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Cost benefit evaluation of advanced primary safety systems: Final report

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Transport Research Laboratory

PUBLISHED PROJECT REPORT PPR586

Cost Benefit Evaluation of Advanced Primary Safety Systems

Final Report

by B Robinson, W Hulshof, R Cookson, R Cuerden, R Hutchins and E Delmonte (TRL)

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Client:	**Department for Transport (DfT), Primary and eSafety Branch, International Vehicle Standards Division** **(Claire Rees)**

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Executive summary

Intelligent vehicles and advanced safety technologies have been the subject of discussion for many years. Recent technological advances have meant that the rate at which new technology has been fitted to vehicles has increased and there is now a large range of production and near production systems that are claimed to have significant safety benefits. In addition, it can be difficult to evaluate the likely casualty savings of features intended to avoid an accident. Predictive studies are often undermined by the argument that the driver’s behaviour would change if the device was fitted and retrospective studies are made complex by the fact that if an avoidance feature is effective, there is no accident data to be used in the comparison.

These factors result in differing claims (according to the assumptions used) for the safety benefits of different systems. Consequently, it can be difficult for policy makers to make an informed assessment about which system(s) might potentially deliver the most cost effective national casualty reductions.

TRL has undertaken two complementary studies on Active Primary safety for the Department: ‘Advanced Safety System Priorities’ (ASSP) and ‘Cost Benefit Evaluation of Advanced Primary Safety Systems’ (this study, EASS).

The ASSP project took a ‘top down’ approach starting with national accident data (from STATS19) and using contributory factors recorded by the Police at the accident scene to broadly align the recorded factors with *safety functions* which may be applicable countermeasures. Using this approach, and adjusting for under-reporting of serious and slight casualties in STATS19, a target population for each safety function representing the casualties which could be influenced by the safety function was estimated.

In contrast, this Evaluation of Safety System Technologies project took a ‘bottom-up’ approach, starting with small number of specific *safety systems* and estimating the target population and cost benefit information for these systems. This was achieved using primarily in-depth accident data, with the results being scaled up to national level (adjusting for under-reporting). The ‘bottom-up’ approach has advantages in determining a more accurate target population estimate because not only is detailed data used using a predictive, case-by-case approach, but more detailed system performance information can be used to more accurately identify relevant accidents.

The analyses carried out as part of this study have evaluated the potential casualty benefits, and compared those to the likely system fitment costs, for four separate advanced primary safety technologies:

- Advanced Emergency Brake Systems (AEBS) for passenger cars;
    - AEBS1 – potentially able to mitigate/avoid all moving target rear shunts but those with stationary targets only if closing speed 40 mile/h or less;
    - AEBS2 – potentially able to mitigate/avoid all rear shunt impacts regardless of whether target (shunted) vehicle is stationary or not;
- Pedestrian capable AEBS for passenger cars;
    - 0.6s/1s/2s systems – applies full braking 0.6s/1s/2s before a detected, imminent impact with a pedestrian;
- Lane Departure Warning Systems for passenger cars;
- Youth/Family key.

In this study the term ‘target population’ was used to describe the group of casualties which could be influenced by the system being considered. Table 1 shows a summary of the results for the four technologies and, where appropriate, the generic variants modelled. “Effectiveness” is calculated by dividing the annual casualty savings (in £m) into the overall annual costs of the casualties in the relevant target populations, and is thus defined as the proportion of the overall costs that would actually be prevented.

Table 1. Summary of system effectiveness, costs and benefits, and burdens of proof, for the four technologies

Technology	Overall effective-ness[1]	System costs (per vehicle)	Annual casualty savings (£m)	Benefit-cost ratios	Burden of proof
Car AEBS1	6-40%	£100-£500	£80-612m	0.07-2.78	Medium-High
Car AEBS2	6-40%	£125-£550	£84-614m	0.07-2.23	Medium-High
Pedn AEBS 0.6s	20-21%	£400-£800	£327-382m	0.19-0.43	High
Pedn AEBS 1s	42%	£400-£800	£673-798m	0.38-0.91	High
Pedn AEBS 2s	49%	£400-£800	£775-917m	0.44-1.04	High
LDWS	12-31%	£100-£300	£162-466m	0.25-2.12	High-V. High
Youth Key	5-13%	£10-£50	£76-247m	0.69-11.2	Low-Medium

The main conclusions from this study can be summarised as:

- Advanced Emergency Braking Systems (AEBS) for passenger cars combine sensing of the environment ahead of the vehicle with the automatic activation of the brakes (without driver input) in order to mitigate or avoid rear shunt accidents with vehicles in front. Based on predictive, detailed, in-depth accident studies, overall the predicted effectiveness for these systems was 6-40% of target population casualty costs saved, and the likely benefit-cost ratios ranged from 0.07 – 2.78. The main factor behind this wide range was the estimated effectiveness of the pre-collision warning function of AEBS, with the best available evidence (from US field operational trials) suggesting an effectiveness range equivalent to 3-38% for the warning system. The autonomous braking component was estimated to provide some additional benefit in cases where the driver failed to react appropriately to the warning;
- Pedestrian AEBS incorporates much of the functionality of a first generation AEB system (i.e. one for rear shunts), but with the addition of a video camera to supplement the Laser or Radar systems and thus the ability to track pedestrians. Based on detailed, in-depth accident studies, overall the predicted minimum effectiveness for these systems was quite high (20-49% of target population casualty costs saved), and the likely benefit-cost ratios were similarly higher (0.19-1.04), but still generally below unity, largely because of the relatively high assumed system costs (£400-800); The higher ratios were associated with systems that started to brake earlier in the impact phase (time to collision), but the compromise with these systems would likely be a high frequency of unnecessary brake activations. These are minimum figures because of the necessary assumption that any pre-collisions warnings issued by the system would not have any effect;
- A lane departure warning (LDW) system is an in-vehicle system that provides a warning to the driver of an unintended lane departure. Based on accident studies and US field operational trials, overall the predicted effectiveness for these systems was 12-31% of target population casualty costs saved, and the likely benefit-cost ratios were 0.25-2.12, implying that the systems could be cost effective. If system developers either further improved their capability, so that

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[1] Overall effectiveness = (annual casualty saving)/(overall annual costs of the casualties in the relevant target populations) in £m; calculated for each technology with more details in Section 3.

they prevent a higher number of casualties, or reduced the system costs (to below £100), or both, this cost-effectiveness would be further improved;

- Youth Key technologies are intended to help and encourage teenagers and younger people to drive more safely. The major limitations of these systems include not being likely to mitigate any accidents where the young drivers were not exceeding the speed limit or were already wearing their seat belt; nor where they are driving their own, rather than their parents' car. Based on predictive, STATS19 accident studies, overall the predicted effectiveness for these systems was quite low (5-13% of target population casualty costs saved), but the system's likely very low cost per vehicle (£10-50) produced much higher benefit-cost ratios (0.69-11.2).

