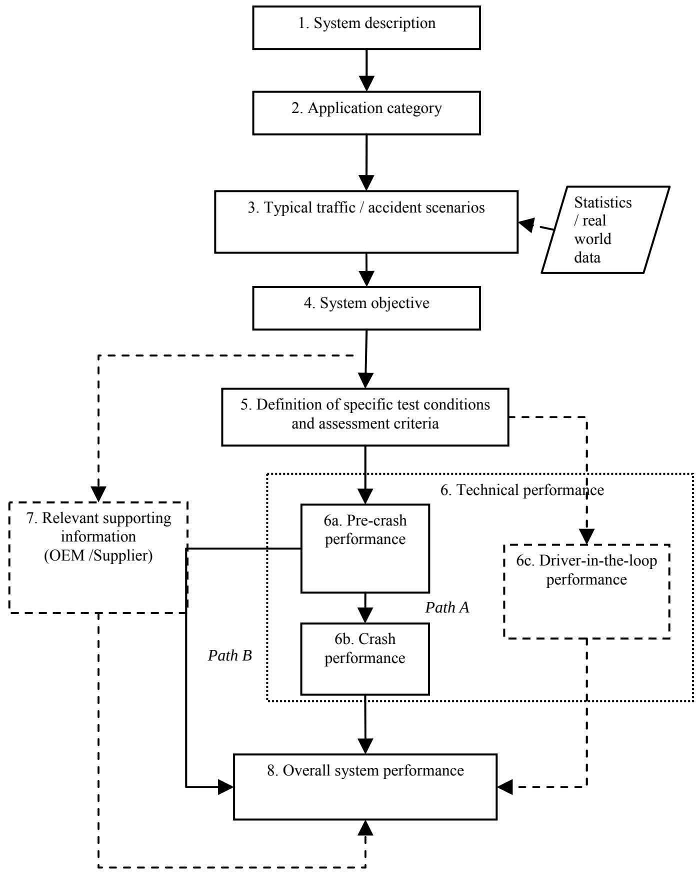

Figure 16. Generic test and assessment for active safety systems proposed in the APROSYS project

4.7 Functional requirements for Automatic Emergency Braking Systems

For the purposes of this report functional requirements have been defined as those relating to the various criteria for determining when the system should be activated and what it should do when it is activated. An ISO standard for this type of system is currently under development but remains confidential to the working group.

4.7.1 MLIT Technical guidelines

In conjunction with the automotive industry, The Japanese Ministry of Land, Infrastructure and Transport (MLIT) has established Annex 5 of the Automotive Technology Guidelines which contains technical guidelines on the functions of, and sets minimum technical requirements for, collision mitigation braking systems with a forward obstacle, that may be fitted on all vehicle types excluding motorcycles and buses (MLIT, 2005). Although there is little scientific literature available to quantify this, it is apparent that application of AEBS on motorcycles may involve technical difficulties unique to the vehicle type. However, the reason for the exclusion of buses is unknown.

The guidelines apply to AEBS, the function of which is to mitigate the damage of vehicle collision with a forward obstacle and have the function of warning the driver when there is a danger of collision with a forward obstacle and controlling of the brakes when a collision is judged imminent or unavoidable. They do not apply to autonomous braking control where the deceleration is between 0.10g and 0.25g (for example as used by ESC or adaptive cruise control systems), the duration of braking control does not exceed 0.80s and the braking control is considered as a warning.

The guidelines state that the vehicle velocity must be in excess of 15km/h, and the relative velocity between vehicles also in excess of 15km/h, for autonomous collision mitigation braking to be considered. The judgement that a collision is highly likely and autonomous braking shall be initiated is based on when the predicted time to collision (TTC) is less than the lower of the time required for collision evasion by steering or braking. Two different times are considered for collision evasion, based on:

- Vehicle performance capability (researched during vehicle braking and handling tests, or if no such test data is available for steering evasion, using values published in the guidelines);
- The lower limit of the distribution of evasion braking or steering start time during regular driving (calculated from formulae published in the guidelines).

Concerning vehicle performance capability the evasion braking limit is set at the predicted collision time determined from the relative velocity and the vehicle's maximum deceleration calculated on the basis of the vehicle's shortest braking distance. The evasion steering limit is set at the predicted collision time, which is the minimum time required for the vehicle to traverse a lateral displacement equivalent to an overlap of 40% of the vehicle width at the relative velocity. In place of this method for determining the evasion steering limit it is permitted to adopt the following limits:

- 0.60s for passenger vehicles with a seating capacity not exceeding 10 occupants;
- 0.80s for passenger vehicles with a seating capacity of 11 or more occupants and goods vehicles with a GVW exceeding 8t or a maximum loading capacity exceeding 5t.

The regular driving braking evasion limit is the predicted collision time calculated as:

- $T = 0.0167V_r + 1.00$ for passenger vehicles with a seating capacity not exceeding 10 occupants;
- $T = 0.0317V_r + 1.54$ for passenger vehicles with a seating capacity of 11 or more occupants and goods vehicles with a GVW exceeding 8t or a maximum loading capacity exceeding 5t;

where T is the predicted collision time (s) and V_r is the relative velocity (km/h).

The regular driving steering evasion limit shall be the following length of time:

- 1.40s for passenger vehicles with a seating capacity not exceeding 10 occupants;
- 1.60s for passenger vehicles with a seating capacity of 11 or more occupants and goods vehicles with a GVW exceeding 8t or a maximum loading capacity exceeding 5t.

However if the collision evasion width may be ascertained for an overlap greater than 40% the regular driving steering evasion limit may be corrected using the following formula:

- $T = 0.0067L + 1.13$ for passenger vehicles with a seating capacity not exceeding 10 occupants;
- $T = 0.0142L + 1.62$ for passenger vehicles with a seating capacity of 11 or more occupants and goods vehicles with a GVW exceeding 8t or a maximum loading capacity exceeding 5t;

where T is the predicted collision time (s) and L is the overlap (%).

For system performance testing the vehicle shall be in a condition that conforms to the brake test method prescribed in the brake system regulation established as an item of the Safety Regulations for Road Vehicles in Announcement 619 of the MLIT (2002), albeit in an unladen state. On a flat surface with a regular coefficient of friction autonomous brake control shall immediately lead to a deceleration exceeding:

- $5m/s^2$ (0.51g) for passenger vehicles with a seating capacity not exceeding nine occupants;
- A $3.3m/s^2$ (0.34g) for passenger vehicles with a seating capacity of 10 or more occupants and goods vehicles.

It is also stated that the vehicle shall be equipped with ABS or another vehicle stabilizing system, and whilst autonomous braking is being applied the vehicle stop lamps shall be illuminated.

4.8 Risks associated with behavioural adaptation

The introduction of any system which automatically alters the behaviour of the vehicle, through taking the driver out of the system feedback loop, may have effects on the behaviour of the drivers in vehicles fitted with this system. The main objective of this research was focussed on the physical characteristics of the systems and not on the behavioural aspects of them. This section, therefore, provides just brief reference to the behavioural aspects.

The design of the system can alter the way in which the driver's behaviour is affected. Should a collision mitigation system be designed in such a way that it will avoid accidents then the driver, once he becomes aware of this through information about the system and then a successful trial, may become reliant on the system to brake and avoid accidents for them. If the collision avoidance system is not 100% effective in all circumstances this could have the unintended consequence of making the collision severity worse in some circumstances. It may be possible, through the design of the system, to counter these effects. Should the way in which the system avoids the accidents give unsatisfactory sensory feedback to the driver, for example the braking is so harsh that it is uncomfortable on the body, this would lower the driver's inclination to rely on this system to brake for them and they may be more likely to choose to brake themselves to avoid the unsatisfactory sensory feedback.

An example of this can be found in research into Adaptive cruise control (ACC). Many researchers found that this reduced mental workload and was thus beneficial. However, some researchers (e.g. Stanton & Marsden, 1996; Nilsson, 1995) found that drivers had difficulties in understanding how an ACC functions and as a result inappropriately relied on the system, in some cases failing to intervene when approaching a queue of vehicles because they believed that the ACC could effectively respond to the situation. Seppelt et al (2004) showed that reliance on ACC led drivers to disengage from driving and increased drivers response time to vehicles ahead braking. However, they also found that the braking action of the ACC had a greater effect than this such that a net benefit remained.

In the case of mitigation systems, the system will not necessarily avoid collisions, only reduce their severity. According to the theory presented above, this should mean that drivers do not come to rely on the system. However, this research has only considered the benefits of the automated braking aspects of an AEBS. In reality all of the current and proposed systems featured ACC and some form of driver warning systems that are activated before the collision becomes unavoidable. It is, therefore, possible that behavioural adaptation by drivers could lead to some element of reliance on the system that could reduce the benefits in some circumstances, depending on the characteristics of the warning aspects of the AEBS.

4.9 Effects on congestion

AEBS are expected to mitigate or avoid accidents in specific circumstances. The immediate benefit of this is a potential reduction in casualties. However, it is increasingly recognised that accidents contribute substantially to congestion and delays on the road network. It is also recognised that, in general terms at least, more severe accidents result in greater disruption due to the time taken to remove and treat casualties at the scene and also due to the time taken to clear damaged vehicles and carry out police investigations of the collision. There are, therefore, two different elements of the effects on congestion; the effect of reducing the severity of collisions and the effect of avoiding collisions. Some earlier forms of AEBS are predominantly likely to affect only severity reduction but future systems are increasingly expected to completely avoid certain types of collision. The effects of each of these features were considered separately, as described below.

4.9.1 The effect of reduced accident severity

This section of the report describes a preliminary analysis of the potential benefits of reducing the severity of accidents in terms of the benefits for reducing congestion. The analysis discusses the value of time (VOT) benefits in terms of reduced delay to all road users caused by accidents that occur in running lanes becoming less severe.

The VOT benefits can be estimated using the INCA (INcident Cost benefit Assessment) tool developed for the UK Department for transport (DfT). This tool can estimate monetary benefits caused by changes to current levels of accident rate and duration. It is based on research carried out in the UK over a number of years. It is limited to the motorway network because relevant data for all purpose inter-urban or urban roads is scarce.

To use INCA, it is necessary to estimate how a particular measure will change the overall rate and average duration of all accidents. Previous research into incident related congestion has examined the frequency of accidents and for how long they inhibit traffic flow in relation to their severity. Using the results of this research, and generic assumptions of how AEBS will change the severity of an accident, annual benefits to users of Great Britain’s motorway network have been estimated. Crude approximations have then been used to multiply up the predicted benefit for the motorway network into an estimate of the effect when all roads are considered.

The investigation has been divided into three parts.

- Estimation of the percentage of accidents that will benefit from the system;
- Translating the percentage of accidents benefiting from the system into an overall percentage change in rate and average duration of all accidents (ready for use in INCA);
- Inputting the values into INCA and obtaining a monetary benefit value.

A simple overall average approach has been adopted, and the effect on journey time variability reduction and detailed traffic diversion opportunities have not been considered.

4.9.1.1 Estimating the percentage of accidents that will benefit from the system

It had originally been intended that the percentage of accidents affected would be derived directly from the accident analysis described in preceding sections. However, because the accident analysis was unable to accurately estimate the severity reduction effect, the analysis has been based on general assumptions. It is clear that where drivers fail to apply the brakes, for example due to driver distraction, introducing such a system will cause some accidents to be less severe allowing them to be cleared from the road more quickly. Future systems may even avoid accidents and be beneficial in a broader range of situations.

A study of 2,114 accidents on all road types in the West Midlands found that for 5.1% of them, driver distraction was a major or contributory factor, and 45% of these resulted in a rear end shunt (Pettit *et al*, 2005). This suggests that AEBS may benefit somewhere in the region of 2.25% of all accidents (assuming all vehicles are equipped). This may be an over estimate, because the driver responsible, although distracted, still may apply the brakes before impact.

Because of the problems of estimating the percentage of accidents that will benefit, a range of values from zero to 5% will be examined so that the results can be used as a lookup table if definitive values become available.

4.9.1.2 Predicting the change in rate and average duration of all accidents

The percentage change in the accident rate is not the same as the percentage of accidents that will benefit. This is because the types of AEBS considered in this section have been assumed only to mitigate accidents and not to avoid them (avoidance effects can be seen in section 4.9.2).

The duration of an accident has been defined as the time for which all or part of the carriageway is blocked. A separate study into incident duration on the West Midlands motorway network examined both injury and non-injury accidents reported to the Police (Frith et al, 2006). It found that the duration of an accident is correlated to the injury severity and whether or not a goods vehicle is involved. For damage only accidents, the vehicles can often be moved to the hard shoulder before the emergency services arrive, this is less likely if injuries have occurred or if vehicles have been severely damaged. Severe damage and injuries are more likely when a goods vehicle is involved. The study covered a 46 week period from December 2002. The total number and average duration are shown in Table 4 and Table 5 respectively.

Table 4 Number of accidents by severity and HGV involvement in West Midlands study.

	fatal	serious	minor	damage only
Goods vehicle not involved	12	56	235	822
Goods vehicle involved	10	21	91	265

Table 5 Average accident duration (minutes) by severity and HGV involvement in West Midlands study.

	fatal	serious	minor	damage only
Goods vehicle not involved	249.6	92.1	48.4	28.4
Goods vehicle involved	317.4	117.5	62.1	37.5

For accidents benefiting from AEBS the calculation of the benefits depends on whether the AEBS is able to prevent accidents altogether. It can reasonably be assumed that AEBS will be able to avoid a high number of accidents from the beginning of the next decade. In some cases, however, AEBS will only be able to mitigate collisions. The proportion of these two accident groups is obviously unknown today. A very conservative assumption (which underestimates the potential of future AEBS assumes that the severity of the accident will be reduced by one level, i.e. each fatal accident will become a serious, each serious will become a slight, each slight will become a non-injury and each non-injury accident will be avoided altogether. For example if 2.25% of accidents were to benefit, then the predicted number of accidents would be as shown in Table 6.

Table 6 Predicted number of accidents by severity and HGV involvement in West Midlands study (assuming EBS with 2.25% benefiting).

	fatal	serious	minor	damage only
Goods vehicle not involved	11.73	55.01	230.97	808.79
Goods vehicle involved	9.78	20.75	89.43	261.09

It should be noted that this assumption is likely to provide an over-estimate of the effect of AEBS because even with collision mitigation systems a small number of accidents would be fully avoided.

In reality the number of accidents would be an integer value, but for computational precision, the values are stored with the maximum number of decimal places.

Using the tables above, a percentage change in total number of accidents (rate) and average duration can be calculated and compared to the values without AEBS. The average duration is weighted by the number in each category. In this example, the number of accidents would be 98.38% of the non AEBS value, while the average duration would be 99.94% of the non AEBS value.

If AEBS were only installed in goods vehicles, then we could assume that the figures in Table 6 for goods vehicles not involved would be unchanged and remain the same as in Table 4, allowing a separate pair of values to be calculated.

Figure 17 shows all four values verses the percentage of accidents benefiting.

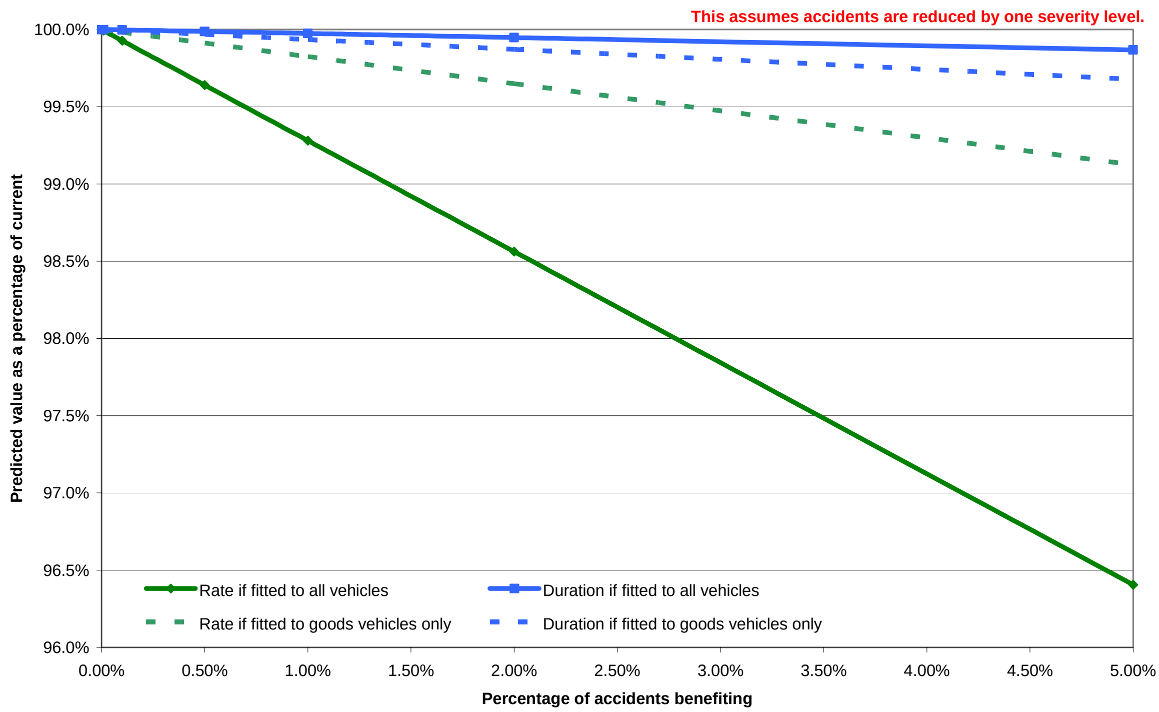

Figure 17 Predicted change in overall accident rate and average duration using AEBS

As the percentage of accidents benefiting increases, both the rate and duration decrease.

If 5% of all vehicles were to benefit, the rate would be reduced to 96.4% of the current level (not 95%) because damage only accidents are assumed to be the only ones with the potential to be completely avoided.

Average duration decreases because a smaller proportion of the remaining accidents are fatal.

If the system were fitted to goods vehicles only, the rate would not reduce as sharply, though the average duration would reduce more sharply, because a higher proportion of the remaining accidents would not involve a goods vehicle.

4.9.1.3 Calculating the benefit.

The INCA spreadsheet contains default values of accident rate and mean accident duration derived from previous studies.

It was assumed that the proportions of accidents in each category observed in the study above are representative of the whole motorway network, thus allowing the changes in accident rate and average duration to be used to calculate the overall benefit. It was assumed that an AEBS has no effect on other incident types i.e. breakdown, debris, load shedding, fire and spillage.

To use the INCA spreadsheet accurately, each motorway link should be entered with specific average daily flow values. This would be a major task, because a maximum of 12 links are allowed, and only one change in accident rate and duration can be estimated per run. To quickly allow approximate estimates for the whole country, the entire British motorway network (3,520 km) was represented using a single link with uniform traffic flow based on an overall figure for motorways quoted in Transport Statistics Great Britain for 2005. All motorways were assumed to have 3 lanes. The spreadsheet was also updated to use values of time at 2002 prices. The results from the INCA spreadsheet are shown in Figure 18.

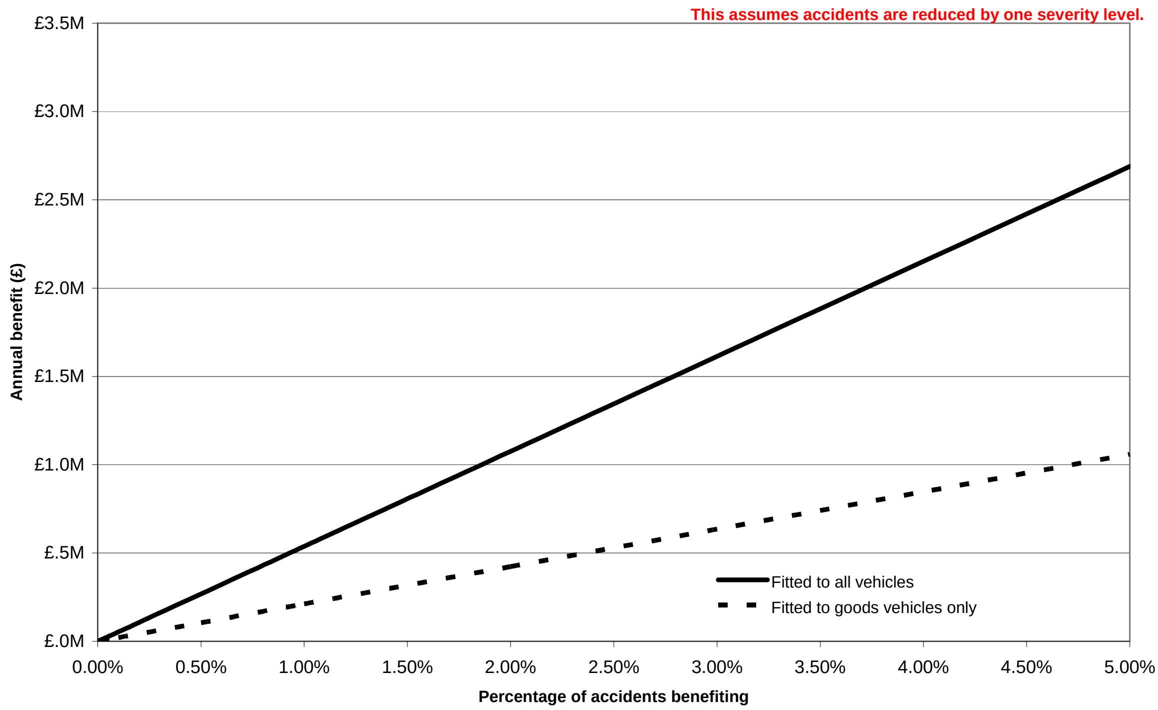

Figure 18 Predicted annual delay time benefit of using AEBS on the UK motorway network (2002 prices).

The chart shows that the benefit is approximately linearly proportional to the percentage of accidents benefiting. For example if 2.25% of all accidents were to benefit from AEBS (as suggested above) to the extent that their severity is reduced by one level, then the delay benefit to all motorway users over a year would be in the order of £1.2M or approximately €1.8m at 2002 prices.