Abstract

Intelligent vehicles and advanced safety technologies have been the subject of discussion for many years and there is now a large range of production and near-production systems that claim to have significant safety benefits. The Evaluation of Safety System Technologies project took a 'bottom-up' approach, starting with small number of specific *safety systems* and estimating the target population of casualties and cost benefit information for these systems. This was achieved using primarily in-depth accident data, with the results being scaled up to national level (adjusting for under-reporting). The analyses carried out as part of this study have evaluated the potential casualty benefits, and compared those to the likely system fitment costs, for four separate advanced primary safety technologies:

- Advanced Emergency Brake Systems (AEBS) for passenger cars;
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    - 0.6s/1s/2s systems – applies full braking 0.6s/1s/2s before a detected, imminent impact with a pedestrian;
- Lane Departure Warning Systems for passenger cars;
- Youth/Family key.

1 Introduction

1.1 Background

Intelligent vehicles and advanced safety technologies have been the subject of discussion for many years. Recent technological advances have meant that the rate at which new technology has been fitted to vehicles has accelerated quickly and there is now a large range of production and near production systems that claim to have significant safety benefits. In addition to this, it can be difficult to evaluate the likely casualty savings of features intended to avoid an accident. Predictive studies[2] are often undermined by the argument that the driver's behaviour would change if the device was fitted and retrospective studies[3] are made complex by the fact that if an avoidance feature is effective, there is no accident data to be used in the comparison.

These factors combine to result in many claims (often differing significantly according to the assumptions used) for the benefits of different systems. Consequently, it can be very difficult for policy makers to make judgements about which system(s) justify a higher priority in terms of national casualty reductions, resulting potentially in poor targeting of resources in respect of casualty reduction. One of the main aims of this study was to take a step backwards from the technological developments and to study the accident data to consider, not what the latest technology can actually do in terms of casualty reduction, but what safety functions would be required to have substantial impacts on the biggest groups of accidents and casualties in the UK. In this way, the results could be used to inform and influence the medium and longer term direction of technology development, as well as trying to understand the implications of more mature technologies that is already in, or near to, production.

1.2 Terminology

In recognition of the importance of reporting with clarity on this research, this section has been included to describe the most important terminology used.

Traditionally in the UK the term 'Primary safety' has been used to denote the performance of a vehicle in terms of its ability to avoid an accident or to reduce the severity of the collision itself (for example, braking performance). 'Secondary safety' has been used to denote the performance of the vehicle in terms of its ability to avoid or mitigate injury, given that a collision has occurred (for example, an occupant restraint system). 'Tertiary safety' is a term which refers to any aspects relating to the time it takes for a casualty to receive medical attention after an accident. In other countries, the terms 'Active' and 'Passive safety' have been used as direct substitutes for Primary and Secondary respectively. However, 'Active' has also been used to describe 'intelligent systems', which can cause confusion because not all such systems relate to Primary safety.

For the purposes of this study, 'Primary' and 'Secondary safety' are used to identify accident avoidance and injury mitigation respectively as described above. 'Passive' is be used to describe any vehicle system that has one fixed, unchangeable, set of characteristics. 'Active' will be used to describe systems that have more than one set of characteristics, or adapt their response based on the measurement of one or more variables in combination with decision criteria. Thus, a seatbelt is a Passive Secondary safety system, the brakes are a Passive Primary safety system, an airbag is an Active Secondary safety system and Brake Assist is an Active Primary safety system. After agreement from the DfT, the focus of this project is on Active Primary systems.

In this study the term 'target population' was used to describe the group of casualties which could be influenced by the function or system being considered. The term

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[2] Studies where accidents involving vehicles not equipped with a system are reconstructed and engineering principles are used to predict the effect that a new system might have on the outcome.

[3] Statistical comparison of accidents involving vehicles that were and were not equipped with the system.

‘effectiveness’ was used as a measure of the effect on casualties and can be described in relation to the target population or with respect to all accidents. In this study, the ‘effectiveness’ was used in terms of the effect of the safety function on the target population.

1.3 Advanced Safety System Priorities (ASSP) and Cost Benefit Evaluation of Advanced Primary Safety Systems (EASS)

TRL has undertaken two studies on Active Primary safety for the Department: ‘Advanced Safety System Priorities’ (ASSP) and ‘Cost Benefit Evaluation of Advanced Primary Safety Systems’ (this study, EASS). These are complementary projects and in some respects overlap in terms of the systems (EASS) or safety functions (ASSP) considered. However, the two projects have different approaches despite having similar overall aims to value the numbers of casualties affected and estimate the cost effectiveness of the solution.

The Advanced Safety Systems Priorities project took a higher level ‘top down’ view starting with national accident data (from STATS19) and using causation factors recorded by the Police at the accident scene to broadly align the recorded factors with safety functions which may be applicable countermeasures. Using this approach, a target population for each safety function representing the casualties which could be influenced by the safety function was estimated. In-depth accident data was used (at a high level) to refine some of these target populations. In contrast, the Evaluation of Safety System Technologies project took a ‘bottom-up’ approach, starting with small number of specific safety systems and estimating the target population and cost benefit information for these systems. This was achieved using primarily in-depth accident data, with the results being scaled up to national level. The ‘bottom-up’ approach has dual advantages for a more accurate target population estimate because not only is detailed data used using a predictive, case-by-case approach, but more detailed system performance information can be used to more accurately identify relevant accidents. Figure 1 provides a schematic of the different methodologies used by the two projects.