Motorways accounted for approximately a fifth of all traffic in 2002, so a crude approximation for the benefit to the whole of GB would be five times this, i.e. £6M or approximately €9m.

Approximately 40% of these benefits would be achievable if only goods vehicles were equipped.

4.9.2 Effect of accident avoidance on congestion

In this section the effect of AEBS that were capable of full accident avoidance rather than severity reduction were assessed. Instead of assuming each accident affected is reduced by one severity level, it was assumed that it was avoided altogether. This means that predicting the new accident frequency and average duration is a much more straightforward process than before. If the system is fitted to all vehicles, the total accident frequency simply reduces by the same proportion as accidents which benefit, and the average duration does not change at all because it was assumed that all accident types are equally likely to benefit. If the system was only fitted to goods vehicles, then the average duration would reduce when the number of accidents benefiting increases, due to the fact that a smaller proportion of the remaining accidents would involve a goods vehicle. Figure 19 shows how these values would change according to the percentage of accidents benefiting.

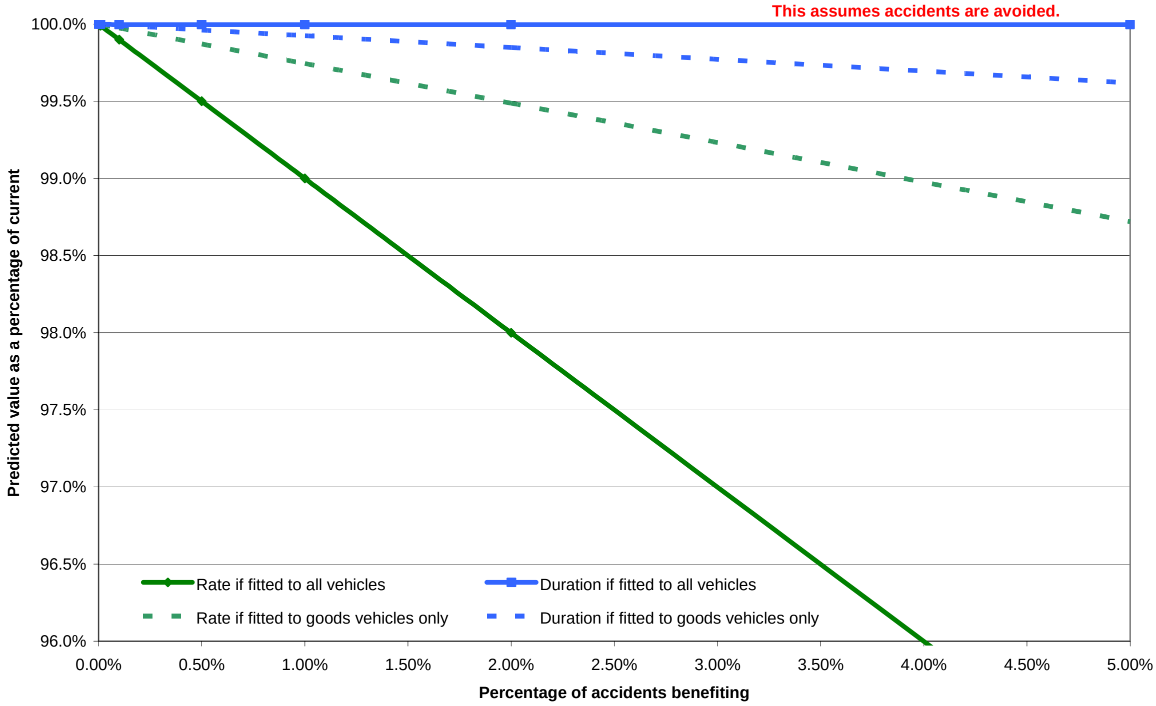

Figure 19. Predicted annual delay time benefit of using AEBS on the GB motorway network (2002 prices).

The chart shows that the benefit is approximately linearly proportional to percentage of accidents benefiting. For example, if 2.25% of all accidents were to benefit from AEBS (as suggested) to the extent that they could be avoided altogether, then the delay benefit to all motorway users over a year would be in the order of £1.6M or approximately €2.4m at 2002 prices.

Motorways accounted for approximately a fifth of all traffic in 2002, so a crude approximation for the benefit to the whole of GB would be five times this, i.e. £8M or approximately €12m.

As before, approximately 40% of these benefits would be achievable if only goods vehicles were equipped.

4.10 Estimate Casualty Saving Benefits

4.10.1 Previous research into potential benefits of automated emergency braking systems

4.10.1.1 Behavioural research

Perron *et al* (2001) carried out experiments where ordinary drivers were asked to follow a vehicle that towed a trailer. To simulate an emergency braking event the trailer was released and braked at 7 m/s^2. It was found that only 20 percent of drivers who braked but did not swerve managed to avoid a collision, 50 percent of all drivers did not brake sufficiently hard to activate the ABS at any point and for 85 percent of drivers there was a substantial delay before maximum braking was achieved. Similar results were noted by Hara *et al* (1998) in tests where the emergency was simulated by unexpectedly throwing an object in front of the vehicle from the side of the road. They also noted that the pedal force applied by drivers that failed to activate the ABS was less than a third of those that did and that in the case of the latter there was a tendency to reduce the force on the pedal during the course of the braking operation.

McCarthy *et al* (2004) carried out a study with ordinary drivers in a driving simulator that was specifically investigating pedestrian collisions. They also found that braking was the most common avoidance strategy and that the brake force applied by different drivers was highly variable.

All of the research noted that there was scope for adaptation of the brake system to improve the actual braking performance that real drivers achieved in emergency braking applications. Brake Assist Systems (BAS) were developed with the intention of improving driver's braking performance in emergency situations. The basic concept is that the system will detect when a driver intends to make an emergency stop and will act to try and increase the likelihood that full ABS braking will be achieved quickly.

Perron *et al* (2001) also considered how a brake assist system should behave in the control phase during the stop. They made no comment with respect to whether the assistance should be a boost in pressure or a full application of ABS braking. However, they noted that in their track trials with ordinary drivers, who were asked to avoid a heavily braked vehicle ahead, that all drivers braked to some extent as part of their collision avoidance strategy. However, 50 percent of the drivers also tried to swerve around the obstacle. Eighty five percent of those drivers who swerved were successful in avoiding a collision compared with only 20 percent of those that braked without swerving. Although it could be argued that swerving may be less successful in a real road environment compared with a test track because of the risk of collision with oncoming traffic or roadside furniture, this research does suggest there are significant benefits to swerving.

The test results (Perron *et al,* 2001) also showed that all drivers that swerved partially released the brake during the swerve, which has the effect of increasing the lateral grip available to help steer. Perron *et al* (2001) concluded that, once activated, an emergency brake assist should keep the driver in the loop such that he can end full braking (ABS) control with only a partial release of the pedal, thus helping in swerving situations.

Daimler Chrysler carried out research in driving simulators to assess the effects of BAS PLUS. This research involved 100 ordinary drivers driving around simulated highways and secondary roads and being presented with a range of critical situations such as approaching the end of a highway traffic jam at high speed and a vehicle ahead suddenly braking. In a vehicle with conventional brakes 44% of drivers suffered a collision but with brake assist plus fitted this was reduced to 11%, suggesting a substantial benefit for front to rear end collisions between cars. More than 200 drivers also took part in practical trials in Europe and the USA, covering a total of more than 450,000km in 24 test cars. Evaluation of the data and video sequences showed that BAS PLUS also makes a major contribution to safety under real conditions.

Daimler Chrysler research in the driving simulator involving deliberate distraction of the driver's attention showed that:

- The majority of the 70 participants reacted spontaneously to the visual and audible warnings provided by the proximity control and were able to avert the accident with support from BAS PLUS. As a result 53 percent of the drives remained accident free.
- Seventeen percent of participants only reacted when the autonomous partial braking occurred and then applied the brake quickly enough to avert the accident with support from PRE-SAFE Brake and BAS PLUS.
- The remainder were so distracted that they did not manage to brake in time. In these cases PRE-SAFE Brake reduced the impact speed from an average of 45 to 35 km/h, meaning 40% lower crash energy and a significantly reduced risk of injury for occupants.

Suzuki (2003) conducted an experimental study in a driving simulator with 25 drivers to investigate behavioural changes relevant to braking manipulation when the intervention parameters of a Forward Collision Avoidance Assistance System were varied. The braking algorithm was manipulated in the study to minimize interference between driver operation and system actuation and minimize over-dependence on the system. The requirements identified as being important in minimizing interference between the driver and the system during braking were:

- Initiation of braking control by the driver; the driver initiates braking operation before braking control by the system;
- Collision avoidance by the driver; the driver performs braking when the Time to Collision becomes minimum, indicating that the danger of the collision is greatest.

In the experimental scenario the vehicle approached a stationary object in the carriageway at 60km/h, simulating a situation in which the forward obstacle collision avoidance assistance system would operate. The drivers' braking behaviour was observed when the start timing of braking control was varied. Although both the braking control function and the forward vehicle collision warning function would be installed in the system in the actual design, only the braking control function, without warnings, was set up in the study in order to analyse the relationship between the start timing of braking control by the system and the drivers' braking behaviour.

The braking control pattern during system actuation is shown in Figure 19. The control pattern when the goal stopping position was in place in front of the obstacle (for avoiding the collision) is illustrated in Figure 19 (left), and that when the goal stopping position was in place behind the obstacle is shown in Figure 19 (right). The car collided with the obstacle when the goal stopping position was set behind the obstacle if the driver did not perform braking operation.

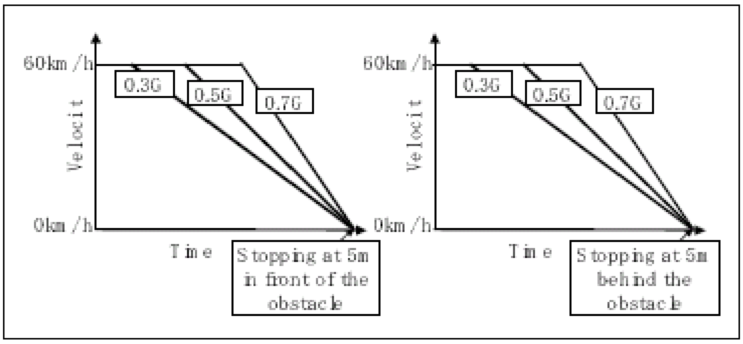

Figure 19: Braking control pattern for stopping position in front of (left) and behind (right) the obstacle

Three deceleration levels, 0.3g, 0.5g and 0.7g, were configured for the vehicle for use during system actuation. Two positions, five metres forward of the obstacle and five metres behind the obstacle, were set up as a target stopping points.

The main findings of the study were:

- All subjects initiated braking before system actuation when the system was actuated at a Time to Collision of 1.7s or less, under conditions in which the car approached a stationary obstruction at 60km/h;
- It appeared that all subjects performed braking during collision avoidance in such a way that Time to Collision remained above 0.84s.

It was concluded that Time to Collision is an effective state variable for analyzing the dependence level on the system, and that a Time to Collision setting of less than 1.7s is optimal for the onset timing to minimize over-dependence on a Forward Collision Avoidance Assistance System. The minimum Time to Collision during braking control by the system should be less than 0.84s.

Renschler (2007) reports the results of a field test performed by DaimlerChrysler to investigate the affects of driver assistance systems on accident involvement frequency and severity. The vehicle fleet comprised 500 Mercedes Benz Actros tractor units fitted with a safety package including Telligent Lane Assistant, Telligent Stability Control and Telligent Distance Control (for maintaining headway). After the fleet had travelled a distance of 100 million km over one year data describing the frequency of accident involvement and severity were compared with a fleet of 500 nominally identical vehicles without the safety package.

The accident data was analysed to identify potential accident scenarios in which the intervention of the systems would have a beneficial effect. Actual accidents figures are not reported, however it is claimed that the intervention of the safety systems in these scenarios resulted in a reduction of approximately 50% in the number of accidents occurring. The reduction in cost associated with these accidents was claimed as 90%. Specifically the accident avoidance potential of the Distance Control on HGVs is reported as 10%.

The accident avoidance of potential of various HGV driver assistance systems that make use of information from the cruise control system were presented by Knoll (2007). It is claimed that 37% of all rear shunt accidents can be avoided with extended ACC and this figure increases to 78% if the driver intervenes by braking and triggers the maximum deceleration. Systems that are capable of recognising stationary objects can avoid 98% of rear shunt accidents if the driver intervenes to trigger maximum braking.

4.10.1.2 Accident research

Najm *et al* (2006) estimated that a “collision avoidance” system incorporating ACC and forward collision warning could avoid 6% to 15% of rear end collisions where the subject vehicle was a light vehicle. This was based on a field operational trial in the US where 66 drivers drove 10 vehicles for 4 weeks each.

Dorner (2007) estimates that 6% of all truck accidents could be prevented by ACC even without any driver intervention but that 7% could be prevented if the driver reacted two seconds after the ACC implemented braking action. This translates to 28% and 34% respectively of truck rear-end collisions. If only accidents on motorways were considered then 20% of all truck motorway collisions could be prevented or 71% of all truck rear end accidents that occurred on motorways.

Sugimoto & Sauer (2005) estimated the effectiveness of a collision mitigation braking system in enhancing safety by simulating approximately 50 cases of rear-end collisions from US National Automotive Sampling System/Crashworthiness Data System. The simulation model consisted of the accident scenario database, the vehicle model, the driver model and the environment model. The vehicle model included a radar model, control logic and a brake actuator model as well as a conventional vehicle dynamics model. The driver model, which could react to the warnings by braking and/or steering, was based on test results using a driving simulator.

The results showed that the collision mitigation braking system had substantial potential to reduce or mitigate rear-end collisions. Based on the results of the simulations and analyses, it was estimated that if it had been installed in all of the vehicles involved in rear-end collisions:

- There would have been a 38% reduction in the number of collisions that occurred;
- For the preliminary model of probability of fatality as a function of the change in velocity, it was estimated that there would have been a 44% reduction in probability of fatality in these rear-end collisions.

The results of track testing carried out with the Nissan ASV 2 (a prototype vehicle equipped with automatic braking and active brake control for emergency manoeuvring) shows that the latter capability compensated for the steering response (Matsumoto et al, 2001). The driver did not have to steer as much, nor hold the steering angle for the emergency manoeuvre for as long a time, indicating that the system assisted the avoidance manoeuvre by steering for the driver.

An evaluation of expected safety benefits of pre-crash systems, including collision mitigation emergency braking systems, is being carried out as part of the European Commission 6th Framework Traffic Accident Causation in Europe (TRACE) project. Consultation with the project co-ordinator revealed that the research is underway, but at the time of writing relevant results are not yet available. Provisional results are scheduled to be available mid 2008 and published subsequently.

4.10.2 Benefits of automatic emergency braking systems

TRL undertook a detailed accident analysis exercise in order to estimate the potential benefits of a generic AEBS modelled on first generation systems in current production. This process is described in detail in Appendix A. As part of this analysis, TRL proposed a specification for a generic AEBS modelled on those systems in current production, that is, radar based systems that function mainly in front-to-rear shunt collisions between vehicles. This specification was then tested against in depth accident data for cars and trucks. While the methodology used was valid, limitations in the data available severely limited the confidence in the conclusions. While it was possible to define the scope of potential benefits of a current AEBS it was not possible to define the effectiveness when fitted to a car. More detailed data was available for accidents involving a truck or bus and it was possible to define an effectiveness estimate in this case, as described in more detail in Appendix A. The detailed analysis of in-depth accident data found that a current AEBS fitted to a heavy vehicle had the potential to reduce fatalities from front to rear shunt accidents by between approximately 25% and 75%. This range is consistent with values shown above by other researchers (e.g. Sugimoto and Sauer, 2005, 44%, Dorner, 2007, 28% to 34% by ACC/FCW assuming driver responds to the system and implements braking). However, the range of predicted values was very wide mainly because the specifications of the two generic systems defined by TRL in consultation with the stakeholder group were based on taking the most extreme values for each parameter used by manufacturers in their first generation CMBS. In addition to this it was acknowledged that the estimation of fatality probability was very crude.

The limitations of the available accident data and further limitations with respect to cost (see section 4.11) meant that it was not possible to carry out a rigorous cost benefit analysis for current AEBS. For this reason, an alternative approach was used to assess, in broad terms, the scope of potential benefits of AEBS in a wide variety of accident mechanisms which the research has suggested may represent future developments of the system. This was carried out on the basis of assessing the casualty populations affected if a system could function in a particular configuration and achieve an effectiveness equivalent to the 25%-75% that was empirically derived for front to rear shunt collisions involving heavy vehicles.

The remaining assumptions and methods used to generate these figures are listed below:

- AEBS was considered to constitute the automated heavy braking immediately before a crash. ACC and forward collision warnings (FCW) that are typically fitted to the same vehicles as AEBS because of shared hardware, were considered as separate systems and were excluded from the analysis. The casualty population that each of these systems target is the same, for example, car occupants injured in front to rear shunt accidents, but the proportion of those casualties that would be avoided or reduced in severity has been calculated only for AEBS and does not, for example, include casualties avoided because the driver responded to a forward collision warning and applied the brakes.
- Not all of the benefits in the accident categories can be added together:
    - The UK national accident database only records one impact with another vehicle or pedestrian but does record impacts with rigid fixed objects separately. Therefore adding the benefits of collisions with rigid fixed objects to collisions with vehicles will double count casualties from accidents that involved both a collision with another road user and with a rigid fixed object;

    - The benefits of equipping a heavy goods vehicle with an AEBS effective in head on collisions cannot be added to the benefits of equipping a car with a head on AEBS because in all cases where the collision is between a HGV and a car the benefits will be double counted such that between 50% and 150% of that type of accident will be mitigated. This is true for all combinations of vehicles that the system could be fitted to in collision types where they collide with each other head-on.

- Only one and two vehicle accidents have been considered because the UK data is not capable of adequately describing the interactions of vehicles where the accident involves more than two vehicles. This will result in a small underestimate of benefits. This will partly but not fully offset the double counting inherent in adding different groups together as described above;

- The research has suggested that between approximately 25% and 75% of fatal rear shunt accidents involving heavy vehicles could be mitigated to serious injury (see Appendix section A.4). It has been assumed that the same proportion will apply when the system is fitted to other vehicle types and in other collision mechanisms;

- The fact that systems are only fully functional in certain accident types has been accounted for in the in-depth accident data used to derive the above effectiveness. However, the extent to which conditions could be accurately excluded is limited by the available weather codes in the accident data.

- No information on the effect on serious or slight injury accidents is available, so it has been assumed that:

    - between 25% and 75% of serious injuries will be mitigated to slight injury;

    - There was a suggestion in the responses from industry that in some very specific instances a collision mitigation braking system could actually fully avoid a collision. For this reason it has been assumed that between 0% and 10% of all slight injury accidents could be fully avoided. As stated above, the number of accidents that AEBS will be able to avoid at the beginning of the next decade is likely to be much higher, so this could constitute a considerable underestimate.

- Only high level data on accidents in Europe was available. It was, therefore, assumed that the UK proportion of each accident type and severity was the same in Europe plus or minus 10%. These proportions were then applied to the EU-25 fatality totals to develop upper and lower estimates of European accident numbers within scope. It should be noted, therefore, that adding all of the "upper" estimates for every collision type possible would result in a total that was 10% in excess of the number of accidents recorded for Europe;

- A European average value for the prevention for injury has been derived using figures for individual countries in 2003 (Elvik and Olsen, 2003), averaging them, expressing the average as a proportion of the UK value for 2003 and then applying that proportion to the UK figure for 2005. Thus it is assumed that the increase in European values between 2003 and 2005 has been proportionally the same as the increase in UK values;

- The total number of vehicles registered and the number of new vehicles registered in 2005 for EU-25 was taken from the EC statistical pocketbook on energy and transport (EC, 2006) and the estimates are subject to all the constraints of that document;

- Congestion costs were based on the UK analysis described in section 4.9 to form a lower boundary. This was supplemented by information used in the SEISS project (Abele *et al*, 2005). This information suggested that the congestion effect of mitigating a fatal accident to a serious accident was valued at €15,000 per accident and mitigating a serious accident to a slight was €5,000 per accident. The SEISS values form an upper boundary;

- The overall upper boundary for cost/vehicle was derived by using all of the upper estimates of benefit and dividing by the number of new vehicle registrations of the relevant type in 2005.

This represents the cost per vehicle that can be sustained for a benefit to cost ratio of one in the steady state period when all vehicles are equipped with the system (i.e. 100% of benefits but costs only applied to new vehicles). This is considered optimistic because it does not consider the interim period when the benefits will be smaller because only part of the vehicle fleet is equipped but the costs remain the same (i.e. same number of new registrations each year);

- The lower boundary for the break-even cost/vehicle was defined using all of the lower estimates of benefits multiplying by eight to get the total benefit in an average eight year vehicle life and dividing by the total number of vehicles of the relevant type registered on the road. This is considered pessimistic because it ignores the greater benefit to cost ratio achieved in the steady state period described above.

Examples of the tables used to calculate the cost benefit analysis are shown in full in Appendix C and summarised below. Table 7 shows the potential of the system in the main accident type that is typically within the scope of those systems that were found to be in current production at the start of this project.