Although both projects report target populations, these are estimates made using different main accident data types and differing analysis approaches. Therefore, these result in target population estimates at differing ‘burdens of proof’ (see Figure 2). The more detailed the information used to define relevant accidents, the more accurate the target population can be expected to be. Therefore an approach using in-depth data and adopting a case-by-case approach (as used in EASS) is considered to result in more accurate target population estimates (often associated with smaller groups of casualties). This is appropriate for a project starting with specific systems with known performance information. For the ‘top down’ approach (as used in ASSP), a macro approach is appropriate to set national priorities. However, the consequence of this is that the estimates made are at a lower burden of proof and may be less accurate than those made using in-depth data and using more specific system performance information.

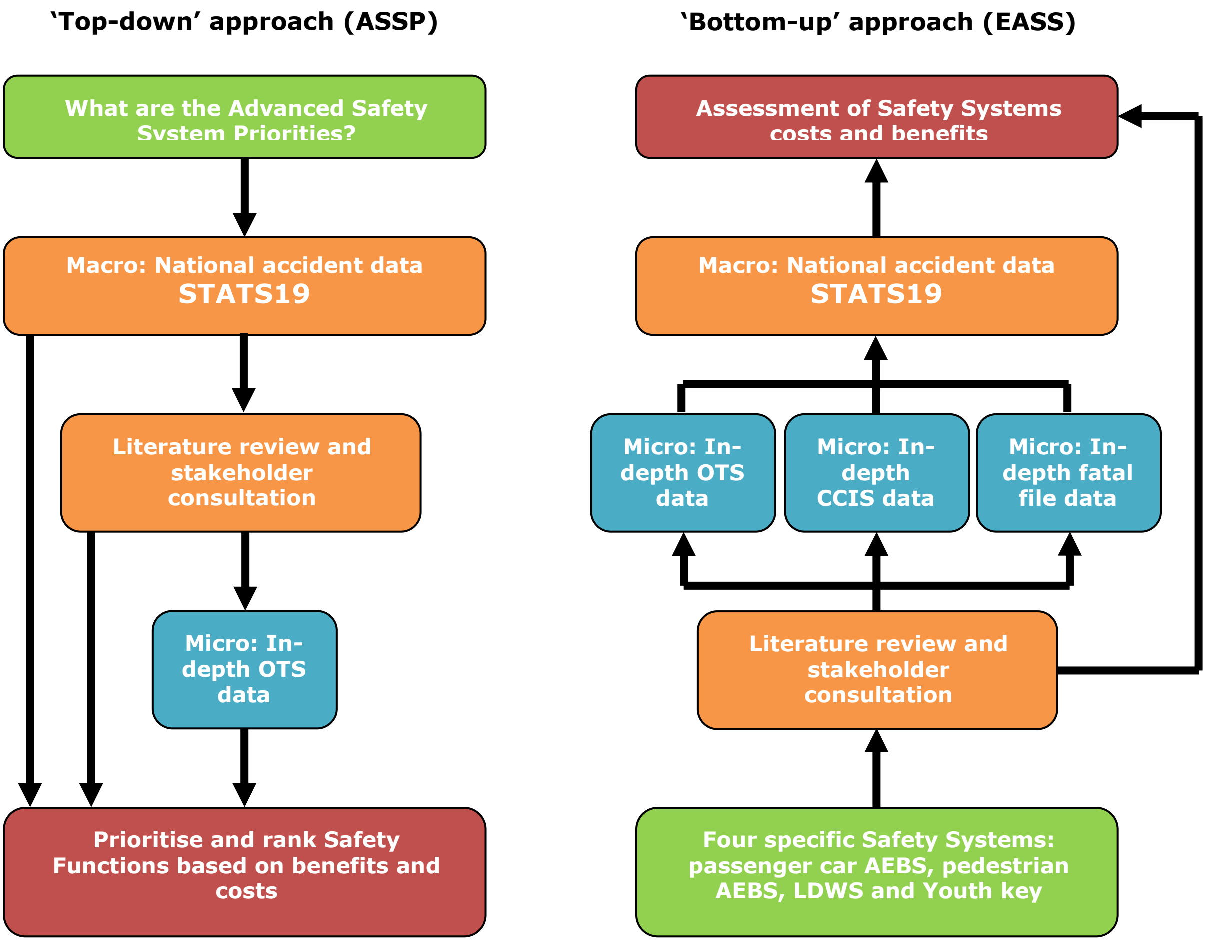

Figure 1. Diagram to show respective methodologies of Advanced Safety System Priorities (ASSP) and Cost Benefit Evaluation of Advanced Primary Safety Systems (EASS)

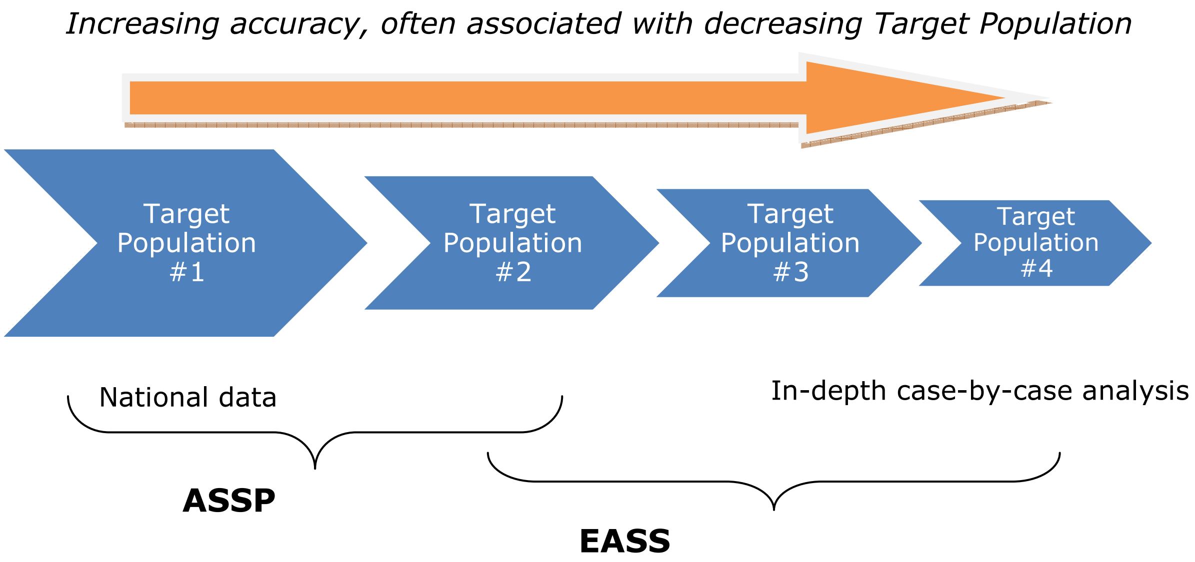

Figure 2. Diagram to show relationship between Advanced Safety System Priorities and Evaluation of Advanced Safety Systems