Accident and casualty type		**Estimated total casualties (EU-25) 2005**		**Predicted reduction in casualty numbers (fatal/serious 25%/75%, slight injuries (0%/10%)**		**Cost per vehicle (€) sustainable for a benefit/cost ratio of 1**	
		Upper	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
All casualties from two-vehicle accidents where the front of an M1 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	709	580	532	145		
	Serious	12,453	10,189	8,808	2,402		
	Slight	506,805	414,659	41,873	-2,402		
M1 Total						**136**	**15**
All casualties from two-vehicle accidents where the front of an M2/M3 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	18	15	14	4		
	Serious	496	406	358	98		
	Slight	17,134	14,018	1,355	-98		
M2/M3Total						**1,450**	**162**
All casualties from two-vehicle accidents where the front of an N1 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	156	128	117	32		
	Serious	1,674	1,369	1,138	310		
	Slight	44,536	36,439	3,315	-310		
N1 Total						**144**	**20**
All casualties from two-vehicle accidents where the front of an N2/N3 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	468	383	351	96		
	Serious	2,340	1,915	1,404	383		
	Slight	31,913	26,111	1,787	-383		
N2/N3 Total						**1,343**	**286**

Table 7. Summary of benefit analysis for AEBS in front to rear shunt accidents

Benefits of automated heavy braking function of AEBS only. Does not consider potential effects of ACC, collision warning or restraint optimisation, which may also be present on vehicles fitted with AEBS

It can be seen that the cost per vehicle that can be sustained for a benefit to cost ratio of one is approximately 10 times greater for heavy vehicles than it is for light vehicles. The reasons for this are that heavy vehicle front to rear shunt accidents are typically more severe than light vehicle shunt accidents with approximately 0.93% of casualties from heavy vehicle shunt accidents killed compared with just 0.15% of casualties from light vehicle shunt accidents being killed. In addition to this the costs of fitment are applied to a much smaller population of heavy vehicles compared with light vehicles. Within the heavy vehicle field the cost per vehicle estimated is comparable for buses and trucks but the total casualty reduction potential is much greater with trucks, with a fatality reduction of up to 351 for trucks and up to 14 for buses. The casualty reduction potential is greatest for passenger cars (M1).

In order to consider the ultimate scope of benefits of such systems it is worth considering the cost per vehicle that would achieve a benefit to cost ratio of one for "perfect" collision avoidance systems. The costs per vehicle that would result in a benefit to cost ratio of one for the full avoidance of all front to rear shunt accidents between the vehicles considered are shown in Table 8.

Table 8. Benefits of fully avoiding ALL front to rear shunt accidents

Accident and casualty type		Estimated total casualties (EU-25) 2005		Predicted reduction in casualty numbers (full avoidance)		Cost per vehicle (€) sustainable for a benefit/cost ratio of 1	
		Upper	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
All casualties from two-vehicle accidents where the front of an M1 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	709	580	709	580		
	Serious	12,453	10,189	12,453	10,189		
	Slight	506,805	414,659	506,805	414,659		
	M1 Total					**463**	**204**
All casualties from two-vehicle accidents where the front of an M2/M3 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	18	15	18	15		
	Serious	496	406	496	406		
	Slight	17,134	14,018	17,134	14,018		
	M2/M3Total					**4,821**	**2,105**
All casualties from two-vehicle accidents where the front of an N1 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	156	128	156	128		
	Serious	1,674	1,369	1,674	1,369		
	Slight	44,536	36,439	44,536	36,439		
	N1 Total					**380**	**181**
All casualties from two-vehicle accidents where the front of an N2/N3 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	468	383	468	383		
	Serious	2,340	1,915	2,340	1,915		
	Slight	31,913	26,111	31,913	26,111		
	N2/N3 Total					**2,570**	**1,737**

It can be seen that the money that could be spent per vehicle on eliminating ALL front to rear shunt accidents remains relatively low for light vehicles (M1/N1) at between €181 and €463 per vehicle. The value for heavy vehicles is considerably greater at between €1,737 and €4,821 per vehicle, largely due to the greater severity of this kind of collision and the greatly reduced number of vehicles the countermeasure must be fitted to in order to generate the benefits.

The research has shown that AEBS technology is a rapidly developing area. Some of the systems in current production will react to rigid fixed objects on the carriageway, depending partly on their shape and radar reflectivity, and some will also react to larger motorcycles in the middle of the same lane that the equipped vehicle is travelling in. The potential scope of benefits for these types of collision is shown in Table 9 below.

It can be seen from Table 9, below, that the difference between light and heavy vehicles still exists. In particular, there were no large bus or coach occupant fatalities in the UK in 2005 (hence none predicted for Europe) resulting from a collision between the bus and a rigid fixed object on the carriageway, yet a break even cost per vehicle of between €35 and €281 was still generated based on the serious casualty savings. Consideration of collisions with objects on the carriageways makes the most difference for passenger cars where a break even cost of between €11 and €80 can be added to the value of €15 to €136 derived from front to rear shunt accidents, an increase of between 59% and 73%. For other vehicle types the increase was proportionally modest, for example an additional 2% to 5% for N2/N3 vehicles. It can also be seen that the frequency of front to rear shunt collisions between passenger cars and powered two wheelers (PTW) is very low such that the break even cost is just €1 to €7 per vehicle.

Accident statistics tend to distinguish between collisions that occur with fixed objects that are on the carriageway (e.g. bridge parapets, crash barriers) and those that are off the carriageway (e.g. trees). No research was identified that considered whether a fixed object such as a tree could be reliably detected while leaving the carriageway and potentially travelling over very uneven territory so the potential benefits of off-carriageway collisions with fixed objects are shown separately in Table 10.

The research has also suggested that systems are close to, or just entering, market that are capable of detecting and responding to collisions with pedestrians. The scope of benefits for systems that can react in these accidents is shown in Table 11, assuming the same level of effectiveness as for heavy vehicles in front to rear shunt accidents.

Table 9. Summary of the benefit analysis for collisions with rigid fixed objects on the carriageway and powered two wheelers (PTW)

Accident and casualty type		Estimated total casualties (EU-25) 2005		Predicted reduction in casualty numbers		Cost per vehicle (€) sustainable for a benefit/cost ratio of 1	
		Upper	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
All casualties from accidents where the front of an M1 vehicle collides with a rigid fixed object located on the carriageway	Fatal	823	673	617	168		
	Serious	6,538	5,431	4,361	1,189		
	Slight	40,168	32,664	-345	-1,189		
M1 Total						**80**	**11**
All casualties from accidents where the front of an M2/3 vehicle collides with a rigid fixed object located on the carriageway	Fatal	0	0	0	0		
	Serious	142	116	106	29		
	Slight	1,858	1,520	79	-29		
M2/M3Total						**281**	**35**
All casualties from accidents where the front of an N1 vehicle collides with a rigid fixed object located on the carriageway	Fatal	57	46	43	12		
	Serious	411	337	266	73		
	Slight	1,901	1,555	-76	-73		
N1 Total						**38**	**7**
All casualties from accidents where the front of an N2/3 vehicle collides with a rigid fixed object located on the carriageway	Fatal	28	23	21	6		
	Serious	397	325	277	75		
	Slight	1,475	1,207	-129	-75		
N2/N3 Total						**132**	**29**
All casualties from two-vehicle accidents where the front of an M1 vehicle collides with the rear of a PTW	Fatal	14	12	11	3		
	Serious	964	789	713	194		
	Slight	11,829	9,678	470	-194		
M1 Total						**7**	**1**

Table 10. Summary of the benefit analysis for collisions with rigid fixed objects located off the carriageway

Accident and casualty type		Estimated total casualties (EU-25) 2005		Predicted reduction in casualty numbers		Cost per vehicle (€) sustainable for a benefit/cost ratio of 1	
		Upper	Lower	Upper	Lower	Upper	Lower
All casualties from accidents where the front of an M1 vehicle collides with a rigid fixed object located off the carriageway	Fatal	4,340	3,551	3,255	888		
	Serious	31,459	25,739	20,339	5,547		
	Slight	181,903	148,830	-2,148	-5,547		
M1 Total						**400**	**56**
All casualties from accidents where the front of an M2/3 vehicle collides with a rigid fixed object located off the carriageway	Fatal	0	0	0	0		
	Serious	184	151	138	38		
	Slight	2,184	1,787	80	-38		
M2/M3Total						**361**	**46**
All casualties from accidents where the front of an N1 vehicle collides with a rigid fixed object located off the carriageway	Fatal	284	232	213	58		
	Serious	1,688	1,381	1,053	287		
	Slight	7,843	6,417	-267	-287		
N1 Total						**173**	**27**
All casualties from accidents where the front of an N2/3 vehicle collides with a rigid fixed object located off the carriageway	Fatal	142	116	106	29		
	Serious	1,149	940	755	206		
	Slight	5,446	4,456	-211	-206		
N2/N3 Total						**488**	**106**

Table 11. Summary of the benefit analysis for collisions with pedestrians

Accident and casualty type		Estimated total casualties (EU-25) 2005		Predicted reduction in casualty numbers		Cost per vehicle (€) sustainable for a benefit/cost ratio of 1	
		Upper	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
Pedestrian casualties in collision with the front of an M1 vehicle	Fatal	5,645	4,619	4,234	1,155		
	Serious	49,600	40,582	32,966	8,991		
	Slight	181,875	148,807	-14,778.5	-8,991		
M1 Total						**566**	**80**
Pedestrian casualties in collision with the front of an M2/3 vehicle	Fatal	468	383	351	96		
	Serious	2,851	2,333	1,787	487		
	Slight	10,652	8,715	-722	-487		
M2/M3Total						**11,963**	**1,686**
Pedestrian casualties in collision with the front of an N1 vehicle	Fatal	440	360	330	90		
	Serious	2,723	2,228	1,713	467		
	Slight	6,964	5,698	-1,016	-467		
N1 Total						**270**	**42**
Pedestrian casualties in collision with the front of an N2/3 vehicle	Fatal	738	603	553	151		
	Serious	936	766	149	41		
	Slight	1,716	1,404	23	-41		
N2/N3 Total						**1,450**	**326**

It can be seen that collisions with rigid fixed objects off the carriageway and collisions with pedestrians have a substantial influence on the amount of money that can be spent per passenger car (M1) in order to achieve a cost benefit of one. It can be seen that if an AEBS fitted to a passenger car could be 25% - 75% effective in frontal collisions with the rear of other vehicles, rigid fixed objects both on and off the carriageway, and pedestrians, then between €163 and €1,189 could be spent per vehicle. The greatest potential benefits (approximately 50%) come from collisions with pedestrians. For N1 class vehicles equipped with a system with the same capabilities, a lower total casualty reduction would be expected, which would enable only €95 - €625 per vehicle to be spent to achieve a benefit/cost ratio of one (of which €42 to €270 would arise from collisions with pedestrians).

Heavy vehicles have a much lower overall casualty reduction potential but keep a benefit to cost ratio that could be an order of magnitude higher. A system with the same capabilities as the system for light vehicles discussed above would enable €747 - €3,413 to be spent on each new N2 or N3 vehicle and €1,929 - €14,055 on each new M2 or M3 vehicle.

There was technical evidence found in the research that suggested that an AEBS system that was effective in head-on frontal collisions between vehicles was being investigated and could potentially, in future, be another function of production systems. The potential benefits of such a system are shown in Table 12, below, assuming the same effectiveness levels of between 25% and 75%. However, it should be noted that there were more technical difficulties noted with this accident mechanism, which may mean that there is always fundamentally less time for the system to respond and, therefore, a reduced effectiveness. Also, closing speeds in head on collisions are typically much higher than in front to rear collisions.

Most of the research identified that discussed mitigation or avoidance systems for front to side junction collisions, suggested that it would be necessary to add vehicle to vehicle and/or vehicle to infrastructure communication systems to the types of on-board sensor used for current generation AEBS. The potential benefits of this as an additional accident type mitigated are shown in Table 13.

Table 14 shows the potential benefit of adding detection of motorcycles to the function of AEBS fitted to other vehicles when functioning in head-on collisions and front to side collisions. Finally, research was identified that considered what type of active safety systems could be appropriate to fit to motorcycles and this included consideration of an AEBS. The potential benefits of fitting a system to a powered two wheeler are considered for a range of impact configurations in Table 15.

Table 12. Potential benefits of AEBS in head on collisions

Accident and casualty type		Estimated total casualties (EU-25) 2005		Predicted reduction in casualty numbers		Cost per vehicle (€) sustainable for a benefit/cost ratio of 1	
		Upper	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
Casualties from accidents where the front of an M1 vehicle collides with the front of another vehicle (exc PTW)	Fatal	3,858	3,156	2,893	789		
	Serious	37,558	30,729	25,275	6,893		
	Slight	304,548	249,176	5,180	-6,893		
M1 Total						**419**	**58**
M1 Casualties from accidents where the front of an M2/3 vehicle collides with the front of an M1 vehicle	Fatal	170	139	128	35		
	Serious	808	661	477	130		
	Slight	4,113	3,365	-67	-130		
M2/M3Total						**3,957**	**557**
M1 Casualties from accidents where the front of an N1 vehicle collides with the front of an M1 vehicle	Fatal	525	429	394	107		
	Serious	2,993	2,449	1,851	505		
	Slight	16,822	13,763	-169	-505		
N1 Total						**315**	**48**
M1 Casualties from accidents where the front of an N2/3 vehicle collides with the front of an M1 vehicle	Fatal	979	801	734	200		
	Serious	2,510	2,054	1,149	315		
	Slight	9,134	7,473	-235	-315		
N2/N3 Total						**2,198**	**490**

Table 13. Potential benefits in front to side collisions

Accident and casualty type		Estimated total casualties (EU-25) 2005		Predicted reduction in casualty numbers		Cost per vehicle (€) sustainable for a benefit/cost ratio of 1	
		Upper	Lower	Upper	Lower	Upper	Lower
Casualties from accidents where the front of an M1 vehicle collides with the side of another vehicle (exc PTW)	Fatal	2,737	2,240	2,053	560		
	Serious	22,878	18,718	15,105	4,120		
	Slight	358,290	293,146	20,723	-4,120		
M1 Total						**284**	**38**
M1 Casualties from accidents where the front of an M2/3 vehicle collides with the side of an M1 vehicle	Fatal	99	81	74	20		
	Serious	426	348	245	67		
	Slight	4,099	3,354	165	-67		
M2/M3Total						**2,260**	**314**
M1 Casualties from accidents where the front of an N1 vehicle collides with the side of an M1 vehicle	Fatal	383	313	287	78		
	Serious	1,092	894	532	145		
	Slight	12,340	10,096	702	-145		
N1 Total						**185**	**28**
M1 Casualties from accidents where the front of an N2/3 vehicle collides with the side of an M1 vehicle	Fatal	582	476	436	119		
	Serious	1,319	1,079	553	151		
	Slight	10,907	8,924	538	-151		
N2/N3 Total						**1,283**	**283**

Table 14 Summary of the benefit analysis for collisions with powered two-wheelers (PTW).

Accident and casualty type		Estimated total casualties (EU-25) 2005		Predicted reduction in casualty numbers (full avoidance)		Cost per vehicle (€) sustainable for a benefit/cost ratio of 1	
		Upper	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
All casualties from two-vehicle accidents where the front of an M1 vehicle collides with the rear of a PTW	Fatal	14	12	11	3		
	Serious	964	789	713	194		
	Slight	11,829	9,678	470	-194		
	M1 Total					**7**	**1**
All casualties from two-vehicle accidents where the front of an M1 vehicle collides head on with the front of a PTW	Fatal	979	801	734	200		
	Serious	9,475	7,752	6,372	1,738		
	Slight	29,870	24,439	-3,385	-1,738		
	M1Total					**103**	**15**
All casualties from two-vehicle accidents where the front of an M1 vehicle collides with the side of a PTW	Fatal	227	186	170	46		
	Serious	5,049	4,131	3,617	986		
	Slight	18,637	15,249	-1,753	-986		
	M1 Total					**41**	**7**

Table 15. Potential benefits of fitting AEBS to powered two wheelers

<table>
<tr><th colspan="2" rowspan="2">Accident and casualty type</th><th colspan="2">Estimated total casualties (EU-25) 2005</th><th colspan="2">Predicted reduction in casualty numbers</th><th colspan="2">Cost per vehicle (€) sustainable for a benefit/cost ratio of 1</th></tr>
<tr><th>Upper</th><th>Lower</th><th>Upper</th><th>Lower</th><th>Upper</th><th>Lower</th></tr>
<tr><td rowspan="3">Casualties from accidents where the front of a PTW collides with the rear of another vehicle</td><td>Fatal</td><td>255</td><td>209</td><td>191</td><td>52</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Serious</td><td>6,368</td><td>5,211</td><td>4,584</td><td>1,250</td></tr>
<tr><td>Slight</td><td>23,956</td><td>19,600</td><td>-2,189</td><td>-1,250</td></tr>
<tr><td colspan="2">Front to rear Total</td><td colspan="4"></td><td>917</td><td>190</td></tr>
<tr><td rowspan="3">Casualties from accidents where the front of a PTW collides with the front of another vehicle</td><td>Fatal</td><td>1,319</td><td>1,079</td><td>989</td><td>270</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Serious</td><td>10,581</td><td>8,657</td><td>6,946</td><td>1,894</td></tr>
<tr><td>Slight</td><td>31,842</td><td>26,053</td><td>-3,762</td><td>-1,894</td></tr>
<tr><td colspan="2">Head onTotal</td><td colspan="4"></td><td>2,046</td><td>486</td></tr>
<tr><td rowspan="3">Casualties from accidents where the front of a PTW collides with the side of another vehicle</td><td>Fatal</td><td>1,447</td><td>1,184</td><td>1,085</td><td>296</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Serious</td><td>16,666</td><td>13,636</td><td>11,414</td><td>3,113</td></tr>
<tr><td>Slight</td><td>59,315</td><td>48,531</td><td>-5,482</td><td>-3,113</td></tr>
<tr><td colspan="2">Front to side Total</td><td colspan="4"></td><td>2,741</td><td>646</td></tr>
</table>

It can be seen that adding functionality in head-on collisions has a very large potential casualty saving benefit, particularly for passenger cars, if systems can be made as effective as they are in front to rear collisions. This also adds substantial costs per vehicle that can be sustained for a benefit to cost ratio of one, particularly for heavy vehicles. The potential casualty reduction if front to side collisions can be added is lower but still substantial.

It can also be seen that if the substantial technical difficulties associated with fitting a system to motorcycles can be solved and the riders accept the systems, then there is a large potential casualty saving and substantial costs per vehicle can be sustained. The potential value of fitting a system to motorcycles substantially exceeds the value of making systems that are fitted to other vehicles effective at detecting and reacting to motorcycles.

4.11 Costs of automatic emergency braking systems

It has not proved possible to generate accurate and reliable estimates of the cost of the AEBS system in terms of the automatic emergency braking function that has been assessed for casualty reduction. A request for information from industry through the stakeholder group was made but the initial response was that for reasons of commercial sensitivity and difficulty in separating the costs of ACC, FCW and AEBS functions, it was not possible to provide information.

However, an article published in Automotive News Europe quotes a cost of 200 to 250 euros per vehicle for a laser system, software, hardware and installation. One research paper identified (Kalhammer *et al*, 2006), stated an aim to develop a low cost sensor system (using Infra Red technology) capable of use for pre-crash functions intended to mitigate pedestrian accidents by the time the second phase of the pedestrian Directive applies to new vehicles (2010-2015). The target cost was <€100 and the paper appeared to consider that this would be achievable.

At the final project stakeholder meeting, representatives of the automotive industry argued that these costs were not representative of the real cost of the system. In particular, it was argued that the quoted costs were for components only and did not include the cost of development, which could be very substantial. It was also argued that although "low-cost" sensors could be developed for specific applications they would be unlikely to have the full functionality that could be offered by more expensive solutions and it would, therefore, be inappropriate to attribute these lower costs to the more advanced systems capable of increased functionality.

Subsequent to this meeting, ACEA provided a range of approximate costs to cover collision mitigation and/or collision avoidance systems that was intended to represent realistic costs of current systems down to estimated target costs. The estimated range was between €1,000 and €6,000. It was also stated that producing more accurate costs was very difficult because the actual figures would be strongly dependant on:

- The specific technical requirements for the system (e.g. lower intervention times required higher sensor resolution)
- The functionality of the system (e.g. ACC, forward collision warning, collision mitigation, collision avoidance, etc)
- Volume - the price of some components could decrease rapidly if fitted to larger numbers of vehicles and this would also spread the development costs over a greater number of vehicles.

5 Analysis and discussion

5.1 Technical requirements for automatic emergency braking systems

Technical requirements covering the function of AEBS have been developed by MLIT in Japan, in consultation with JAMA. These guidelines appear to provide a sound basis for initial control of the basic functions of the system. However, when considering their applicability in Europe it is worth noting that although the principles appear valid some of the limit values may need to be re-considered. The main example of this is in terms of the minimum deceleration that the guidelines state should be applied once a collision has become unavoidable. The MLIT guidelines state that the autonomous deceleration shall be in excess of $5m/s^2$. At least one AEBS that is in current production in Europe provides autonomous deceleration of *"up to 4 m/s^2"*, which is clearly below the recommended minimum in the MLIT guidance. However, this particular system also activates with the longest time remaining before collision, longer than the generic figure in the MLIT guidelines represents but potentially within the allowance for manufacturers to specify a specific value for a specific vehicle. At present, no research has identified whether, when both maximising speed reduction and minimising unintended consequences are considered, it is more effective to activate hard braking for a short time or gentler braking for a longer time. Therefore, there seems to be no evidence to justify excluding this type of system from compliance with guidelines. Both systems will be capable of comparable speed reduction but the former system may activate when the driver is planning to take action but may also prompt an inattentive driver into action in time to avoid the collision. The latter system removes the driver influence much more by only activating at a time when it is too late for the driver to avoid the collision and braking at a rate the driver cannot better.

Although the MLIT document specifies functional requirements and provides tools enabling specification of certain system characteristics, it does not offer any techniques for testing and demonstrating minimum performance standards for the completed system as a whole. It was identified that a draft ISO standard was also under development but the technical content of that standard will remain unavailable until such time that it is published for comment. No other accepted guidelines were found but there was much evidence that research was on-going in this area.

As well as considering the functional and performance aspects it is also important to consider both the integrity level of the system under test and the measurement uncertainty of the test itself. Several technical requirements and test methods are not yet covered in EU Regulations, for example protection from nearby lightning, electrostatic discharges in general and low frequency electric and magnetic fields. The following list outlines the generic requirements needed for testing electronic equipment fitted to vehicles:

- RF emissions as described in 2004/104/EC;
- RF immunity as described in 2204/104/EC;
- Immunity to transients as described in 2004/104/EC;
- Immunity to electrostatic discharge;
- Requirements for transmitters used in vehicles;
- Protection from lightning;
- System safety according to IEC 61508 (to become ISO 26262 late 2007);
- Requirements for measurement uncertainty;
- Requirements for low frequency electric and magnetic fields;
- Specific requirements for safety critical systems – linking test levels to system integrity;
- Environmental requirements based upon EN60068;
- Vehicle sensing systems need to be included in regulations (e.g. radar and laser etc.);

- The potential for system interaction needs to be included.

The last point is considered as being very important. In the future, when it is anticipated that the majority of new vehicles entering the international fleet will be fitted with such devices, it is essential that the sensor systems on various vehicles operate independently of one another. Should multiple vehicles with similar sensing systems approach one another, the systems in each vehicle must not be affected by that of any other vehicles in the vicinity. This concern is raised primarily with respect to active sensing systems that emit a signal of some form and rely upon the signal received for interpretation of the environment. A lack of interference between systems may potentially be achieved by ensuring each device operates in such a manner that it has its own unique signature preventing confusion with emissions from other systems.

5.2 Costs and benefits of automatic emergency braking systems

Substantial difficulties have been encountered in trying to define the costs and benefits of AEBS. Fundamentally there are problems associated with the availability of accident databases with sufficient pre-crash information to enable the types of calculation and prediction required. The accident configuration considered in detail was front to rear shunt accidents (see Appendix A). However, the difficulties were such that it proved impossible to generate a reliable estimate of the effectiveness of AEBS for light vehicles even in this relatively simple accident configuration.

A better estimate of system effectiveness in front to rear shunt accidents has been possible for heavy vehicle because of the existence of the HVCIS fatal database in the UK which was able to provide detailed information on a sufficiently large sample of relevant accidents to provide a tentative estimate of the speed reduction that the autonomous braking will typically produce. However, the range of theoretically possible systems encompassed by the generic systems specified for the research, and agreed with industry and the EC at the mid-term meeting, was very large and produced a consequently large range of possible effects. The accident database considered only fatal accidents and so it was not possible to generate technically correct injury risk functions for the relevant accident types. The numbers presented could be considered as underestimates because future AEBS systems have the potential not only to mitigate but also to avoid a large number of accidents but these analyses are predominantly considering only the injury mitigation effects. In addition to this, the industry was not able to provide the cost information requested as part of the industry survey for a variety of technical reasons. This meant that the cost benefit analysis has been limited to generating estimates of the cost per vehicle of providing the automated heavy braking function of AEBS only (i.e. ignoring collision warnings and adaptive cruise control effects) that could be sustained to result in a benefit to cost ratio of one. These estimates have been extended to a wide range of collision types outside of the definition of front to rear shunt accidents in an initial scoping study in order to provide an indication of the potential benefits *if* systems can be developed that work in these situations with the same level of effectiveness expected for fitment to heavy vehicles in front to rear shunt accidents.

Considering both the technical research reviewed and the analysis of accident data, it is possible to approximately define three stages of system development:

- "Current" systems – These can be defined as systems that are effective in front to rear shunt collisions with other 4+wheel vehicles and collisions with rigid fixed objects on the carriageway. These could be fitted to any M or N class vehicle;
- "Near future" systems – These systems may be expected to add function in collisions with rigid fixed objects off the carriageway and with pedestrians;
- "Longer term future developments" – These may be expected to add functionality in head on collisions and front to side collisions at junctions and could also be fitted to motorcycles.

Assuming an equal effectiveness for each type of system and collision configuration, Table 16 summarises the potential benefits. It should be noted that the benefits for future systems are in addition to those for current systems.

Table 16. Summary of potential benefits

Vehicle class AEBS fitted to.		System class		
		Current	Near future	Longer term
M1	**Fatality reduction**	313 – 1,149	2,043 – 7,489	1,349 – 4,946
	Break even cost (€)	26 – 216	136 – 966	96 – 703
M2/3	**Fatality reduction**	4 – 14	96 – 351	55 – 202
	Break even cost (€)	197 – 1,731	1,732 – 12,324	871 – 6,217
N1	**Fatality reduction**	44 – 160	148 – 543	185 – 681
	Break even cost (€)	26 – 182	68 – 443	76 – 500
N2/3	**Fatality reduction**	102 – 372	180 - 659	319 – 1,170
	Break even cost (€)	314 – 1,475	432 – 1,938	773 – 3,481
L	**Fatality reduction**			618 – 2,265
	Break even cost (€)			1,322 – 5,704

It can be seen that for all stages of development of the systems, fitment to passenger cars carries the greatest casualty reduction potential. However, the large numbers of passenger cars means that the break even costs are low compared with heavy vehicles. The low number of buses on the road means that the break even costs are very high but the total casualty reduction potential is low in comparison to fitment to other vehicle types. Fitment to heavy goods vehicles offers moderately high casualty saving potential in comparison to the other vehicle types as well as relatively high break even costs.

In terms of system development, it can be seen that the largest potential benefits come from the accident categories classed as “near future”, that is pedestrians and collisions with fixed objects off the carriageway. The potential benefits that could also be obtained from a system effective in head on and front to side collisions would also add substantial benefits in general and would be the most effective function for goods vehicles.

There are considerable additional technical difficulties associated with fitting automated braking systems to motorcycles so they had to be considered as longer term developments. However, the analysis suggests that such a measure has considerable casualty saving potential and has a high break even cost associated with it such that even relatively high cost systems would prove cost beneficial.

There is a lack of robust quantitative evidence of the cost of AEBS for a variety of reasons. There is some evidence to suggest that the cost to vehicle manufacturers is of the order of €250 per vehicle and that some systems under development aim to be less than €100 per vehicle. However, vehicle manufacturers consider that this is an under-estimate that ignores the substantial cost of development and cannot be applied to more sophisticated and/or robust systems. ACEA suggest that a realistic range of costs spanning the cost of current systems and future avoidance systems would be between €1,000 and €6,000 per vehicle, although they also acknowledge the difficulties in estimating costs and the fact that prices could reduce substantially if production volume was increased significantly.

This suggests that fitting current, first generation, systems to heavy vehicles would be likely to have a positive benefit to cost ratio if the cost could be kept at least to the low end of the range quoted by ACEA and preferably lower. However, it would be unlikely that current systems fitted to light vehicles would have a benefit to cost ratio in excess of one until such time that the cost has reduced substantially through higher volumes.

If the target cost of <€100 (Kalhammer *et* al, 2006) can be achieved by 2010-2015 then the analysis suggests that AEBS fitted to heavy vehicles would have a benefit to cost ratio of at least 2:1 and potentially much greater (up to 17:1), even if there was no technical development to increase the functionality by that time. If the lower cost suggested by ACEA was all that could be achieved the benefit to cost ratio could be either positive or negative depending on the actual performance of the system in service.

If functionality could be expanded during the same time period to include pedestrians and fixed objects off the carriageway than the ratio would be between approximately 7:1 and 34:1, based on the low estimates of cost. However, the complexity of the system would be increased such that the higher costs estimated by ACEA may be more likely. In this situation the benefit to cost ratio would be less certain and a positive outcome would be strongly dependant on the actual cost that systems could be produced for. Based on the full range of possible costs the benefit to cost ratio could be between 0.12:1 and 34:1. For systems aimed at protecting pedestrians it is worth noting that the costs would be borne by the vehicle purchaser but the benefits would accrue to the pedestrians.

At a cost of €100 there is a reasonable chance that fitting current AEBS to light vehicles would prove to have a positive benefit to cost ratio (0.3:1 to 2.2:1). If pedestrian protection can be added by 2010-2015, which the research strongly suggests is likely, and this can be achieved with a "low-cost" sensor as suggested by Kalhammer *et* al (2006) then the analysis suggests that very large casualty savings are possible with a substantially positive benefit to cost ratio in the range of 1.6:1 to 12:1. However, if the systems were more expensive as suggested by ACEA then the benefit to cost ratio would be likely to remain negative.

This initial analysis of potential costs and benefits can be summarised as suggesting that fitting first generation AEBS to light vehicles immediately would be unlikely to be a cost beneficial measure. However, fitting it to all heavy vehicles is quite likely to be. The rapid development of this technology is likely to mean that within the next three to eight years or so the fitment of AEBS to all vehicles will offer very substantial casualty savings. However, this would need to be achieved at lower cost, perhaps through increased production volume, than currently estimated by the European vehicle manufacturers if substantially positive benefit to cost ratios are to be achieved. The addition of function in pedestrian collisions is likely to form a key part of achieving these benefits. If technical difficulties can be overcome it is also very likely that fitting systems to motorcycles will be a very beneficial measure.

Obviously, this cost benefit analysis is extremely limited. Only UK accidents and UK and German congestion figures are considered in detail and the estimates of effectiveness are of limited robustness. The extension to a European Level relies on a range of assumptions about the relationship between UK accidents and the high-level fatality statistics available for the EU-25, as well as the constraints inherent in the official estimates of EU-25 casualty statistics. A full business case and cost benefit analysis, considering realistic implementation rates and the benefits and costs while the proportion of vehicles equipped with the system has not, therefore, been carried out.

In addition to this, the cost benefit analysis has focussed on systems that automatically apply the brakes on behalf of the driver and has, therefore, ignored the effects of collision warnings and systems that fall between the two such as predictive brake assist, where the need to brake is identified by the forward looking sensors but no action is taken unless the driver activates the brakes. Once the driver has activated the brakes the system optimises the level and distribution of braking independently of driver demand in order to maximise the chances of avoiding the accident. Some industry stakeholders have suggested that pure warning systems may not be as effective as automated braking systems and may not be very well accepted by drivers. However, while fully automated systems, such as those considered in this analysis, would have the most benefits the need for the systems to be very reliable and the liability risks for the manufacturers mean that they will be very expensive and only introduced to the market slowly. These stakeholders suggest that intermediate systems such as predictive brake assist systems, would offer a better compromise and an improved benefit to cost ratio in the shorter term. They suggest that the functionality could then be increased in small steps.

6 Conclusions

1. Automatic emergency braking systems (AEBS) were in production on a number of current vehicles at the top end of the market in the early stages of this work and are capable of autonomously mitigating two-vehicle front to rear shunt accidents as well as some collisions with fixed objects and motorcycles. Such systems were fitted alongside ACC and forward collision warning systems that shared the same hardware.

2. Systems are currently in various phases of development that will also act in pedestrian collisions and towards the end of the project at least one system offering some pedestrian functionality was released on a production vehicle. There is also a strong research base that aims to develop systems capable of acting in other vehicle to vehicle impact configurations.

3. Clear functional requirements for AEBS are in existence in Japan and appear to be appropriate to use as guidance for systems in Europe subject to modification of some limit values. An ISO standard is under development but was not yet available for study. There remains insufficient information available at this time to produce more rigorous standards that more closely define performance or to define methods of testing the effectiveness of the whole system. Further research may be required in this area.

4. Further requirements are required to cover the integrity of the system. Some of these, such as reliability of the system and resistance to EMC issues are already embodied in regulation and are covered, at least to a minimum standard. There was however, evidence to suggest that further research was required to examine whether the safety critical nature of AEBS requires more stringent limits in these areas. Other areas such as environmental protection including immunity to electro-static discharge and particularly relating to the compatibility and reliability of similar and different systems when numerous modules are on the road are not covered and may need additional measures. In particular, the possibility that interference could occur when multiple sensing systems “meet” at a busy road section may require further investigation.

5. Substantial difficulties have been encountered in trying to define the benefits of an AEBS in terms of casualty reduction. These are related to fundamental limitations in terms of the detail available in accident databases and the reconstruction methods used to generate them and also related to the limited scope of the project which considered only the benefits of the automated braking and not the benefits of ACC, the collision warning and optimised restraint functions.

6. It was not possible to establish detailed and accurate estimates of the costs of systems because of commercial sensitivity and difficulties in separating the costs of different functions that shared the same hardware. Only current retail prices of optional systems, target costs for future systems, and a broad range of estimated costs from industry were available.

7. Instead of a detailed analysis of the costs and benefits of current, first generation AEBS, a high level scoping analysis was carried out to indicate the potential benefits if certain levels of effectiveness could be achieved in a wide range of collision situations. This analysis reached the following conclusions.

    a. Immediate introduction of AEBS that approximated first generation system functions (front to rear collisions and collisions with rigid fixed objects located on the carriageway) to all light vehicles offered considerable casualty reduction potential but was unlikely to be cost effective unless substantial cost reductions could be achieved. The main reasons for this were the high frequency/low severity nature of light vehicle shunt accidents and the high number of vehicles that must be fitted with the technology to achieve the benefits.

    b. Immediately equipping all new heavy vehicles with such a system would yield a lower casualty reduction but a better benefit to cost ratio because of the much lower number of vehicles requiring fitment and the increased severity of front to rear collisions involving heavy vehicles.

c. Introducing AEBS that was also effective in collisions with pedestrians and with fixed objects off the carriageway substantially changed the view of the systems. The casualty reduction potential in this situation was greatly increased and if fitted to all M and N vehicles it would be likely to have a fatality saving potential in the thousands if implemented across the EU vehicle fleet. The research suggests that at some point in the next three to eight years the technology to enable these functions will be readily available. The limited evidence available regarding the costs of the systems suggested alternative possibilities where either a combination of "low cost" sensors and increased production volumes decreased the cost or where increased technical complexity increased the costs. Achieving the considerable potential benefits with a substantially positive benefit to cost ratio is therefore strongly dependant on the system cost, although positive ratios are much more likely for fitment to M2, M3, N2 and N3 vehicles.

d. Further developments to allow function in head on and junction collisions also offer a substantial increase in both the casualty reduction potential and the benefit to cost ratio, although increased technical difficulty may increase costs or limit benefits.

e. Substantial technical difficulties are likely to be encountered when considering fitment of AEBS to motorcycles but if these can be overcome then substantial casualty savings are achievable with a high potential for a benefit to cost ratio in excess of one.

8. Overall, it was found that AEBS is highly likely to be a very effective safety measure in terms of both casualty reduction and benefit to cost ratio in the relatively near future, provided that further technical development and cost reduction take place.

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Appendix A. Detailed study of the accident benefits of "current" AEBS

A.1 Accident mechanisms and the overall scope of potential benefits

Using the UK National accident database (STATS19) it is possible to identify what manoeuvre was being performed prior to the accident:

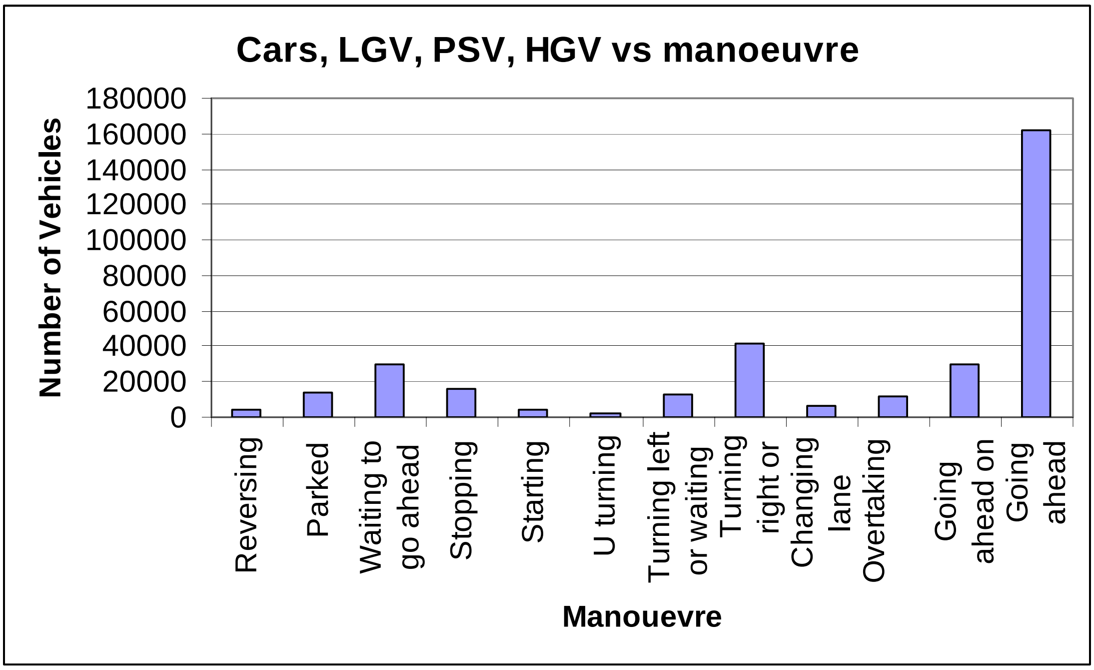


Figure A1: Accident frequency by Manoeuvre in the UK (STATS 19)

The main crash pre-crash manoeuvres are “turning” and “going ahead other”. In STATS 19 “Going Ahead Other” is not divided any further and can contain several different accident mechanisms. To gain further information on specific types of crash more detailed databases can be used. Figure A2, below, shows the collision type categories available in the UK OTS database and Figure A3 shows the numbers and proportions of cases recorded in each category.

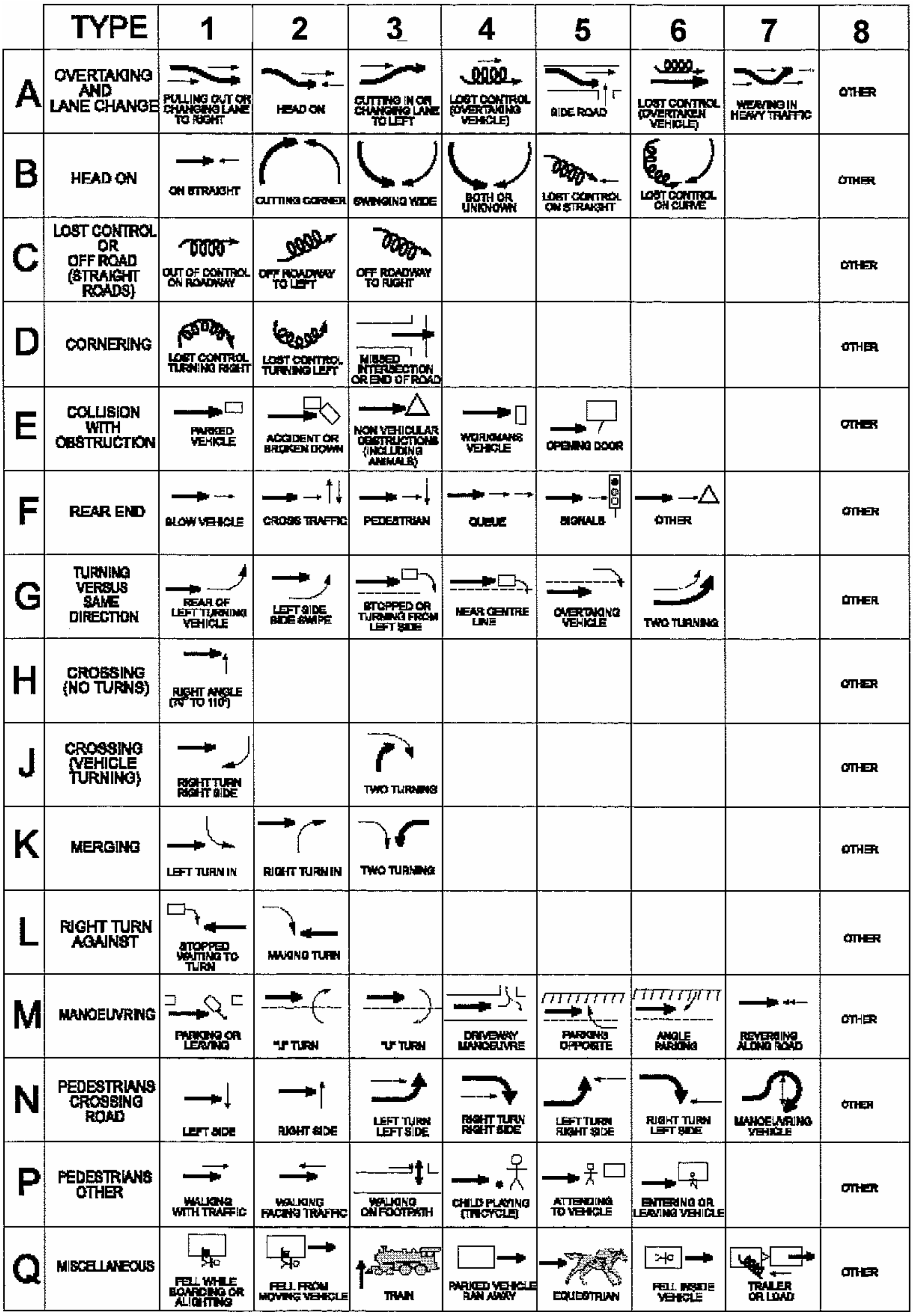


Figure A2. UK OTS phase 2 collision type matrix

		Number									Total
		0	1	2	3	4	5	6	7	8	
Letter	Count	5	0	0	0	0	0	0	0	0	5
	% of Total	.4%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.4%
A	Count	0	49	12	39	15	0	4	0	2	121
	% of Total	.0%	3.9%	1.0%	3.1%	1.2%	.0%	.3%	.0%	.2%	9.6%
B	Count	0	15	3	9	5	8	10	0	0	50
	% of Total	.0%	1.2%	.2%	.7%	.4%	.6%	.8%	.0%	.0%	4.0%
C	Count	0	64	90	49	0	0	0	0	2	205
	% of Total	.0%	5.1%	7.2%	3.9%	.0%	.0%	.0%	.0%	.2%	16.3%
D	Count	0	87	92	16	0	0	0	0	1	196
	% of Total	.0%	6.9%	7.3%	1.3%	.0%	.0%	.0%	.0%	.1%	15.6%
E	Count	0	28	1	12	1	3	0	0	3	48
	% of Total	.0%	2.2%	.1%	1.0%	.1%	.2%	.0%	.0%	.2%	3.8%
F	Count	0	69	8	2	96	24	22	0	3	224
	% of Total	.0%	5.5%	.6%	.2%	7.6%	1.9%	1.7%	.0%	.2%	17.8%
G	Count	0	1	14	3	7	11	3	0	0	39
	% of Total	.0%	.1%	1.1%	.2%	.6%	.9%	.2%	.0%	.0%	3.1%
H	Count	0	94	0	0	0	0	0	0	0	94
	% of Total	.0%	7.5%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	7.5%
J	Count	0	64	1	3	0	0	0	0	2	70
	% of Total	.0%	5.1%	.1%	.2%	.0%	.0%	.0%	.0%	.2%	5.6%
K	Count	0	16	21	2	0	0	0	0	0	39
	% of Total	.0%	1.3%	1.7%	.2%	.0%	.0%	.0%	.0%	.0%	3.1%
L	Count	0	2	53	1	0	0	0	0	1	57
	% of Total	.0%	.2%	4.2%	.1%	.0%	.0%	.0%	.0%	.1%	4.5%
M	Count	0	8	4	11	3	1	0	1	4	32
	% of Total	.0%	.6%	.3%	.9%	.2%	.1%	.0%	.1%	.3%	2.5%
N	Count	0	32	20	0	1	1	0	0	1	55
	% of Total	.0%	2.5%	1.6%	.0%	.1%	.1%	.0%	.0%	.1%	4.4%
P	Count	0	1	0	1	0	1	2	0	3	8
	% of Total	.0%	.1%	.0%	.1%	.0%	.1%	.2%	.0%	.2%	.6%
Q	Count	0	1	1	0	3	0	0	2	8	15
	% of Total	.0%	.1%	.1%	.0%	.2%	.0%	.0%	.2%	.6%	1.2%
Total	Count	5	531	320	148	131	49	41	3	30	1258
	% of Total	.4%	42.2%	25.4%	11.8%	10.4%	3.9%	3.3%	.2%	2.4%	100.0%

Figure A3: Number/proportion of difference Accident types in UK OTS phase 2 data

Figure A4, below, summarises the data above in a graphical format.