1.4 The primary safety systems evaluated

Four technologies are reviewed for this project, namely:

- Advanced Emergency Brake Systems (AEBS)[4] for passenger cars;
- Pedestrian capable AEBS for passenger cars;
- Lane Departure Warning Systems for passenger cars;
- Youth/Family key.

The following sections briefly describe each technology. Fuller descriptions, where appropriate, of the generic systems used in any accident studies are given in the Results section.

1.4.1 Passenger car AEBS for rear shunts

Advanced emergency braking systems (AEBS) combine sensing of the environment ahead of the vehicle with the automatic activation of the brakes (without driver input) in order to mitigate or avoid an accident. The level of automatic braking varies, but may be up to full ABS braking capability. First generation AEBS are in production on a number of current vehicles at the top end of the market and are capable of automatically mitigating the severity of two-vehicle, front to rear shunt accidents on straight roads and gentle curves (dependent on sensor line of sight, weather conditions and environment "clutter").

Research literature highlights a range of different sensors: radar, passive infrared, active infrared imaging, far infrared, ultrasonic and laser/lidar. AEBS systems on current vehicles typically use radar sensing, although some combine radar with imaging sensors and lidar systems will enter the market soon. Typically, sensor fusion is required if the system has additional functionality which necessitates classification of the object (e.g. detecting whether an object is a car or a pedestrian). "Second generation" AEBS are much more likely to involve the combination of a sensor for location (typically radar/lidar) and a sensor for classification (typically imaging or infrared). Most AEBS share hardware and are integrated with other systems that do not involve automated emergency braking, such as adaptive cruise control, forward collision warning (FCW), and predictive brake assist systems. It is, therefore, important to consider carefully the definition of the system characteristics in any assessment of casualty benefits to ensure that functions such as warnings and cruise control, that will be present on all AEBS equipped vehicles, are treated in the correct way in both costs of the system and benefits of casualty reduction. The warning function can provide significant benefit on its own, indeed discussions with industry experts indicate that activation of the warning (as would be provided by the FCW part of an AEBS) is likely to provide the majority of the overall casualty prevention effectiveness, with the autonomous braking providing a smaller additional benefit. Recent research in the USA (Nodine et al, 2011, based on field trial data) provides a central estimate that passenger car FCW would prevent about 16% of all rear end collisions (the 95% confidence limits were 2-30%). For the purposes of this study, AEBS is assumed to combine FCW and autonomous braking in the event that the driver fails to react to the warning appropriately.

The effectiveness of systems can be reduced in adverse weather conditions and different systems employ different activation strategies, for example acting early but braking moderately or acting late but braking very heavily.

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[4] Also known as Autonomous Emergency Braking Systems

1.4.2 Passenger car AEBS for pedestrian impacts

Pedestrian AEBS (or second generation AEBS) is still in the early stages of development with only one company currently identified to be including such a system on their vehicles. Volvo have recently included a pedestrian detection system with full 'autobrake'. This system is available as part of an optional extra that also includes adaptive cruise control ACC. This optional extra package is available on the S60, V60, and the XC60 and costs £1,380 in the UK market (what proportion of this is made up by the pedestrian detection is not known, but both this and the ACC system share much of the same hardware). As this is still a fairly new technology with Volvo being first to market, very little literature exists on the technical specifications for this technology, and no detailed specifications for the system were found on the Volvo web site, although an official Volvo promotional video is available (Volvo, 2011).

For the purposes of this study, it is assumed that a generic pedestrian AEBS incorporates much of the functionality of a first generation AEB system (i.e. one for rear shunts), but with the addition of a video camera to supplement the Laser or Radar systems.

1.4.3 Passenger car LDWS

A lane departure warning (LDW) system is an in-vehicle system that provides a warning to the driver of an unintended lane departure. The system monitors the lateral position of the vehicle within the lane boundary and issues a warning to the driver if warning threshold criteria are met. These criteria may include vehicle speed, rate of departure and time to lane crossing. An LDW system will not take any automatic action to prevent possible lane departures and the safe operation of the vehicle remains the responsibility of the driver.

The types of accidents influenced by an LDW system include head-on or side swipe collisions on single carriageway roads; single vehicle accidents where the vehicle leaves the carriageway; or side-swipe accidents on multi-lane roadways where two vehicles are travelling in the same direction. However, identifying the proportion of these accidents for which LDW is an effective countermeasure is difficult, for example, because the condition/visibility of the lane markings may not be known. Published benefit estimates vary, both in terms of the estimated target populations and system effectiveness.

There are a range of systems currently on the market (Visvikis et al, 2008). The majority of systems use a forward looking video camera mounted behind the windscreen. Other systems use infra-red sensors or laser scanning technologies. The current systems utilise a range of different types of warning: visual, audible or haptic, or a combination of these. Audible warnings include the use of a "rumble strip" noise and haptic warnings include vibrating steering wheels or seats. The systems are only active above a certain speed. The trigger speeds identified range from 56 to 80km/h for passenger cars.

The analyses performed for this study have utilised data from production systems fitted to real-world vehicles in use. It has, therefore, not been necessary to define a generic LDW system (as was necessary for the car and pedestrian AEB system accident studies).

1.4.4 Passenger car "youth key"

Youth Key technologies are intended to help and encourage teenagers and younger people to drive more safely. They can also provide some reassurance for parents or guardians who are considering allowing a younger driver access to their car. The technology works by limiting or restricting some electronic functions. The controlled parameters can range from the vehicle's speed and acceleration to the volume of the sound system.

The vehicle owner is afforded the full range of performance and functionality of the vehicle and has more choice with regards to the use of safety devices and features; whilst for younger drivers the performance of the car can be limited and safety devices and features cannot be deactivated. This is achieved by using a transponder chip in each ignition key, which is read by the car and identifies the driver and modifies the vehicle's characteristics accordingly to pre-programmed settings.

The concept behind these systems is based on the hypothesis that tuning the vehicle characteristics can reduce the risk of accident involvement or mitigate any injuries should a collision occur. The system can either be designed to encourage certain behaviours, for example muting the radio until all appropriate seat belts are fastened in the car, or it can insist upon them for the vehicle to function, such as preventing the car from starting until all seat belts are correctly worn (seat belt ignition inter-locks). Further limits could include preventing the key owner from driving at certain times of the day, which are known to represent higher risk with respect to accident propensity; or preventing the engine from starting if there are more than two people in the car to reduce the adverse influence of peer pressure and distractions for younger drivers.

Ford's 'MyKey' technology was recently introduced to certain vehicle models in the USA. The MyKey system allows the parent to program any key through the vehicle message centre, which updates the SecuriLock Passive Anti-Theft System. When the MyKey is inserted into the ignition; the system reads the transponder chip in the key and enables certain pre-programmed driving modes, including:

- *Persistent seat belt reminder with audio mute. Ford's 'Belt-Minder' system typically provides a six-second reminder chime every minute for five minutes. With MyKey, the Belt-Minder chime continues at the regular interval and the audio system is muted until the safety belt is buckled. A message centre display, "Buckle Up to Un-mute Radio," also appears on the instrument cluster*.
- *Earlier low-fuel warning. Rather than a warning at 50 miles to empty, MyKey provides a warning at 75 miles to empty.*
- *If MyKey is in the ignition, features such as park aid and BLIS® (Blind Spot Information System) with cross-traffic alert cannot be deactivated*

Additional MyKey features that can be programmed through the vehicle's message centre setup menu:

- *Limited top speed of 80 mph.*
- *Traction control system, that limits tyre spin, cannot be deactivated.*
- *Limited audio volume to 44 percent of total volume.*
- *A speed alert chime at 45, 55 or 65 mph.*

(Source Ford media website, 2011)

The proposed 'Youth Key' system evaluated for this study is based on the MyKey functionality; this is because it is already available in the USA and therefore is known to be a practicable option with known technologies and associated costs.

2 Project tasks and methodology

2.1 The methodology for assessing advanced safety systems

The study has used a methodology designed by TRL on behalf of the DfT (Smith et al, 2008). The methodology is intended to identify the most suitable and cost effective method of assessing the potential benefits of advanced safety systems, and to allow this assessment to be undertaken in a consistent and objective manner.

The methodology consists of three main steps as shown in Figure 3.

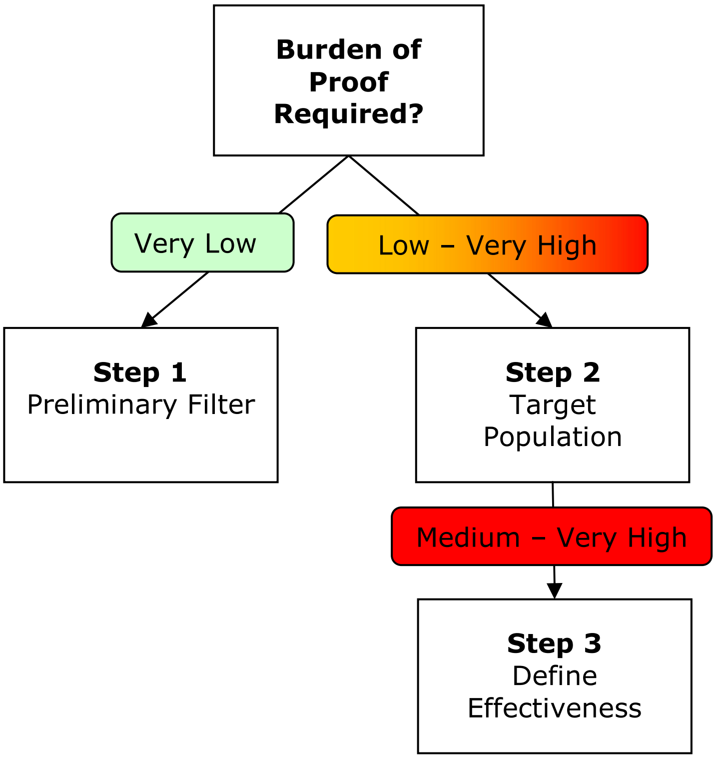

Figure 3: Overview of methodology.

The methodology starts by identifying the burden of proof required. For example, if decision makers are considering a large range of potential new safety systems and it is only necessary to identify which measures warrant further investigation then rigorous proof of the exact effects may not be required. This sort of requirement is considered to represent a low burden of proof.

By contrast, if a major new regulation is planned that is likely to cost substantial amounts of time or money and/or to encounter significant opposition, then it may be necessary to have very rigorous supporting analysis that accurately and incontrovertibly demonstrates the effects. This would represent a very high burden of proof. For this study the burden of proof requirement is in the range medium to very high.

2.1.1 Preliminary filter

Step 1 of the methodology is the definition of a preliminary filter that can be applied to accident data. The primary objective of this step is to define groups of accidents, against which an initial evaluation of the potential benefit of a countermeasure can be assessed. The key considerations for the preliminary filter are:

1. What is an appropriate data set?
2. How should the accidents be grouped in the filter?
3. How will the groups be compared?

The output from Step 1 of the methodology is an initial estimate of maximum potential benefit. This estimate will be based on the sum of the casualty groups that can potentially be affected by the system under consideration. However, the burden of proof provided by the preliminary filter is generally considered to be very low (see Figure 3).

2.1.2 Defining target population

Step 2 of the methodology is intended to identify more accurately the accidents that could be affected by the system under consideration (defined as the target population). The target population is specific to the safety system and should be as accurate as possible including causation factors where required. This is the maximum potential benefit for the system, i.e. if the system were 100% effective its target population would be equal to the expected benefit.