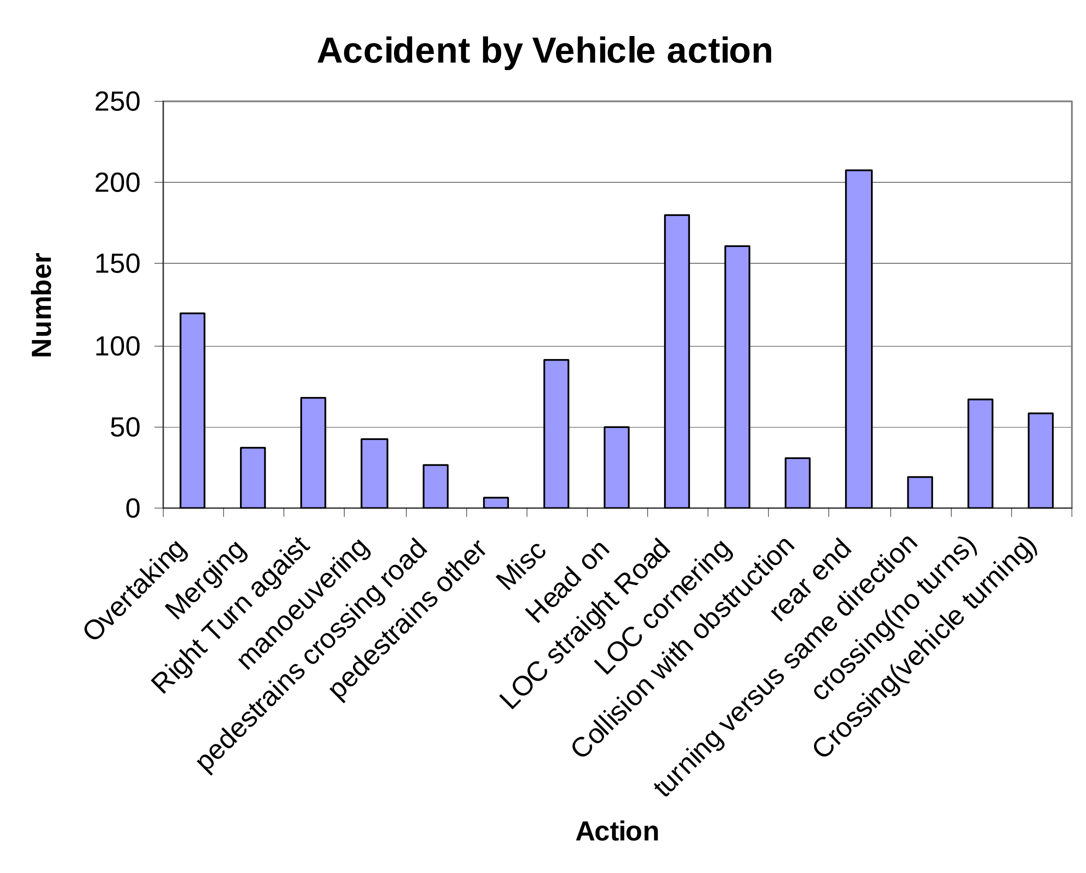


Figure A4: Summary of row totals for UK OTS crash types

It can be seen that the main crash types recorded on the UK OTS database are loss of control, rear end collisions, overtaking, and turning. OTS also collects data relating to the interactions of the drivers involved in collisions. Using this data it is possible to see how many drivers took avoiding action when they were involved in a collision.

Table A1: Driver avoidance reactions in UK OTS database

Driver's Reaction	Number of vehicles
no reaction	983
Accelerated (also steering somewhat to the right)	15
Steered Right (also Accelerating somewhat	75
Steered Right without significant braking or acceleration	108
Steered Right (also braking somewhat)	70
Braked (also steering somewhat to the right)	58
Braked without significant change in steering	520
Braked (also steering somewhat to the left)	60
Steered Left also braked somewhat	65
Steered Left without significant braking or acceleration	71
Steered Left (Also accelerating somewhat)	22
Accelerated (also steered somewhat to left)	4
Accelerated without significant change in steering	35
Not coded	32
Unknown	118
TOTAL	**2236**

Table A1, above, shows that 44% of vehicles in the sample took no avoiding action prior to the collision.

It is clear from this data that front to rear shunt type accidents do offer the potential for AEBS to provide benefits. Analysis of STATS 19 data from 2005 shows that there were 50 fatal, 878 serious and 35,732 slight casualties from accidents where the front of an M1 vehicle collided with the rear of any other vehicle with three or more wheels (i.e. excluding motorcycles and pedestrians). It should be noted that this analysis is based only on two vehicle collisions and thus excludes some potential benefits that may arise in collisions involving multiple vehicles but restrictions in the data make it impossible to analyse such accidents accurately. It does include casualties from both the bullet and the target vehicles.

It can be seen that although this type of accident is relatively frequent (13.5% of all casualties in 2005) it is not particularly severe (1.6% of all fatalities in 2005), making up a far larger proportion of slight injury accidents than it does fatal accidents. In fact, only approximately 0.14% of casualties from shunt type collisions are fatally injured compared with 1.2% of all casualties being fatally injured.

Comparable data for heavy vehicles (2003-2005) has also been generated as part of a separate project (Smith *et al*, 2007). Table A2, below shows an extract of injuries from different types of heavy vehicle accidents which may be relevant to AEBS.

Table A2: Casualties from heavy vehicle accident types potentially relevant to AEBS

Collision type	**Casualty group considered**	**Mean number of UK casualties 2003-2005**		
		Fatal	**Serious**	**Slight**
Accident types considered to definitely fall within the scope of current AEBS in production at the start of the project				
HGV front to rear of other vehicles (not motorcyclists/pedestrians)	Casualties from either vehicle	33	165	2,250
LCV front to rear of other vehicles (not motorcyclists/pedestrians)	Casualties from either vehicle	11	118	3,140
Bus front to rear of other vehicles (not motorcyclists/pedestrians)	Casualties from either vehicle	1.3	35	1,208
Accident types which may be included in future developments of the systems				
HGV front to Car front	Car occupants	69	177	644
HGV Front to Pedestrian	Pedestrian	52	66	121
HGV front to car side	Car occupant	41	93	769
LCV front to car front	Car occupant	37	211	1186
Bus front to pedestrian	Pedestrian	33	201	751
LCV front to pedestrian	Pedestrian	31	192	491
LCV front to car side	Car occupants	27	77	870
Bus front to car front	Car occupants	12	57	290
Bus front to car side	Car occupant	7	30	289
	TOTAL	**354.3**	**1,422**	**12,009**

This analysis is of UK data only because it is not possible to gain access to the required fields (collision location) in the CARE database and TRL cannot gain access to the detailed levels of individual member states databases. Figure A5 and Figure A6 (Smith et al, 2007, based on analysis of the CARE database) show that heavy vehicle accidents typically make up a high proportion of our national accident total but that in terms of accident rates the UK perform well compared with the rest of Europe. This is likely to mean that the benefits are greater if Europe is considered as a whole and may be balanced more in favour of light vehicles than would appear the case based on UK data alone.

Figure A5: Proportion of national fatality total in LCV, HGV and LPV accidents, 2000 – 2004

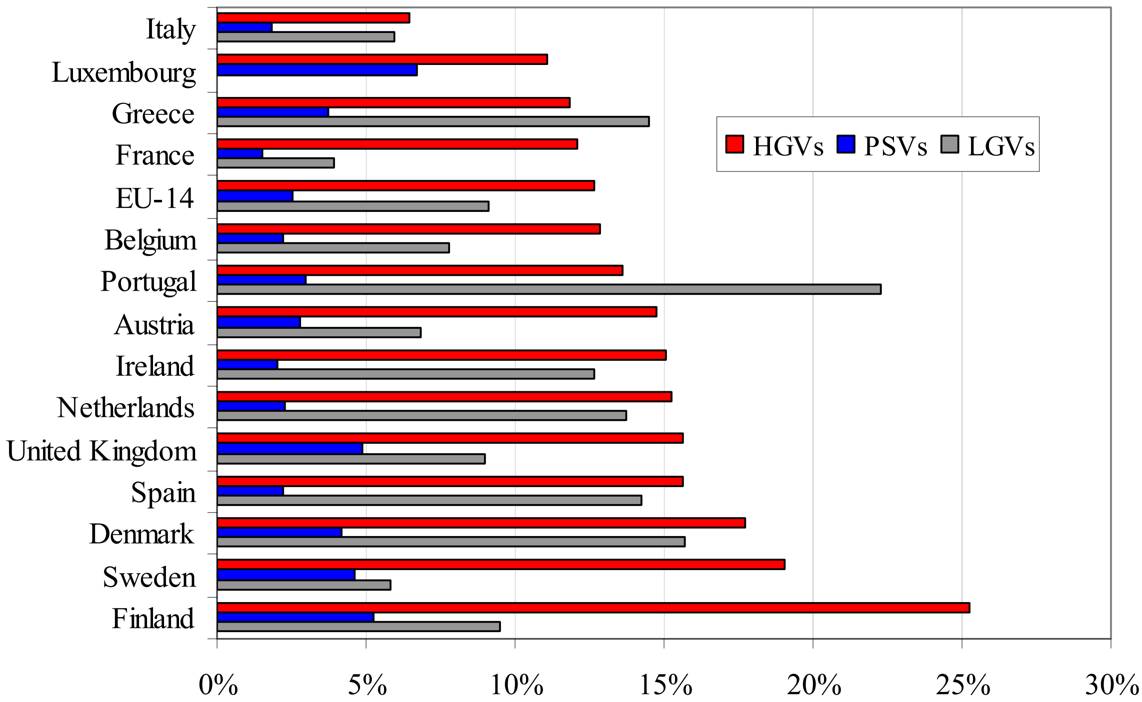
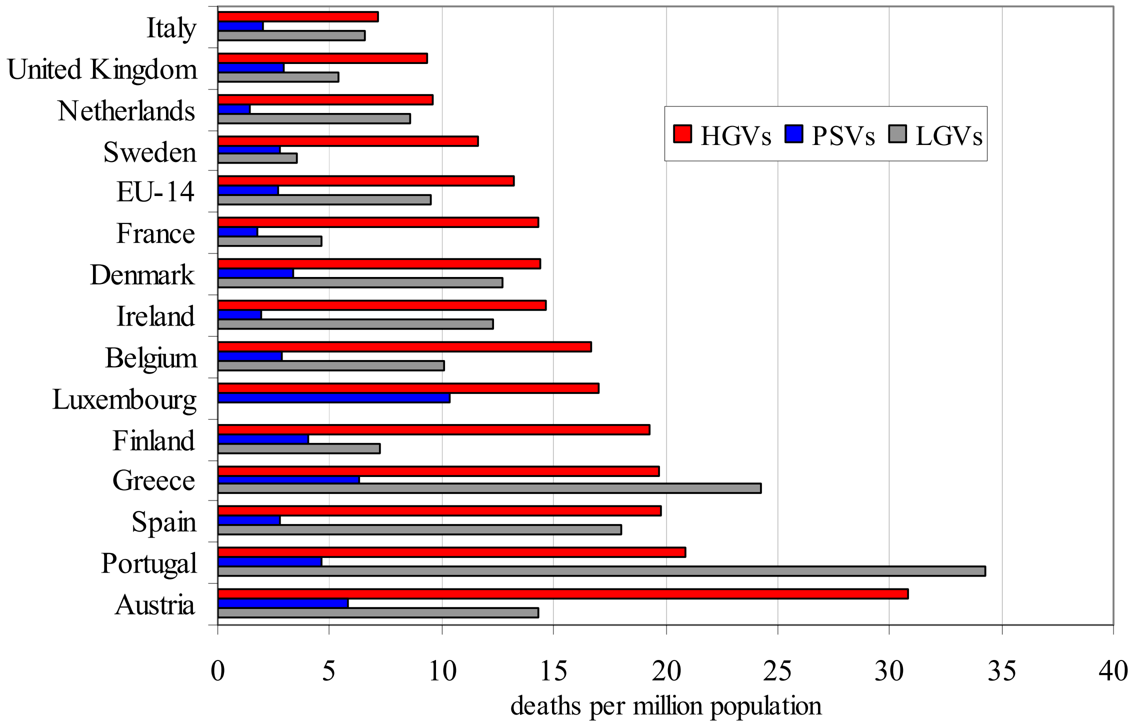


Figure A6: National fatality rates per million population in LCV, HGV and LPV accidents, 2000 – 2004



A.2 Effectiveness of current AEBS in production at the start of the project

The preceding section briefly outlined the scope of potential benefits in terms of the numbers of accidents which AEBS has the potential to affect. In order to provide estimates of the benefits of AEBS it is necessary to assess the effectiveness of AEBS in terms of the proportion of the accidents within the scope that AEBS may reduce the injury severity from. In order to attempt this TRL has carried out predictive studies based on a set of theoretical characteristics of a generic system which was then tested against sources of accident data to identify the effects that such a generic system would have been likely to have on the accidents.

It is important to emphasis that this analysis was based on the characteristics of AEBS that were in production near the start of this project. This is a rapidly changing field and at the time of publication some systems containing additional functionality may have entered series production.

A.2.1 TRL generic system characteristics

The assumptions and specifications describing the operation and performance of the AEBS that were used to estimate ranges for the casualty saving benefits that may be achieved are described below.

These assumptions and specifications should be treated as being distinct from the technical requirements for AEBS that are reported elsewhere in this document. They are a simplified set of assumptions and specifications that facilitate the analysis of accident data to estimate the potential casualty saving benefits, acknowledging the restrictions imposed by the level of detailed information available within the databases.

Separate systems are described for light and heavy vehicles because of their inherently different braking systems and handling capabilities. Light vehicles are assumed to be equipped with a hydraulic braking system. Rigid heavy vehicles are assumed to be fitted with EBS. The tow vehicles of articulated heavy vehicles are assumed to be equipped with EBS and the trailers an air braking system. The deceleration profile assumed for braking evasion and automatic braking assumes that the vehicle deceleration builds linearly to the maximum value typical for the vehicle type, and then remains constant at that value for the remainder of the braking.

For both light and heavy vehicles two AEBS with extreme performance characteristics were considered which will provide lower (System 1) and upper (System 2) estimates for the casualty saving benefits.

To simplify the analysis it was assumed that the AEBS will only be effective in reducing the collision speed in frontal collisions with forward obstacles where there was no driver reaction to avoid the collision. To include collisions with:

- All moving and stationary vehicles, including motorcycles travelling centrally in the lane.

Collisions and obstacles excluded:

- Two wheeled vehicles travelling in the edge of the lane;
- Pedestrian impacts;
- When the obstacle suddenly appears in front of the vehicle (sudden encounters such as a vehicle cutting immediately in front or emerging at a junction).

The selection criteria above basically restrict the accidents in which the system is considered to be effective to front to rear shunt accidents. This is in-line with the responses to the industry survey that indicated that all current production systems this was the only circumstances in which it was possible to be confident that the system was effective.

Sensing system and automatic braking system activation summaries are provided in tabular form, below, followed by justifications for the assumptions made and specifications selected.

Table A3: Automatic emergency braking system sensing system summary

Vehicle type	Light (M1<3.5t, N1)		Heavy (M1>3.5t, M2, M3, N2, N3 towing O3 O4)	
System	System 1	System 2	System 1	System 2
Effective at identifying collisions on	Straight roads and slight bends	Straight roads, slight and moderate bends	Straight roads and slight bends	Straight roads, slight and moderate bends
Effective in all weather conditions excluding	Heavy and light snow, hail and heavy rain	Heavy and light snow	Heavy and light snow, hail and heavy rain	Heavy and light snow
Active in speed range (km/h)	10 to 180		10 to 90	
Minimum relative speed (km/h)	10			
Braking evasion time (s)	Calculated using TTC = $(-u + a_{max}.t_{rise} / 2) / a_{max}$			
Maximum deceleration a_{max} (g)	1.00		0.70	
Deceleration rise time t_{rise} (s)	0.30		Rigid 0.60 Articulated 0.80	
Steering evasion time (s)	0.60	1.00	0.80	1.40
Automatic braking triggered when TTC falls below lesser value of time required for braking or steering evasion				

Table A4: Automatic emergency braking system activation summary – System 1

Vehicle type	Class	Maximum deceleration a_{max} (g)			Deceleration build up time t_{rise} (s)
		Dry	Wet	Icy	
Light vehicles	M1<3.5t, N1	0.40	0.40	0.20	0.20
Rigid heavy vehicles	M1>3.5t, M2, M3, N2, N3	0.40	0.40	0.20	0.40
Articulated heavy vehicles	N2, N3 towing O3 and O4	0.40	0.40	0.20	0.60

Table A5: Automatic emergency braking system activation summary – System 2

Vehicle type	Class	Maximum deceleration a_{max} (g)			Deceleration build up time t_{rise} (s)
		Dry	Wet	Icy	
Light vehicles	M1<3.5t, N1	1.00	0.65	0.20	0.30
Rigid heavy vehicles	M1>3.5t, M2, M3, N2, N3	0.70	0.50	0.20	0.60
Articulated heavy vehicles	N2, N3 towing O3 and O4	0.70	0.50	0.20	0.80

In the industry survey stakeholders reported varying capability for reliably identifying collision risk when travelling around bends, therefore two identification capabilities were considered to provide the lower and upper limit. Within the accident data the road type is classified subjectively as straight, slight, moderate and sharp. For System 1 only collisions occurring on roads classified as straight or a slight bend will be considered. For System 2 collisions occurring on a moderate bend as well as those for System 1 will be analysed.

The point in time at which a collision is deemed as being inevitable is when the time to collision (TTC) is less than that required for braking or steering evasion.

Braking evasion was assumed to be calibrated on a uniform dry high friction surface to identify last moment of collision evasion under optimum conditions. The deceleration profile assumed for braking evasion is that the vehicle deceleration builds linearly to the maximum value typical for the vehicle type, and then remains constant at that value for the remainder of the braking, yielding the following equation to calculate the TTC (a rearrangement of v = u + at), where the lead vehicle is stationary.

$$TTC = (-u + a_{max}.t_{rise} / 2) / a_{max}$$

Where

- u – relative velocity (m/s)
- a_{max} – maximum deceleration achievable for vehicle type (m/s^2)
- t_{rise} – time taken for deceleration to build to maximum level (s)

- TTC > t_{rise}, which is valid for system operation only where the relative velocity is greater than 10km/h.

Values that were used for the deceleration profiles are:

Table A6: Assumed deceleration profiles

Vehicle type	Class	Brake systems type	Maximum deceleration a_{max} (g)	Deceleration build up time t_{rise} (s)
Light vehicles	M1<3.5t, N1	Hydraulic	1.00	0.30
Rigid heavy vehicles	M1>3.5t, M2, M3, N2, N3	EBS	0.70	0.60
Articulated heavy vehicles	N2, N3 towing O3 and O4	EBS tractor, air trailer	0.70	0.80

For a production AEBS the steering evasion capability of the vehicle would also be calibrated on a uniform dry high friction surface to identify last moment of collision evasion under optimum conditions. However in the absence of test data for a specific vehicle, a lower and upper value for the TTC was assumed for each vehicle type for this generic system.

For light vehicles the minimum TTC for collision evasion steering was that specified in the Japanese MLIT AEBS Technical Guidelines. This value of 0.60s is the minimum time assumed to be required for avoiding a collision where the overlap is 40%, and may be used in the absence of actual test data describing the vehicle capability. Previous TRL test data, albeit of limited scope, indicated that 1.00s is required for a light vehicle to achieve a lateral displacement equivalent to 100% vehicle overlap. Therefore, for light vehicles, lower and upper bounds of 0.60s and 1.00s TTC were used to determine the limit point at which collision evasion by steering may be achieved.

The MLIT Technical Guidelines also specify a minimum time of 0.80s for a heavy vehicle to evade the same collision configuration by steering. The time assumed to evade a 100% overlap collision by steering is 1.40s. Therefore, for heavy vehicles, lower and upper bounds of 0.80s and 1.40s TTC were used to determine the limit point at which collision evasion by steering may be achieved.

The TTC, sensor range, sensor scanning rate, the number of tracking data points required to identify an obstacle and reliably predict its path and the algorithm processing time (assumed to be negligible in this context with respect to the sensor scanning and obstacle tracking time) dictate the maximum relative speed at which AEBS will be effective.

Responses from the industry survey identified that the sensors used for obstacle detection, recognition and path prediction monitor the road ahead typically a minimum distance of 100m, up to a maximum of 200m, and have a scanning rate of 10 to 25Hz. This offers time for multiple scans of the road ahead by the sensor system for typical operative speeds, indicating that a number of obstacle tracking points are required reliably identify the potential collision threat. However the sensors are also used to provide ACC functionality, for which following vehicle separation in terms of time and distance are greater than those at which an automatic emergency braking would be operative.

In the absence of any technical information, TRL estimate that between a minimum of six, and more likely 10, data points would be required from the sensor system to reliably predict the obstacle path and assess the collision threat. On this basis the worse case performance sensor system would be able to reliably identify the collision threat in a period of one second, assuming 10 data points are required from a sensor scanning at a rate of 10Hz. For light vehicles travelling at higher speeds, the maximum TTC at which automatic braking would be triggered is that required for steering evasion, namely one second for the systems specified. Therefore in total the sensor system must be able to provide a view of the road ahead equivalent to the distance travelled in two seconds to be able to reliably identify a potential collision and facilitate automatic braking for the full time period that the collision is deemed as being unavoidable. Therefore a sensor range of 100m yields an operative relative speed up to 50m/s, or 180km/h assuming the sensor range is covered at constant speed.

Although the time required by heavy vehicles for steering evasion is greater than that for light vehicles, the maximum relative speeds will be lower because heavy vehicles are fitted with speed limiters that govern their maximum speed to 90km/h. Therefore the maximum relative speed between vehicles in the collision types that AEBS will be effective in is 90km/h. Again worse case sensor performance is more than adequate for identifying the collision risk and activating automatic braking at the relative speeds for these vehicles.

The shortest range sensors offer the potential to identify and mitigate collisions at very high relative speeds, therefore a sensor performance specification was not specified. It was assumed that the sensor system will be capable of tracking and reliably identifying the obstacle ahead providing there is clear line of sight.

Automatic braking will be activated when a collision is judged as being inevitable considering the time required for braking and steering evasion.

Two levels of autonomous braking were considered to provide lower and upper limits for the estimates of the potential casualty saving benefits.

To achieve the maximum speed reduction prior to collision a deceleration equivalent to full ABS braking for the particular vehicle type will be applied. The same deceleration profile as that assumed for braking evasion will be applied (deceleration building linearly to the maximum value and then remaining constant at that value for the remainder of the braking), albeit with different maximum deceleration values depending on the vehicle type and pavement conditions at the time of the collision. The deceleration values that will be used are:

Table A7: Assumed maximum deceleration values – best case

Vehicle type	Class	Maximum deceleration a_{max} (g)			Deceleration build up time t_{rise} (s)
		Dry	Wet	Icy	
Light vehicles	M1<3.5t, N1	1.00	0.65	0.20	0.30
Rigid heavy vehicles	M1>3.5t, M2, M3, N2, N3	0.70	0.50	0.20	0.60
Articulated heavy vehicles	N2, N3 towing O3 and O4	0.70	0.50	0.20	0.80

A system that applies a deceleration of similar magnitude to the minimum deceleration identified in the industry survey will also be considered. The deceleration values that will be used are:

Table A8: Assumed maximum deceleration values – worst case

Vehicle type	Class	Maximum deceleration a_{max} (g)			Deceleration build up time t_{rise} (s)
		Dry	Wet	Icy	
Light vehicles	M1<3.5t, N1	0.40	0.40	0.20	0.30
Rigid heavy vehicles	M1>3.5t, M2, M3, N2, N3	0.40	0.40	0.20	0.60
Articulated heavy vehicles	N2, N3 towing O3 and O4	0.40	0.40	0.20	0.80

In the industry survey stakeholders commented that it was difficult to reliably identify and assess the collision risk posed by obstacles moving slowly relative to the vehicle. Therefore the system was deemed to be ineffective when:

- The vehicle speed is less than 10km/h;
- The relative speed between the vehicle and the obstacle is less than 10km/h.

It was also identified that the collision judgement capability may be adversely affected as a result of the sensor being 'blinded' by heavy precipitation (rain, hail, snow etc.) therefore the systems are at least partially deactivated under such conditions. In order to account for this an estimate of the casualty saving benefits of AEBS was made in only restricted weather conditions.

A.3 Estimates of effects for light vehicles

A.3.1 Sample Size and Distribution

Phase II of the On-The-Spot (OTS) project calculated, where possible, impact and approach speeds of the vehicles involved in accidents investigated. Using only accidents from Phase II of the project gives a sample of 1512 accidents.

The OTS team assign each accident a code which relates to the type of impact; analysis of the 1504 accidents provided a breakdown of the accidents as follows:

Table A9: Distribution of accident types in OTS Phase II

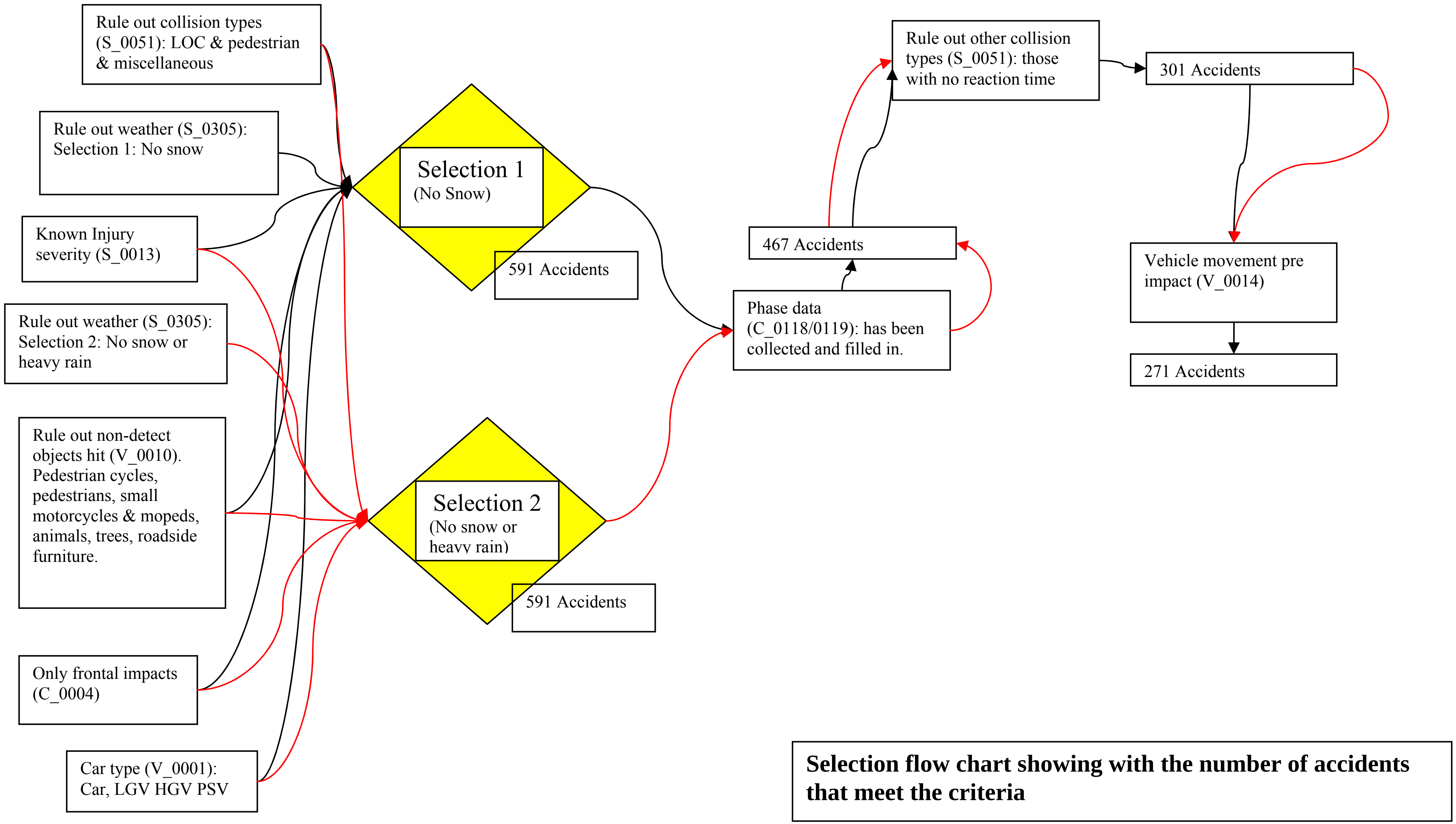
Collision Letter	Impact Type	Number of Accidents
A	Overtaking and lane change	137
B	Head on	67
C	Lost control or off road (Straight Roads)	232
D	Cornering	245
E	Collision with obstruction	57
F	Rear End	271
G	Turning versus same direction	49
H	Crossing (no turns)	96
J	Crossing (vehicle turning)	96
K	Merging	51
L	Right turn against	73
M	Manoeuvring	44
N	Pedestrians crossing road	67
P	Pedestrians other	9
Q	Miscellaneous	18

A.3.2 Selection of valid cases for reconstruction

To focus attention on crashes that meet the criteria for a collision mitigation braking system, selection criteria were applied to reduce the total of 1512 accidents to a smaller number of relevant accidents. To select the relevant collisions for reconstruction selection criteria were applied, these are listed below and the results are shown in the flowchart:

- **Crash types:** Exclude LOC straight road, LOC cornering, pedestrian crossing road, Pedestrians other, Miscellaneous
- **Weather:** Selection 1: Exclude light snow, Heavy snow
- **Weather:** Selection 2: Exclude heavy shower, Heavy rain, light snow, Heavy snow, hail
- **Non-detectable objects:** Exclude pedal cycle, moped/scooter, Motorbike <125cc, pedestrian, Lamppost, Road sign, Tree, Animal
- **Frontal impacts only**
- **Car type:** Exclude Pedal cycle, Shoe (do not exclude motorcycles here as this will exclude some valid cases later)
- **Rule out collision where severity is not known**
- **Rule out cases with no phase data**
- **Rule out additional crash types:** Exclude crossing no turns, crossing vehicle turning, merging, right turn against, Manoeuvring. Reason for ruling out other crash types is that they would either leave no time to react and therefore not be able to helped by a current system or the system sensors would not be able to perform in that scenario.
- **Vehicle movement pre impact:** Exclude going round a roundabout, going round mini-roundabout, turning from side road into main road, turning from main road into side road, pulling out of lay-by onto main road, driving round a right hand bend, driving round a left hand bend, driving round a series of bends, swerved to avoid animal in the road, swerved to avoid person in the road, reversing out of driveway, reversing out of car parking space, reversing into a parking space, turning onto carriageway, making u-turn onto carriageway, merging from slip road onto main carriageway, lost control of vehicle

Figure A7: Selection flowchart for OTS accidents



A.3.3 Reconstruction of the accidents

Applying the selection criteria to the total number of OTS accidents reduced the number of accidents in the sample from 1512 to 271 possible accidents to reconstruct. The majority of these accidents were rear shunt accidents, this being the main scenario the collision mitigation system specification would apply to.

In order to gain an estimate for the severity distribution of accidents in the target scenario the overall injury severity distribution in rear shunt accidents is shown in Table A10.

Table A10:Accident severity distribution for rear shunt accidents in OTS Phase II

	Fatal	Serious	Slight	Uninjured	Unknown
Percentage	0.5%	5.3%	47.5%	46.2%	0.5%

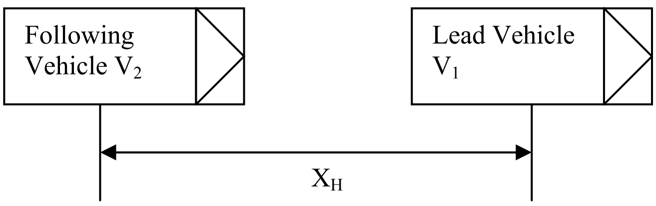
As can be seen there are a relatively low number of killed and seriously injured (KSI) accidents only 5.8% compared to the overall spread of severity in the OTS sample which has 13.8% KSI accidents. It should also be noted that this is broadly representative of the STATS 19 data reported in Section 4.10.2

Table A11: Accident severity distribution for ALL OTS Phase II cases

	Fatal	Serious	Slight	Uninjured	Unknown
Percentage	1.8%	12.0%	44.5%	39.0%	2.7%

Compared to the overall severity distribution for OTS Phase II the injury severity distribution for rear shunts is disproportionately skewed towards the slight and uninjured severities. This is comparable with UK national accident data, although it does appear that the OTS data has a slightly higher proportion of fatal accidents than the UK national data. The fact that rear shunt accidents are of relatively low severity means that within OTS there is a low sample size for killed and seriously injured casualties in this accident group To obtain a statistically valid sample for a small dataset, combined with the knowledge that only a small proportion of the cases sampled will yield enough detail to be reconstructed, a sampling technique that includes a higher weighting of the KSI severities was selected. The technique selected was disproportionate stratified sampling (http://www.napier.ac.uk/depts/fhls/peas/sratheory.asp/ http://www.statistics.com/resources/glossary/s/stratsamp.php).

The result of applying this sampling technique was that all 18 KSI cases were sampled but only 9 each from the slight and uninjured severity. The results for the slight and uninjured categories require a weighting to be applied of a factor of 14. The 9 cases from both the uninjured and slight categories were randomly sampled from a list of all the slight or uninjured categories.



*V_2 is also referred to as the bullet vehicle.

Figure A8: Classification of lead and following vehicle

An initial investigation on all 36 cases was undertaken to analyse the cases and create a mini database for the selected cases. The variables recorded in the mini-database are listed below:

- Case Number
- Vehicle Number the collision mitigation system would apply to
- Collision
- Road condition at time of accident
- Class and Speed limit of road
- Object hit
- Accident Severity
- Phase data present
- Type of phase data
- Any emergency action taken
- Type of emergency action taken
- Possible for a collision mitigation system to act

The final field is the researcher's initial assessment of the case and whether they considered it may be possible to review the case in further detail and reconstruct applying a collision mitigation system to the vehicle.

The complexity and variability of real world accidents meant it was not possible to reconstruct a large portion of the identified cases. The main reason for it not being possible to reconstruct a case was that one of the vehicles had recently changed lanes. It is likely that this would leave the system with insufficient time to monitor and detect that system, although this would depend on the performance and specification of a final system. However the lack of time for reaction meant that it was not possible to reconstruct the case and model the effects of a collision mitigation system, thus these cases were discarded. The number of cases, thus, selected for reconstruction was 17 out of the possible 36.

A.3.4 Results

The collection of the impact and approach speeds within the OTS database is carried out by investigators attending the scene of the accident. For light vehicles that are not equipped with tachograph recording equipment, the reconstruction of accidents from tyre marks is the standard method of estimating travel and collision speeds for accident. The accidents that were sampled for reconstruction were only selected where impact and approach speeds were present. Thus, by definition, the cases selected have predominantly been where vehicles were braking. In cases where the vehicle was not braking, or braking at levels below the point of wheel lock, travel speed can only be generally estimated from witness evidence (if available). Collision speed could be identified indirectly from vehicle damage but this is not routinely carried out as part of the OTS study.

The generic system described in Section A.2.1 is a simplified model for situations which is most effective where the struck vehicle is stationary and the impacting vehicle is not braking. However, the number of cases in the OTS database of this type with sufficient detail is limited because of the data gathering techniques used. Therefore, it has been necessary to also include cases which include the struck vehicle moving before the impact, and cases where one or both vehicles are braking.

In cases with braking, the travel speed before the incident and the speed at impact are recorded within the database. However, it is necessary to estimate the deceleration profile of the vehicle between these two speeds. Analysis of skid marks and witness accounts are used to determine a probable deceleration, however, this can only ever be an approximation.

In total it was possible to reconstruct 11 cases comprising of three serious accidents, six slight accidents and two uninjured accidents. Of these cases, only three involved a vehicle hitting the rear of another which was stationary before the event. The results of the reconstructions are shown in Table A12, below.

Table A12: Table of reconstructed accidents having a collision mitigation systems applied

Bullet vehicle	Reaction	Struck vehicle	Severity	Impact speed without system (km/h)	Impact speed with System 1 (km/h)	Impact speed with System 2 (km/h)	Average reduction in delta v with each system (km/h)			
							SYSTEM 1		SYSTEM 2	
							Struck delta v	Bullet delta v	Struck delta v	Bullet delta v
HGV	-	Car	Serious	90.1	82.6	56.7	6.8	0.6	30.5	2.9
Car	Braking	Car	Serious	16.1	16.1	4.3	0.0	0.0	5.1	6.8
HGV	-	Car	Serious	70.8	63.3	37.2	6.6	0.6	27.2	2.3
Car	Braking	Car	Slight	32.2	32.2	4.9	0.0	0.0	14.9	12.4
Car	-	HGV	Slight	112.6	103.9	-	0.6	8.1	-	-
Car	Braking	Car	Slight	22.5	22.5	-	0.0	0.0	-	-
Car	Braking	Car	Slight	32.2	32.2	-	0.0	0.0	-	-
Car	Braking	Car	Slight	19.3	19.3	-	0.0	0.0	-	-
Car	Braking	Car	Slight	16.1	16.1	4.4	0.0	0.0	6.5	5.2
Car	Braking	Car	Non-injured	16.1	16.1	-	0.0	0.0	-	-
Car	Braking	Car	Non-injured	40.2	40.2	-	0.0	0.0	-	-

It can be seen from Table A12 that System 1 only reduced the impact speed in three of the cases. In each of these cases the bullet vehicle did not brake. In the other cases the estimated deceleration applied by the driver is greater than that of the system, therefore the system does not intervene and offers no benefit. In the three cases in which System 1 would activate there was a small decrease in the speed of the bullet vehicle at impact, however, the speed differential was still substantial and the likelihood is that there would have been little or no reduction in accident severity.

The system developed in Section A.2.1 was designed for cases where the vehicle was approaching a stationary vehicle with no braking. Therefore, the decision logic uses only the headway between the vehicles at any point in time, rather than determining the relative change in headway. Hence, the system is not able to modify its activation time based on the relative movement of the two vehicles. If the front vehicle is moving, the point that the system determines that it is no longer possible to evade the vehicle in front by either steering or braking does not account for that front vehicle moving forwards. As such, in some instances the system activates before the collision is unavoidable.

For a system to provide only collision mitigation rather than collision avoidance between two moving vehicles it would be necessary for the system activation logic to include the relative change in headway between vehicles. The system would need to be a lot more complex to account for the rate of change of headway. However, it is possible that an impact could still be avoided with such a system depending on the actions of the front vehicle. Development of a system with this degree of complexity is beyond the scope of this project.

As a result of this decision logic six of the 11 collisions in Table A12 are avoided when System 2 is installed. In three of the five cases where collision still occurs the stuck vehicle is stationary, therefore eliminating the issues highlighted in the previous paragraphs. In the other two collisions the struck vehicle is moving very slowly so are a close approximation to the stationary cases. In all of these cases there is a significant reduction in the impact speed when System 2 is activated.

Cases where the following vehicle did not react to the impending collision can be identified in the OTS data and the numbers of such cases are shown in Table A13, below.

Table A13: Number of following, V_2, drivers who reacted in selected OTS accidents

No Reaction	149	46.0%
Reacted	165	50.9%
Unknown	10	3.1%

As previously stated, the limitations of accident reconstruction technique has meant that in most of these cases it has not been possible to identify sufficient information from the accident case to assess the benefit of AEBS. In actual fact, it is these cases where the core benefit of AEBS is expected to lie. Therefore, in order to provide some measure of effect this type of accident has been assessed theoretically for a range of initial speeds, assuming the lead vehicle was stationary.

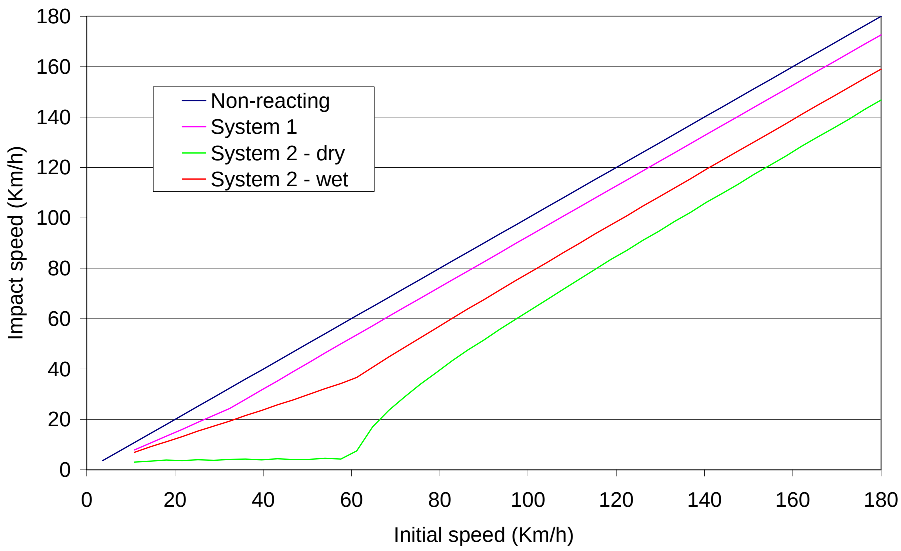


Figure A9: Plot of impact speed and reduced impact speed after collision mitigation system has been applied

A.3.5 Injury risk as a function of collision speed

In order to estimate the effect that a reduction in Delta-V will have on the severity of injury sustained by the vehicle occupants in rear shunt collisions it is necessary to derive an injury risk function. However, the low numbers of accidents that could be accurately reconstructed means that the results of this analysis can provide an indication of possible methods only and not a statistically significant result.