The key considerations when defining the target populations are:

1. In what situations is the system intended to assist the driver?
2. What are the relevant types of accident and vehicle for the system being assessed?
3. What information is available to estimate the target population?
4. How can these relevant accidents be identified in the accident data?
5. Have the correct accidents been identified?

Target populations can provide a low to medium burden of proof but in reality, most systems are not 100% effective at preventing the collisions/casualties for which they are designed and thus, step 3 is required to more accurately quantify the expected benefits and to provide the higher level burdens of proof.

2.1.3 Defining effectiveness

Step 3 of the methodology is intended to refine the benefit estimate that was defined in Step 2, that is, to translate the analysis from the maximum possible benefit (target population) to a realistic likely benefit. The main objective of this step is to determine how effective the system will be for preventing the casualties/accidents that make up the target population. There are a number of different methods for determining/identifying the effectiveness of the system and this step is intended to help identify the most appropriate method for the quality of estimate/burden of proof required. The inputs into step 3 of the methodology can depend on the approach taken, but can include:

- Accident data;
- Literature;
- System specification;
- Quality requirements;
- Test/trials of technologies and human factor experiments.

The key considerations when assessing the system’s effectiveness are:

1. What burden of proof is required?
2. What is the most appropriate assessment method for the information available?
3. Is the system available on the market in sufficient numbers for statistically significant analysis?
4. What sources of information are available for determining the effectiveness?

The manner in which the effectiveness of a system is determined will depend on the burden of proof required. Figure 4 summarises how the most appropriate method can be determined.

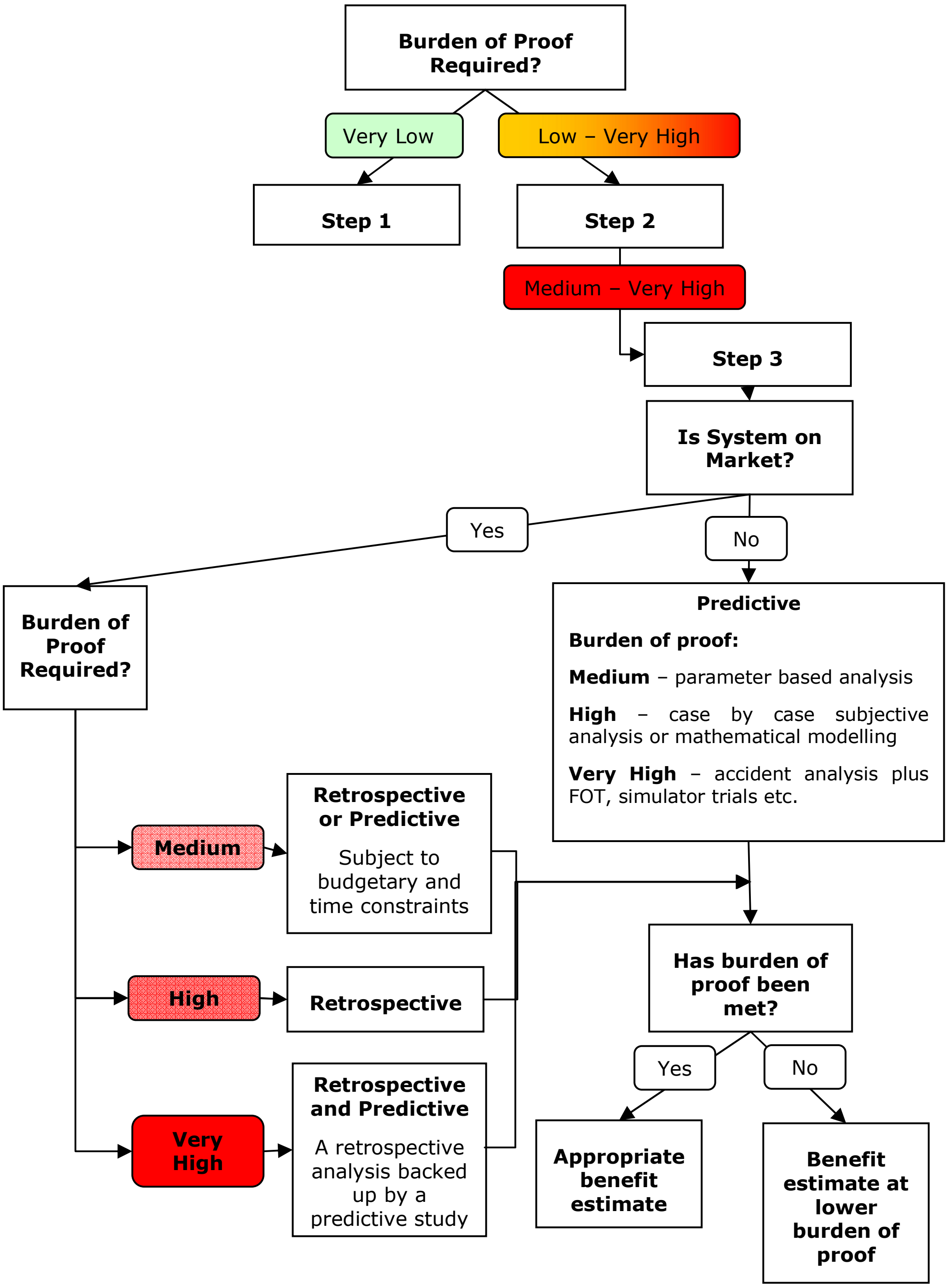

Figure 4: Generic methodology flow chart (Smith et al, 2008)

Predictive studies examine accidents where vehicles were not equipped with the specific feature under consideration and make calculations and/or judgements to assess whether the accident would have been avoided or mitigated if the safety feature had been present. A limitation of predictive techniques is that it is difficult to rigorously include driver behaviour factors associated with the new system in the assessment of its effectiveness. Particularly for primary safety systems, this means that it can be easy for critics to argue that the results are not valid because the system would induce a behavioural change that would reduce or eliminate the predicted benefits. Where the highest burden of proof is required this limitation can be overcome through the use of physical trials involving ordinary drivers as subjects (driver in the loop trials). These can take the form of simulator trials, track trials or field operational trials. This method can allow for human behavioural factors to be combined with the accident data assessment; however the reliability of the data is dependent on assumptions made and the design of the experiment used.