To obtain injury risk curves for each severity of accident the Delta-V of impact in a sample of cases was recorded and a histogram plotted. This provides a generic curve showing the maximum, minimum and median Delta-V's sustained in impacts of a given severity.

The reduction in Delta-V at impact can be calculated from the reconstructed collisions, this value is then applied to the curve for a given severity of impact to shift the median by the average Delta-V reduction using given collision mitigation system towards a lower Delta-V for impact. Once this has been done an estimation of how many higher severity accidents will have been reduced in severity due to the shifting of the Delta-V on impact can be derived.

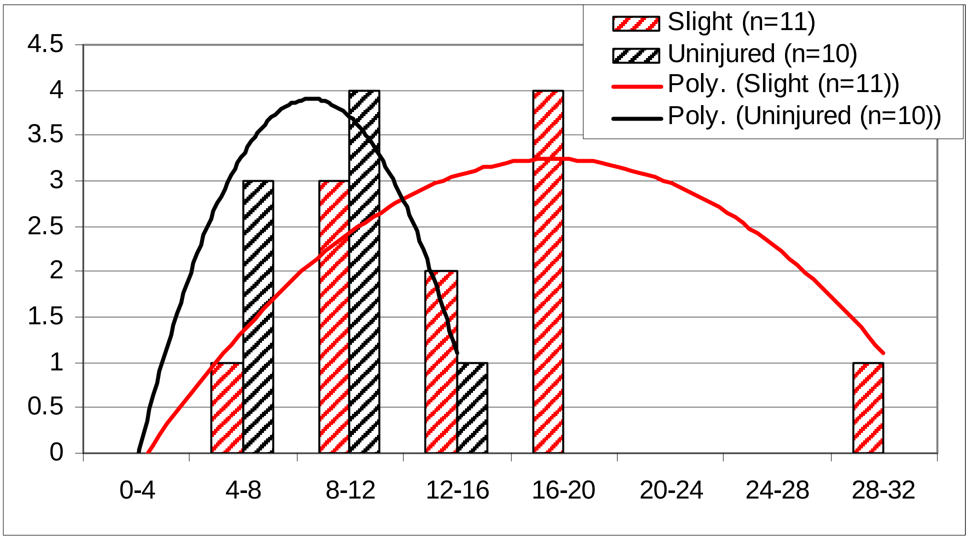


Figure A10: Delta-V of impact for given accident severities

A.4 Analysis of heavy vehicle accidents

Cases were selected from the Heavy Vehicle Crash Injury Study (HVCIS) fatal database. HVCIS contains over 1,800 fatal accident cases involving larger vehicles. Fatalities are comprised of large vehicle occupants and their opponents.

A.4.1 Selection criteria

Shunt-type accidents were selected from the database with the following criteria:

- Bullet vehicle is an HGV, LCV or PSV;
- Frontal impact on bullet vehicle;
- Rear impact on target vehicle;
- The target vehicle is stationary prior to the impact;
- Any road conditions excluding snow.

70 cases which met the above criteria and contained enough information for reconstruction were identified within the database.

A.4.2 Reconstruction methodology

The reconstruction methodology is the same as that used for the OTS cases analysed in the preceding section.

Where the bullet vehicle braked before impact it was assumed that this occurred after the point of inevitability. The HVCIS does not contain sufficient detail to determine over what distance a vehicle decelerated from the travel speed to the impact speed, so it has been necessary to estimate this value based on the information within the accident file. It should be noted that, compared with the analysis of the OTS database for passenger cars, the analysis for the heavy vehicles was simpler because of the nature of the vehicles and the crashes that they were involved in.

For passenger cars in the OTS database, impact and travel speeds are often defined by interpretation of skid marks left at the scene such that the necessary speed information did not exist in the accident situation of most relevance (where the bullet vehicle did not brake). Also, in a relatively large proportion of cases the vehicle struck in the rear was moving and braking at the time of impact.

The heavy vehicle accidents were dominated by those involving heavy goods vehicles. These vehicles are by law equipped with tachographs meaning that speed information does exist even when there has been no braking and no tyre marks. In addition to this, a high proportion of the accidents involved the heavy vehicles failing to notice the stationary traffic ahead such that the bullet vehicle did not brake and the target vehicle was stationary, thus considerably simplifying the analysis.

A.4.3 HGV cases

- All cases occurred in dry conditions;
- 38 cases where the HGV did not brake;
- 76% of the unbraked cases had an impact speed of 80km/h or greater;
- Mean impact speed of 81km/h (max: 90km/h, min: 40km/h);
- 20 cases where the HGV braked;
- One case was identified where the travel speed of the HGV was below the system activation level (10km/h);
- Of the 20 braked cases, System 1 would only reduce the impact speed in four cases. This is because the deceleration that is assumed to have been applied by the driver is greater than that applied by the system;
- In six of the braked cases System 2 does not reduce the impact speed because the driver braked harder. As System 2 applies maximum braking this indicates that the vehicle was braking before the system activation point.

Table A14: Average speed reduction for HGVs

	Average reduction in delta v with each system (km/h)			
	SYSTEM 1		SYSTEM 2	
Bullet vehicle response	**Struck delta v**	**Bullet delta v**	**Struck delta v**	**Bullet delta v**
No braking	5.3	3.0	21.3	11.6
Braking	1.5	0.3	15.2	3.5
All	4.0	2.1	19.2	8.8

Two of the common types of shunt-type accidents involving HGVs are:

- Car occupants killed when their vehicle is struck from the rear (mean impact speed: 82km/h);
- HGV occupants when they strike the rear of another HGV (mean impact speed: 81km/h).

In cases where the bullet HGV was not braking the following reductions are predicted:

- Δv reduction for car hit in the rear by an HGV of 8.1km/h with System 1 and 32.6km/h with System 2;
- Δv reduction for HGV hitting the rear of another HGV of 8.6km/h with System 1 and 33.4km/h with System 2.

A.4.4 LCV cases

- Eight cases, one in which the LCV braked before impact;
- Mean impact speed: 65km/h (min:40km/h, max:97km/h).

In the braked case, System 1 provided no assistance as the assumed deceleration profile applied by the driver is more than the system would apply, however System 2 would reduce the impact speed.

Table A15: Average speed reduction for LCVs

	Average reduction in delta v with each system (km/h)			
	SYSTEM 1		SYSTEM 2	
Bullet vehicle response	Struck delta v	Bullet delta v	Struck delta v	Bullet delta v
No braking	1.7	5.9	13.6	42.0
Braking	0.1	0.6	8.2	35.2
All	1.5	5.3	13.0	41.1

A.4.5 PSV cases

- Four cases, three with braking before impact;
- Mean impact speed: 61km/h (min:16km/h, max:95km/h).

The braked cases involved an impacts with the rear of HGVs, therefore a high benefit is conferred to vehicle 2 (bullet vehicle). In contrast two of the braked cases involved impacts with cars so the benefit for the target vehicle is greater.

Table A16: Average speed reduction for PSVs

	Average reduction in delta v with each system (km/h)			
	SYSTEM 1		SYSTEM 2	
Bullet vehicle response	Struck delta v	Bullet delta v	Struck delta v	Bullet delta v
No braking	4.8	2.1	8.1	3.6
Braking	2.2	0.8	19.5	6.8
All	2.8	1.2	16.7	6.0

A.4.6 Effect of speed reduction on probability of fatalities

The cumulative frequency curve for the HGV accident cases is plotted against the impact speed in Figure A11. System 1 has the effect of shifting the curve left by a small amount, whereas System 2 provides a much larger shift.

The HVCIS database, from which this sample was selected, contains only fatal impacts, therefore it is only possible to assess a possible reduction in fatalities. It can be assumed that a fatal injury will be reduced to serious injury.

Another limitation of the data is that the majority of the HGV impacts occurred at above 80km/h. It is not possible to determine whether this is because the accidents do not occur at lower speeds, or because accidents that occur at lower speed result in fewer fatalities.

By making the assumption that lower speed impacts occur but do not result in fatalities it is possible to determine a reduction in the number of fatalities. The maximum impact speed with System 1 is reduced to 87km/h, which corresponds to a 28% decrease in fatalities. With System 2 the maximum impact speed is reduced to 69km/h, which corresponds to a 72% decrease in fatalities.

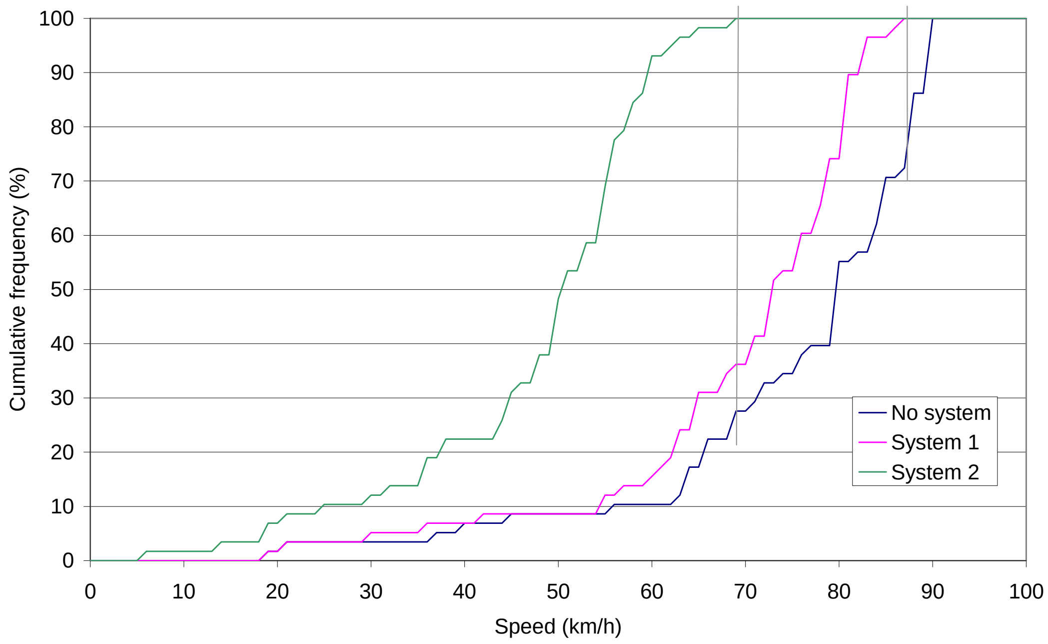


Figure A11: Cumulative collision speed distribution with and without AEBS

An alternative approach is to assume a speed that is survivable and assess what proportion of cases are at survivable speeds in each case. However, unlike collisions to the front of cars there are no test standards that can be related to survivable injury criteria at a specific speed. If it is assumed that similar speeds are survivable on the basis there are less crashworthy structures at the rear of the car but a greater intrusion required before direct contact with front seat occupants, then 64 km/h collisions should be survivable. This provides a greater range of estimate of effects that can be approximated to between 17% and 97% of all fatalities, depending on which system is used.

Appendix B. Full list of HVCIS cases reconstructed

Bullet vehicle	Reaction	Struck vehicle	Impact speed without system (km/h)	Impact speed with System 1 (km/h)	Impact speed with System 2 (km/h)	Average reduction in delta v with each system (km/h)			
						SYSTEM 1		SYSTEM 2	
						Struck delta v	Bullet delta v	Struck delta v	Bullet delta v
Articulated	-	LCV	90.1	82.6	60.2	6.9	0.6	27.4	2.5
Rigid	-	Car	90.1	81.1	56.5	7.5	1.5	28.0	5.6
Rigid	-	HGV	90.1	81.1	56.5	2.9	6.2	10.6	23.0
Rigid	-	HGV	90.1	81.1	56.5	4.5	4.5	16.8	16.8
Rigid	-	HGV	90.1	81.1	56.5	1.9	7.1	7.1	26.5
Rigid	-	Car	90.1	81.1	56.5	7.2	1.8	26.9	6.7
Articulated	-	Car	90.1	82.6	60.2	7.2	0.3	28.8	1.1
Articulated	-	Car	90.1	82.6	60.2	7.0	0.5	28.0	1.9
Articulated	-	LCV	88.5	81.0	58.3	6.7	0.8	26.9	3.3
Rigid	-	HGV	88.5	79.5	54.6	4.2	4.9	15.6	18.3
Rigid	-	Car	88.5	79.5	54.6	7.9	1.2	29.5	4.4
Rigid	-	Car	88.5	79.5	54.6	8.1	0.9	30.3	3.6
Articulated	-	Car	88.5	81.0	58.3	7.1	0.4	28.7	1.4
Articulated	-	HGV	86.9	79.4	56.7	3.7	3.7	15.1	15.1
Rigid	-	HGV	85.3	76.2	50.9	2.9	6.2	10.8	23.5
Articulated	-	HGV	85.3	77.8	54.9	3.7	3.7	15.2	15.2
Articulated	-	Car	85.3	77.8	54.9	6.2	1.2	25.3	5.1
Rigid	-	HGV	85.3	76.2	50.9	2.0	7.0	7.7	26.7
Articulated	-	Car	85.3	77.8	54.9	6.5	1.0	26.4	4.0
Articulated	-	Car	83.7	76.2	53.0	6.7	0.8	27.3	3.3
Articulated	-	HGV	83.7	76.2	53.0	3.7	3.7	15.3	15.3
Articulated	-	LPV	80.5	71.4	45.3	1.9	7.2	7.3	27.8
Articulated	-	Car	80.5	73.0	49.5	6.9	0.5	28.6	2.3
Articulated	-	Car	80.5	73.0	49.5	3.0	4.5	12.4	18.5
Rigid	-	OMV	80.5	71.4	45.3	8.3	0.7	32.3	2.8
Articulated	-	LCV	80.5	73.0	49.5	7.0	0.5	29.0	1.9
Articulated	-	Car	80.5	73.0	49.5	6.9	0.5	28.6	2.3
Rigid	-	HGV	80.5	71.4	45.3	4.5	4.5	17.6	17.6
Articulated	-	HGV	80.5	73.0	49.5	3.7	3.7	15.5	15.5
Articulated	-	Car	75.6	68.1	44.0	7.1	0.4	30.2	1.5
Rigid	-	Car	74.0	64.8	37.7	8.0	1.2	31.8	4.6
Rigid	-	HGV	72.4	63.2	35.8	0.6	8.6	2.5	34.1
Rigid	-	HGV	72.4	63.2	35.8	1.5	7.7	6.0	30.6
Rigid	-	Car	69.2	60.0	31.6	8.2	1.0	33.6	4.0
Articulated	-	Car	69.2	61.6	36.3	6.6	1.0	28.6	4.3
Articulated	-	LCV	64.4	56.7	30.2	5.0	2.7	22.2	11.9
Rigid	-	Car	64.4	55.2	24.8	7.1	2.0	30.8	8.8
Rigid	-	HGV	40.2	30.5	5.9	1.0	8.7	3.6	30.8
Articulated	Braking	Car	88.5	82.7	60.2	5.6	0.2	27.2	1.1
Rigid	Braking	HGV	88.5	85.5	65.4	2.0	1.0	15.2	7.8
Articulated	Braking	LCV	88.5	87.1	68.9	1.3	0.1	18.5	1.1
Articulated	Braking	Car	83.7	81.4	59.2	2.2	0.1	23.4	1.2
Articulated	Braking	Car	82.1	80.6	62.0	1.4	0.1	19.3	0.8
Articulated	Braking	HGV	80.5	79.0	63.0	0.8	0.6	9.7	7.8
Articulated	Braking	HGV	77.2	73.2	49.9	2.0	2.0	13.7	13.7
Articulated	Braking	Car	75.6	74.2	58.1	1.3	0.1	16.7	0.8
Articulated	Braking	Car	70.8	69.4	53.0	1.2	0.2	15.7	2.1

Bullet vehicle	Reaction	Struck vehicle	Impact speed without system (km/h)	Impact speed with System 1 (km/h)	Impact speed with System 2 (km/h)	Average reduction in delta v with each system (km/h)			
						SYSTEM 1		SYSTEM 2	
						Struck delta v	Bullet delta v	Struck delta v	Bullet delta v
Articulated	Braking	LCV	69.2	67.8	51.4	1.2	0.2	15.6	2.2
Articulated	Braking	LPV	66.0	64.6	47.9	0.8	0.7	9.6	8.4
Articulated	Braking	Car	66.0	64.6	47.9	1.2	0.2	15.9	2.1
Articulated	Braking	HGV	66.0	64.6	47.9	0.9	0.5	12.1	5.9
Articulated	Braking	Car	64.4	62.9	46.3	1.2	0.2	15.9	2.1
Articulated	Braking	Car	62.8	61.3	44.5	1.3	0.1	17.1	1.2
Articulated	Braking	LPV	56.3	54.9	37.5	0.8	0.6	10.4	8.4
Rigid	Braking	Car	45.1	42.1	18.6	2.8	0.2	25.0	1.5
Articulated	Braking	Car	37.0	35.6	13.8	1.3	0.1	22.2	1.1
Rigid	Braking	Car	20.9	20.9	20.9	0.0	0.0	0.0	0.0
Rigid	Braking	Car	19.3	19.3	19.3	0.0	0.0	0.0	0.0

Bullet vehicle	Reaction	Struck vehicle	Impact speed without system (km/h)	Impact speed with System 1 (km/h)	Impact speed with System 2 (km/h)	Average reduction in delta v with each system (km/h)			
						SYSTEM 1		SYSTEM 2	
						Struck delta v	Bullet delta v	Struck delta v	Bullet delta v
LCV	-	Car	88.5	81.0	4.4	4.0	3.5	45.3	38.8
LCV	-	HGV	40.2	32.3	4.2	1.2	6.7	5.4	30.7
LCV	-	HGV	96.5	89.1	28.0	0.9	6.6	8.4	60.1
LCV	-	HGV	48.3	40.5	4.1	2.1	5.7	11.7	32.5
LCV	-	LCV	48.3	40.5	4.1	2.7	5.1	15.2	28.9
LCV	-	HGV	48.3	40.5	4.1	0.5	7.2	3.0	41.1
LCV	-	HGV	72.4	64.9	4.2	0.7	6.8	6.5	61.7
LCV	Braking	HGV	80.5	79.7	37.0	0.1	0.6	8.2	35.2

Bullet vehicle	Reaction	Struck vehicle	Impact speed without system (km/h)	Impact speed with System 1 (km/h)	Impact speed with System 2 (km/h)	Average reduction in delta v with each system (km/h)			
						SYSTEM 1		SYSTEM 2	
						Struck delta v	Bullet delta v	Struck delta v	Bullet delta v
PSV	-	HGV	16.1	9.2	4.5	4.8	2.1	8.1	3.6
PSV	Braking	Car	40.2	37.1	6.0	2.6	0.5	29.1	5.1
PSV	Braking	Car	94.9	92.0	72.1	2.5	0.4	19.4	3.4
PSV	Braking	HGV	64.4	61.4	42.4	1.4	1.6	10.1	11.9

Appendix C. Detailed cost benefit analysis tables

Table C1: UK cost benefit calculation spreadsheet for current production AEBS

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	Number	Proportion (%)	Total vehicle population		N1 as proportion of N1+M1 total	New registrations		Casualty valuation (€)		congestion benefit UK/%	€/%		
Total number of UK fatalities 2004	3201	1.18%	Number of M1	26,208,000		M1	2,334,572	Fatal	2,142,690	Heavy vehicle	300,000	Retrofit payback perio	8
UK Serious 2004	28954	10.68%	Number of M2+M3	103,000		M2+M3	8,900	Serious	240,765	Car	495,000		
UK Slight 2004	238862	88.14%	Number of N1	3,019,000	10.33%	N1	268,928	Slight	18,570	Congestion EU (German)			
UK Total 2004	271017	100.00%	Number of N2 + N3	433,000		N2+N3	51,200			Fatal to serious	15,000		
UK KSI 04	32155	11.86%	N1 as proportion of N total		87.46%	M1+N1	2,603,500			Serious to slight	5,000		

Casualty category		Number	Proportion of all UK (%)	Effectiveness of CMBS (%) Upper	Lower	Reduction in casualty numbers Upper	Lower	Total benefit (€) Upper	Lower	UK valuation upper	Congestion benefit UK Valuation Lower	German Valuation upper	German valuation lower	Accident Benefit per equipped vehicle (€) (retrofit approach) Upper	Lower	AccidentBenefit per equipped vehicle (€) (steady state approach) Upper	Lower	Total benefit (€) Upper	Lower
Number of casualties when an M1	Fatal	50	1.56%	75%	25%	37.50	12.50	80,350,875.00	26,783,625.00			562,500.00	187,500.00	24.53	8.18	34.42	11.47		
vehicle front collides with any vehicle	Serious	878	3.03%	75%	25%	621.00	207.00	149,515,065.00	49,838,355.00			3,105,000.00	1,035,000.00	45.64	15.21	64.04	21.35		
rear	Slight	35732	14.96%	10%	0%	2,914.70	-219.50	54,125,979.00	-4,076,115.00					16.52	-1.24	23.18	-1.75		
Total net saving								**283,991,919.00**	**72,545,865.00**	**5,021,834.42**	**0.00**	**3,667,500.00**	**1,222,500.00**	**86.69**	**22.14**	**121.65**	**31.07**	**123.22**	**22.14**
Number of casualties when an M2/3	Fatal	1.3	0.04%	75%	25%	0.98	0.33	2,089,122.75	696,374.25			14,625.00	4,875.00	162.26	54.09	234.73	78.24		
vehicle front collides with rear of any	Serious	35	0.12%	75%	25%	25.28	8.43	6,085,335.38	2,028,445.13			126,375.00	42,125.00	472.65	157.55	683.75	227.92		
other vehicle	Slight	1208	0.51%	10%	0%	94.55	-8.75	1,755,793.50	-162,487.50					136.37	-12.62	197.28	-18.26		
Total net saving								**9,930,251.63**	**2,562,331.88**	**103,302.56**	**34,434.19**	**141,000.00**	**47,000.00**	**771.28**	**199.02**	**1,115.76**	**287.90**	**1,131.60**	**201.69**
Number of casualties when an N1	Fatal	11	0.34%	75%	25%	8.25	2.75	17,677,192.50	5,892,397.50			123,750.00	41,250.00	46.84	15.61	65.73	21.91		
vehicle front collides with rear of any	Serious	118	0.41%	75%	25%	80.25	26.75	19,321,391.25	6,440,463.75			401,250.00	133,750.00	51.20	17.07	71.85	23.95		
other vehicle	Slight	3140	1.31%	10%	0%	225.50	-29.50	4,187,535.00	-547,815.00					11.10	-1.45	15.57	-2.04		
Total net saving								**41,186,118.75**	**11,785,046.25**	**447,800.78**	**149,266.93**	**525,000.00**	**175,000.00**	**109.14**	**31.23**	**153.15**	**43.82**	**155.10**	**31.62**
Number of casualties when an N2/3	Fatal	33	1.03%	75%	25%	24.75	8.25	53,031,577.50	17,677,192.50			371,250.00	123,750.00	979.80	326.60	1,035.77	345.26		
vehicle front collides with rear of any	Serious	165	0.57%	75%	25%	99.00	33.00	23,835,735.00	7,945,245.00			495,000.00	165,000.00	440.38	146.79	465.54	155.18		
other vehicle	Slight	2250	0.94%	10%	0%	101.25	-41.25	1,880,212.50	-766,012.50					34.74	-14.15	36.72	-14.96		
Total net saving								**78,747,525.00**	**24,856,425.00**	**203,234.48**	**67,744.83**	**866,250.00**	**288,750.00**	**1,454.92**	**459.24**	**1,538.04**	**485.48**	**1,554.96**	**460.49**

Table C2: Calculated EU benefits spreadsheet for current AEBS, based on detail from UK case

DO NOT ENTER DATA IN SHADED CELLS

EU casualty valuation factor 0.49

	Number	UK Proportion (%)	Total vehicle population		New registrations		Casualty valuation (€)		congestion benefit UK/%	€/%		
Total number of EU-25 fatalities 2005	41,274	1.18%	Number of M1	219,787,000	M1	14,885,400	Fatal	1,049,918	Heavy vehicle	300,000	Retrofit payback perio(	8
EU-25 Serious 2005 (Estimated)	373,336	10.68%	Number of M2+M3	729,760	M2+M3	49,070	Serious	117,975	Car	495,000		
EU-25 Slight 2005 (Estimated)	3,079,909	88.14%	Number of N1	27,838,293	N1	2,045,272	Slight	9,099	Congestion EU (German)			
EU-25 Total 2005 Estimated	3,494,519	100.00%	Number of N2 + N3	3,992,707	N2+N3	418,925			Fatal to serious	15,000		
EU-25 KSI 05	414,610	11.86%	Number of N	31,831,000	M1+N1				Serious to slight	5,000		

Casualty category		Number (upper)	Number (lower)	Effectiveness of CMBS (%) Upper	Effectiveness of CMBS (%) Lower	Reduction in casualty numbers Upper	Reduction in casualty numbers Lower	Total Accident Benefit (€) Upper	Total Accident Benefit (€) Lower	Congestion benefit UK valuation upper	Congestion benefit UK Valuation Lower	Congestion benefit German Valuation upper	Congestion benefit German valuation lower	Accident Benefit per equipped vehicle (€) (retrofit approach) Upper	Accident Benefit per equipped vehicle (€) (retrofit approach) Lower	AccidentBenefit per equipped vehicle (€) (steady state approach) Upper	AccidentBenefit per equipped vehicle (€) (steady state approach) Lower	Total benefit (€) Upper	Total benefit (€) Lower
Number of casualties when an M1 vehicle front collides with any vehicle rear	Fatal	709	580	75%	25%	531.88	145.06	558,431,954.37	152,299,623.92			7,978,221.65	2,175,878.63	20.33	5.54	37.52	10.23		
	Serious	12,453	10,189	75%	25%	8,807.96	2,402.17	1,039,117,370.61	283,395,646.53			44,039,783.51	12,010,850.05	37.82	10.32	69.81	19.04		
	Slight	506,805	414,659	10%	0%	41,872.54	-2,402.17	381,010,838.87	-21,858,065.57					13.87	-0.80	25.60	-1.47		
Total net saving								**1,978,560,163.85**	**413,837,204.88**	**5,524,017.87**	**1,506,550.33**	**52,018,005.15**	**14,186,728.68**	**72.02**	**15.06**	**132.92**	**27.80**	**136.41**	**15.12**
Number of casualties when an M2/3 vehicle front collides with car rear	Fatal	18	15	75%	25%	13.83	3.77	14,519,230.81	3,959,790.22			207,433.76	56,572.84	159.17	43.41	295.89	80.70		
	Serious	496	406	75%	25%	358.49	97.77	42,292,578.97	11,534,339.72			1,792,440.46	488,847.40	463.63	126.45	861.88	235.06		
	Slight	17,134	14,018	10%	0%	1,354.88	-97.77	12,328,453.49	-889,633.83					135.15	-9.75	251.24	-18.13		
Total net saving								**69,140,263.27**	**14,604,496.11**	**113,632.82**	**30,990.77**	**1,999,874.23**	**545,420.24**	**757.95**	**160.10**	**1,409.01**	**297.63**	**1,449.77**	**160.44**
Number of casualties when an N1 vehicle front collides with car rear	Fatal	156	128	75%	25%	117.01	31.91	122,855,029.96	33,505,917.26			1,755,208.76	478,693.30	35.31	9.63	60.07	16.38		
	Serious	1,674	1,369	75%	25%	1,138.23	310.43	134,282,075.67	36,622,384.27			5,691,131.44	1,552,126.76	38.59	10.52	65.65	17.91		
	Slight	44,536	36,439	10%	0%	3,315.39	-310.43	30,167,767.63	-2,824,653.40					8.67	-0.81	14.75	-1.38		
Total net saving								**287,304,873.26**	**67,303,648.14**	**492,580.86**	**134,340.24**	**7,446,340.21**	**2,030,820.06**	**82.56**	**19.34**	**140.47**	**32.91**	**144.11**	**19.38**
Number of casualties when an N2/3 vehicle front collides with car rear	Fatal	468	383	75%	25%	351.04	95.74	368,565,089.89	100,517,751.79			5,265,626.29	1,436,079.90	738.48	201.40	879.79	239.94		
	Serious	2,340	1,915	75%	25%	1,404.17	382.95	165,656,392.42	45,179,016.11			7,020,835.05	1,914,773.20	331.92	90.52	395.43	107.85		
	Slight	31,913	26,111	10%	0%	1,787.12	-382.95	16,261,556.03	-3,484,619.15					32.58	-6.98	38.82	-8.32		
Total net saving								**550,483,038.33**	**142,212,148.75**	**223,557.93**	**60,970.35**	**12,286,461.34**	**3,350,853.09**	**1,102.98**	**284.94**	**1,314.04**	**339.47**	**1,343.37**	**285.07**

Table C3: EU cost benefit analysis if AEBS is assumed to be 100% effective (i.e. max benefit including ACC, FCW and optimised restraints)

DO NOT ENTER DATA IN SHADED CELLS

EU casualty valuation factor 0.49

	Number	UK Proportion (%)	Total vehicle population		New registrations		Casualty valuation (€)		congestion benefit UK/%	€/%		
Total number of EU-25 fatalities 2005	41,274	1.18%	Number of M1	219,787,000	M1	14,885,400	Fatal	1,049,918	Heavy vehicle	300,000	Retrofit payback perio	8
EU-25 Serious 2005 (Estimated)	373,336	10.68%	Number of M2+M3	729,760	M2+M3	49,070	Serious	117,975	Car	495,000		
EU-25 Slight 2005 (Estimated)	3,079,909	88.14%	Number of N1	27,838,293	N1	2,045,272	Slight	9,099	Congestion EU (German)			
EU-25 Total 2005 Estimated	3,494,519	100.00%	Number of N2 + N3	3,992,707	N2+N3	418,925			Fatal to serious	15,000		
EU-25 KSI 05	414,610	11.86%	Number of N	31,831,000	M1+N1				Serious to slight	5,000		

				Effectiveness of CMBS (%)		Reduction in casualty numbers		Total Accident Benefit (€)		Congestion benefit				Accident Benefit per equipped vehicle (€) (retrofit approach)		AccidentBenefit per equipped vehicle (€) (steady state approach)		Total benefit (€)	
Casualty category		Number (upper)	Number (lower)	Upper	Lower	Upper	Lower	Upper	Lower	UK valuation upper	UK Valuation Lower	German Valuation upper	German valuation lower	Upper	Lower	Upper	Lower	Upper	Lower
Number of casualties when an M1 vehicle front collides with any vehicle rear	Fatal	709	580	100%	25%	709.18	145.06	744,575,939.16	152,299,623.92			10,637,628.87	2,175,878.63	27.10	5.54	50.02	10.23		
	Serious	12,453	10,189	100%	25%	11,743.94	2,402.17	1,385,489,827.48	283,395,646.53			58,719,711.34	12,010,850.05	50.43	10.32	93.08	19.04		
	Slight	506,805	414,659	100%	0%	495,061.06	-2,402.17	4,504,709,138.90	-21,858,065.57					163.97	-0.80	302.63	-1.47		
Total net saving								**6,634,774,905.55**	**413,837,204.88**	**7,365,357.15**	**1,506,550.33**	**69,357,340.21**	**14,186,728.68**	**241.50**	**15.06**	**445.72**	**27.80**	**450.38**	**15.12**
Number of casualties when an M2/3 vehicle front collides with car rear	Fatal	18	15	100%	25%	18.44	3.77	19,358,974.42	3,959,790.22			276,578.35	56,572.84	212.22	43.41	394.52	80.70		
	Serious	496	406	100%	25%	477.98	97.77	56,390,105.30	11,534,339.72			2,389,920.62	488,847.40	618.18	126.45	1,149.18	235.06		
	Slight	17,134	14,018	100%	0%	16,655.69	-97.77	151,555,120.96	-889,633.83					1,661.42	-9.75	3,088.55	-18.13		
Total net saving								**227,304,200.67**	**14,604,496.11**	**151,510.42**	**30,990.77**	**2,666,498.97**	**545,420.24**	**2,491.82**	**160.10**	**4,632.24**	**297.63**	**4,686.58**	**160.44**
Number of casualties when an N1 vehicle front collides with car rear	Fatal	156	128	100%	25%	156.02	31.91	163,806,706.62	33,505,917.26			2,340,278.35	478,693.30	47.07	9.63	80.09	16.38		
	Serious	1,674	1,369	100%	25%	1,517.64	310.43	179,042,767.56	36,622,384.27			7,588,175.26	1,552,126.76	51.45	10.52	87.54	17.91		
	Slight	44,536	36,439	100%	0%	43,018.57	-310.43	391,438,884.32	-2,824,653.40					112.49	-0.81	191.39	-1.38		
Total net saving								**734,288,358.50**	**67,303,648.14**	**656,774.48**	**134,340.24**	**9,928,453.61**	**2,030,820.06**	**211.02**	**19.34**	**359.02**	**32.91**	**363.87**	**19.38**
Number of casualties when an N2/3 vehicle front collides with car rear	Fatal	468	383	100%	25%	468.06	95.74	491,420,119.85	100,517,751.79			7,020,835.05	1,436,079.90	984.64	201.40	1,173.05	239.94		
	Serious	2,340	1,915	100%	25%	1,872.22	382.95	220,875,189.89	45,179,016.11			9,361,113.40	1,914,773.20	442.56	90.52	527.24	107.85		
	Slight	31,913	26,111	100%	0%	30,040.66	-382.95	273,349,013.18	-3,484,619.15					547.70	-6.98	652.50	-8.32		
Total net saving								**985,644,322.92**	**142,212,148.75**	**298,077.24**	**60,970.35**	**16,381,948.45**	**3,350,853.09**	**1,974.89**	**284.94**	**2,352.79**	**339.47**	**2,391.90**	**285.07**

Table C4: EU benefit analysis for future development to be functional in pedestrian collision

DO NOT ENTER DATA IN SHADED CELLS							EU casualty valuation factor	0.49				
	Number	UK Proportion (%)	Total vehicle population		New registrations		Casualty valuation (€)		congestion benefit UK/%	€/%		
Total number of EU-25 fatalities 2005	41,274	1.18%	Number of M1	219,787,000	M1	14,885,400	Fatal	1,049,918	Heavy vehicle	300,000	Retrofit payback perioc	8
EU-25 Serious 2005 (Estimated)	373,336	10.68%	Number of M2+M3	729,760	M2+M3	49,070	Serious	117,975	Car	495,000		
EU-25 Slight 2005 (Estimated)	3,079,909	88.14%	Number of N1	27,838,293	N1	2,045,272	Slight	9,099	Congestion EU (German)			
EU-25 Total 2005 Estimated	3,494,519	100.00%	Number of N2 + N3	3,992,707	N2+N3	418,925			Fatal to serious	15,000		
EU-25 KSI 05	414,610	11.86%	Number of N	31,831,000	M1+N1				Serious to slight	5,000		

Number of casualties when an N2/3 vehicle front collides with a pedestrian	Fatal	738	603	75%	25%	553.16	150.86	580,769,232.55	158,391,608.88			8,297,350.52	2,262,913.78	1,163.66	317.36	1,386.33	378.09		
	Serious	936	766	75%	25%	702.08	191.48	82,828,196.21	22,589,508.06			3,510,417.53	957,386.60	165.96	45.26	197.72	53.92		
	Slight	1,716	1,404	10%	0%	171.62	0.00	1,561,625.62	0.00					3.13	0.00	3.73	0.00		
Total net saving								**665,159,054.38**	**180,981,116.93**	**21,826.12**	**5,952.58**	**11,807,768.04**	**3,220,300.37**	**1,332.75**	**362.62**	**1,587.78**	**432.01**	**1,615.96**	**362.64**
Number of casualties when an M1 vehicle front collides with a pedestrian	Fatal	5,645	4,619	75%	25%	4,233.78	1,154.67	4,445,118,356.81	1,212,305,006.40			63,506,644.33	17,319,993.91	161.80	44.13	298.62	81.44		
	Serious	49,600	40,582	75%	25%	37,199.79	10,145.40	4,388,639,426.36	1,196,901,661.73			185,998,940.72	50,726,983.83	159.74	43.57	294.83	80.41		
	Slight	181,875	148,807	10%	0%	18,187.51	0.00	165,493,597.55	0.00					6.02	0.00	11.12	0.00		
Total net saving								**8,999,251,380.72**	**2,409,206,668.14**	**2,519,108.86**	**687,029.69**	**249,505,585.05**	**68,046,977.74**	**327.56**	**87.69**	**604.57**	**161.85**	**621.33**	**87.72**

Table C5: EU benefit analysis for theoretical "perfect" collision avoidance system

DO NOT ENTER DATA IN SHADED CELLS

EU casualty valuation factor 0.49

	Number	UK Proportion (%)	Total vehicle population		New registrations		Casualty valuation (€)		congestion benefit UK/%	€/%		
Total number of EU-25 fatalities 2005	41,274	1.18%	Number of M1	219,787,000	M1	14,885,400	Fatal	1,049,918	Heavy vehicle	300,000	Retrofit payback perio(	8
EU-25 Serious 2005 (Estimated)	373,336	10.68%	Number of M2+M3	729,760	M2+M3	49,070	Serious	117,975	Car	495,000		
EU-25 Slight 2005 (Estimated)	3,079,909	88.14%	Number of N1	27,838,293	N1	2,045,272	Slight	9,099	Congestion EU (German)			
EU-25 Total 2005 Estimated	3,494,519	100.00%	Number of N2 + N3	3,992,707	N2+N3	418,925			Fatal to serious	15,000		
EU-25 KSI 05	414,610	11.86%	Number of N	31,831,000	M1+N1				Serious to slight	5,000		

				Reduction in casualty numbers		Total Accident Benefit (€)		Congestion benefit				Accident Benefit per equipped vehicle (€) (retrofit approach)		AccidentBenefit per equipped vehicle (€) (steady state approach)		Total benefit (€)	
Casualty category		Number (upper)	Number (lower)	Upper	Lower	Upper	Lower	UK valuation upper	UK Valuation Lower	German Valuation upper	German valuation lower	Upper	Lower	Upper	Lower	Upper	Lower
Number of casualties when an M1 vehicle front collides with any vehicle rear	Fatal	709	580	709.18	580.23	744,575,939.16	609,198,495.68			10,637,628.87	8,703,514.53	27.10	22.17	50.02	40.93		
	Serious	12,453	10,189	12,453.12	10,188.91	1,469,154,672.14	1,202,035,640.84			62,265,587.63	50,944,571.70	53.48	43.75	98.70	80.75		
	Slight	506,805	414,659	506,805.01	414,658.64	4,611,570,792.78	3,773,103,375.91					167.86	137.34	309.80	253.48		
Total net saving						**6,825,301,404.08**	**5,584,337,512.43**	**7,365,357.15**	**1,506,550.33**	**72,903,216.49**	**59,648,086.22**	**248.43**	**203.26**	**458.52**	**375.16**	**463.42**	**203.32**
Number of casualties when an M2/3 vehicle front collides with car rear	Fatal	18	15	18.44	15.09	19,358,974.42	15,839,160.89			276,578.35	226,291.38	212.22	173.64	394.52	322.79		
	Serious	496	406	496.42	406.16	58,565,391.26	47,917,138.30			2,482,113.40	2,030,820.06	642.02	525.29	1,193.51	976.51		
	Slight	17,134	14,018	17,133.67	14,018.46	155,904,441.89	127,558,179.73					1,709.10	1,398.36	3,177.18	2,599.51		
Total net saving						**233,828,807.57**	**191,314,478.92**	**151,510.42**	**30,990.77**	**2,758,691.75**	**2,257,111.43**	**2,563.35**	**2,097.29**	**4,765.21**	**3,898.81**	**4,821.43**	**2,097.63**
Number of casualties when an N1 vehicle front collides with car rear	Fatal	156	128	156.02	127.65	163,806,706.62	134,023,669.05			2,340,278.35	1,914,773.20	47.07	38.51	80.09	65.53		
	Serious	1,674	1,369	1,673.65	1,369.35	197,449,033.38	161,549,209.13			8,368,268.04	6,846,764.76	56.74	46.43	96.54	78.99		
	Slight	44,536	36,439	44,536.21	36,438.71	405,248,300.94	331,566,791.68					116.46	95.28	198.14	162.11		
Total net saving						**766,504,040.95**	**627,139,669.86**	**656,774.48**	**134,340.24**	**10,708,546.39**	**8,761,537.96**	**220.27**	**180.22**	**374.77**	**306.63**	**380.00**	**180.26**
Number of casualties when an N2/3 vehicle front collides with car rear	Fatal	468	383	468.06	382.95	491,420,119.85	402,071,007.15			7,020,835.05	5,744,319.59	984.64	805.61	1,173.05	959.77		
	Serious	2,340	1,915	2,340.28	1,914.77	276,093,987.36	225,895,080.57			11,701,391.75	9,573,865.98	553.20	452.62	659.05	539.23		
	Slight	31,913	26,111	31,912.89	26,110.54	290,384,929.02	237,587,669.20					581.83	476.04	693.17	567.14		
Total net saving						**1,057,899,036.23**	**865,553,756.92**	**298,077.24**	**60,970.35**	**18,722,226.80**	**15,318,185.57**	**2,119.66**	**1,734.27**	**2,525.27**	**2,066.13**	**2,569.96**	**1,734.39**
Accident mechanisms not currently in scope																	
Number of casualties when an N2/3 vehicle front collides with a pedestrian	Fatal	738	603	737.54	603.44	774,358,976.73	633,566,435.51			11,063,134.02	9,051,655.11	1,551.55	1,269.45	1,848.44	1,512.36		
	Serious	936	766	936.11	765.91	110,437,594.94	90,358,032.23			4,680,556.70	3,829,546.39	221.28	181.05	263.62	215.69		
	Slight	1,716	1,404	1,716.20	1,404.17	15,616,256.18	12,776,936.88					31.29	25.60	37.28	30.50		
Total net saving						**900,412,827.86**	**736,701,404.61**	**21,826.12**	**5,952.58**	**15,743,690.72**	**12,881,201.50**	**1,804.12**	**1,476.09**	**2,149.34**	**1,758.55**	**2,186.92**	**1,476.11**
Number of casualties when an M1 vehicle front collides with a pedestrian	Fatal	5,645	4,619	5,645.04	4,618.67	5,926,824,475.75	4,849,220,025.62			84,675,525.77	69,279,975.63	215.73	176.51	398.16	325.77		
	Serious	49,600	40,582	49,599.72	40,581.59	5,851,519,235.15	4,787,606,646.94			############	202,907,935.33	212.99	174.26	393.10	321.63		
	Slight	181,875	148,807	181,875.09	148,806.89	1,654,935,975.48	1,354,038,525.39					60.24	49.29	111.18	90.96		
Total net saving						**13,433,279,686.38**	**10,990,865,197.95**	**2,519,108.86**	**687,029.69**	**############**	**272,187,910.97**	**488.96**	**400.06**	**902.45**	**738.37**	**924.80**	**400.08**
All casualties in All accidents	Fatal	45,401	37,147	45,401.40	37,146.60	47,667,751,625.34	39,000,887,693.46			############	557,199,000.00	1,511.18	1,236.42	2,739.74	2,241.60		
	Serious	410,669	336,002	410,669.21	336,002.08	48,448,638,242.61	39,639,794,925.77			############	1,680,010,397.38	1,535.93	1,256.67	2,784.62	2,278.32		
	Slight	3,387,900	2,771,919	#########	2,771,918.52	30,827,522,184.77	25,222,518,151.17					977.30	799.61	1,771.83	1,449.68		
Total net saving						**126,943,912,052.71**	**103,863,200,770.40**	**40,837,500.00**	**11,137,500.00**	**############**	**2,237,209,397.38**	**4,024.41**	**3,292.70**	**7,296.19**	**5,969.61**	**7,479.88**	**3,293.11**