Retrospective studies treat the feature under investigation as a risk factor and use statistical methods to compare the relative risk of accidents in real world accident data where vehicles can be identified that both do and do not have the safety feature fitted. Where such an approach is possible, it has the most potential for providing a rigorous and defendable outcome because it seeks to objectively measure the actual effect on real vehicles in service with real drivers, thus accounting for many of the factors that can confound predictive studies. The size of the sample will have a strong affect on whether statistically significant conclusions can be drawn and the analytical design, particularly the control of confounding factors (e.g. systematic biases such as age of driver etc) will strongly affect the quality of the results.

For example, the proposal for the mandatory fitment of Electronic Stability Control (ESC) could be, under the method described above, considered to be supported by benefit estimates with a very high burden of proof. A range of studies have been undertaken:

- target population studies;
- predictive studies using both parameter and individual case reviews;
- track and simulator trials of driver behaviour; and
- retrospective statistical studies from different parts of the world.

Although the exact estimates of benefits varied quite considerably, all suggested strongly positive benefits with the same general trends. However, one recent TRL study (Broughton et al., 2010) highlights the importance of considering in detail the quality of the studies (e.g. sample size, confounding factors, bias etc). This study identified that many previous retrospective studies of the effectiveness of ESC were based on the reasonable sounding assumption that the exposure to risk of a specific make and model of car would be the same for variants equipped with ESC and for those that were not equipped. These studies implicitly assume that cars with and without ESC are driven in similar circumstances, for similar mileages and with similar drivers, so that any differences in their accident-involvements can be interpreted as the effects of ESC. Analyses of Stats19 accident data demonstrate, however, that the driver profiles of the two groups of car may well differ in terms of age and sex, with non-ESC variants more frequently driven by younger, ‘riskier’ drivers.

2.2 Compensating for under-reporting

It is widely recognised that there is a significant degree of under-reporting of accidents, the extent of which varies by accident and vehicle type but which is most prevalent amongst slight injury cases, but also amongst serious injury accidents. The STATS19-derived target population estimates make no allowance for this, they simply record all reported cases only, and are thus considered as under-estimates of the true casualty numbers.

While fatality numbers in STATS19 are generally considered to be an accurate reflection of the true picture, UK studies (summarised by Ward et al, 2006) suggested adjustment factors of about 1.6-2 (based on police and hospital data) were likely to be appropriate for serious and slight casualties. Since that time, the Department for Transport have made further investigations into the under-reporting issue, mainly by comparing hospital admissions and travel/crime survey data with STATS19. Their latest analysis (Department for Transport, 2010a) concludes that the approximate 95% confidence limits for serious casualties give adjustment factors of between 2.0 and 4.2, and between 2.6 and 3.4 for slight injuries. For car occupants and pedestrians (the two casualty groups likely to be most relevant to the technologies assessed in this study), the central estimates are for overall adjustment factors (for all casualties) of 3.1 and 2.8 respectively (the breakdowns by serious and slight are not given).

For the purposes of making GB estimates for this project, the STATS19 target populations have been adjusted by factors of 2.7 (lower scenario) and 3.3 (upper scenario) for both serious injuries and slight injuries, to give ranges of estimates of the true situation. These imply a central estimate adjustment factor of 3.0, and have been chosen as being conservatively representative of the ranges quoted in the most recent DfT published literature. The STATS19 fatality numbers have been left unadjusted, on the basis that any under-reporting of fatalities is assumed to be negligible.

2.3 Cost benefit analysis

The generic methods described above only cover the estimation of casualty effects. They do not consider the identification of costs and other societal effects (for example, increased mass, increasing fuel consumptions and emissions). These must also be considered in a comprehensive cost benefit analysis, particularly in light of the Stern and Eddington reports.

The system costs themselves can be considered in a variety of ways, for example, retail cost to the consumer, costs to the OEM, or raw material costs, depending on how corporate profit and taxation is considered. The relationship between volume independent development costs, unit costs and volumes of production also need to be considered.

There are also a number of different methods in use for undertaking the cost benefit comparison itself, each of which has strengths and limitations. For example, simple studies can be based on past accident data and compare the cost of equipping new registrations with the benefits predicted for the whole fleet. More sophisticated analyses will forecast trends into the future and evaluate on an annual basis from the predicted year of implementation accounting for implementation rates, the risk characteristics associated with new vehicle purchasers, the effect of other safety interventions, inflation and discounted cash flow. The method used can have a very substantial influence on the benefit to cost ratio predicted from the same base data (for example, Robinson and Chislett, 2010).

As outlined in the TRL PPR 381 (Smith et al., 2008) report, any evaluation of primary safety systems needs to have a tailored methodological approach to meet the necessary minimum burden of proof requirements, which for this project is “Medium to Very High”. Depending on the current state of the art knowledge and the amount of procurable resource, a method may involve literature reviews only, or it may extend to undertaking accident analysis in conjunction with Field Operation Trials (FOT) or Human Factor experiments using a simulator etc.

The methods used for each of the primary safety systems to be assessed follow similar protocols with respect to defining their target populations and quantifying their costs. Different methods to evaluate the effectiveness of the candidate primary safety systems are used in this study because there is considerable variation both with regards to what is known about each one and to what extent they are fitted in the vehicle fleet. These factors directly influence the methodological choices that are prescribed within the PPR 381 approach, Step 3 (see Figure 4).

For the purposes of this study, given the generally hypothetical nature of the technologies assessed (generic systems are assumed), a simple cost-benefit approach is considered appropriate. This reflects the steady-state ratio once the whole vehicle fleet has been equipped with the system, meaning the full annual casualty savings are achieved, and where the annual fitting costs apply only to new vehicle registrations. It is acknowledged that this will tend to produce higher benefit-cost ratios, for a given evaluation period, than a more refined method that considers the phased implementation over that period (and of the kind that would be used for a formal Impact Assessment). This is to some extent compensated for, however, by using the current system costs, or estimates of what the initial system costs would be, and not factoring in any reductions in those costs over time. There is also no allowance in the analysis for improvements in system effectiveness over time (from advances in technology).

Two calculations are performed; the first uses available data on likely system costs to generate a likely benefit-cost ratio; the second calculates a target break-even cost, indicating the maximum cost of the system that would provide a benefit-cost ratio of more than one.

In addition, the concept of a “break-even effectiveness” is explored, which involves calculating the overall effectiveness that would be needed, for a given target population and per vehicle system cost, for the overall casualty savings and fitment costs to balance.

For the benefit-cost ratios to be meaningful, it is desirable for the costs and benefits to be calculated from the same perspective. Casualty costs published by the Department for Transport, and used in this study to calculate the system benefits, are aimed at representing societal benefits, i.e. the overall value to society of avoiding that casualty. Ideally, then, for a proper comparison at the appropriate level, the system costs should also be societal costs. These costs will not necessarily be the same as the full fitment costs available to end consumers, particularly where systems are offered as optional extras. The profit margins could be considered a societal benefit, because they help to create wealth and jobs and fund investment. It is considered that a better system cost basis is the actual cost to the vehicle manufacturer, as this should better reflect genuine societal costs such as resource use, and is also a better indicator of the ultimate cost to the consumer once systems are mass produced and fitted as standard to all vehicles, and thus subject to full market competitiveness pressures between competing manufacturers.

Transport Statistics Great Britain (Department for Transport, 2010b) reports new car and light goods vehicle registrations of about 2 million in 2009, having been nearer 2.6 to 2.8 million before the current economic downturn. Of these, it is likely (based on overall vehicle fleet data) that about 10% are light goods vehicles. For the cost-benefit calculations in this report, a figure of 2.2 million new car registrations per year is assumed.

The casualty costs used are taken from the latest official DfT figures (Department for Transport, 2010a), which are:

Fatal:	£1,585,510
Serious:	£178,160
Slight:	£13,740

3 Results

3.1 Knowledge of real-world driver reactions to in-vehicle warnings

All of the technologies assessed for this study have the capability to provide some form of warning to the driver, of an imminent collision, lane departure or seat-belt misuse, for example. Their overall effectiveness thus, to a greater or lesser extent, depends on the effectiveness of these warnings. The following sections describe the results of a generic literature review on the subject of driver reactions to in-vehicle warnings. This analysis was used to inform the technology-specific assessments and guide the extent to which the systems' warning capabilities were considered in the overall effectiveness.

3.1.1 What are collision warning systems?

Driver inattention (lack of concentration) has been identified as being one of the leading causes of car accidents (e.g. Gibson & Crooks, 1938; Treat *et al.*, 1997; Wang *et al.,* 1996). Vehicles are becoming more technologically advanced[5] and drivers are provided with an increasing number of potential distractions. In an attempt to mitigate against these distractions, safety warning systems are being developed to try and promote safe driving (Lee, 2004).

The HMI (Human-Machine Interface) aspects of information and warning functions for active safety systems are not standardised and there are many different interfaces used on production vehicles. Most relevant to information messages is the European Statement of Principles (ESoP) on Human-Machine Interfaces which was developed within an expert group partly supported by the EC. This guidance has been encapsulated within the Commission Recommendation of 26/V/2008 on safe and efficient in-vehicle information and communication systems (EC, 2008).

Guidelines on establishing requirements for high-priority warning signals are being developed by the UNECE/WP29/ITS Informal Group and there has also been work in standardisation groups to identify how to prioritise warnings when multiple messages need to be presented and one "Technical specification" has been produced:

ISO/TS 16951: Road Vehicles – Ergonomic aspects of transport information and control systems – Procedures for determining priority of on-board messages presented to drivers. Note: A TS is not a full standard but may be developed or withdrawn following further work.

In addition two Technical Reports are relevant that contain a mixture of general guidance information, where supported by technical consensus, and discussion of areas for further research:

ISO/PDTR 16352: Road Vehicles – Ergonomic aspects of transport information and control systems – MMI of warning systems in vehicles, and;

ISO/PDTR 12204: Road Vehicles – Ergonomic aspects of transport information and control systems –Introduction to integrating safety critical and time critical warning signals.

3.1.2 Types of warning

Several different types of warning device were identified when searching the literature, summarised below.

Auditory

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[5] For example, BMW has developed in-vehicle computer systems used to control many of the secondary vehicle systems. This user interface consists of a LCD panel mounted in the dashboard and a controller knob mounted on the centre console. Reviews of the iDrive include comments on its steep learning curve and its tendency to cause the driver to look away from the road (James & Cobb, 2004; Van Kuijk, 2007).

The audio alarm is one of the most common alarms and is used in a wide range of applications (Jenkins, Stanton, Walker & Young, 2007). The main benefits of an audio alarm are that the user is not required to focus on a specific display. The selection of the type of audio alarm is very important; it needs to be of the right pitch, tone and volume to be heard above the other noises in the car, without being so loud that it startles or panics the driver. The driver also needs to be able to relate the sound to the problem causing the alarm. Pohl & Ekmark (2003) identified that false auditory alarms can be considered by the driver as patronising and consequently annoying, so thought should be given to the way in which they are presented.

Vibrotactile

A fairly unexplored way of communicating these warning signals to the driver is the use of vibrotactile information. Vibrotactile warnings may be channelled through one of several different parts of the vehicle, for example, the foot pedal (*Rosario et al*., 2010), the seat (Rosengren & Wennerholm, 2008), or the steering wheel. Haptic braking is another way of simulating the vibration feedback of rumble strips. The system rapidly applies and releases the brakes creating a juddering vibration in the car similar to that of running over the bumpy surface of the rumble strips.

Visual displays

The introduction of computer screens into the driving environment has become far more common in recent years. As discussed earlier, most car radios now contain a computerised graphic display showing progressively more information. An increasingly popular way of monitoring a screen while conducting another visual task is in the use of head up displays. The advantages of head up displays are primarily based around the fact that the driver does not have to keep changing their focal range – this is done by moving the important information a driver needs to see up into their line of sight, so they don't have to take their eyes off the road as the image appears to float in mid air, just past the front end of the vehicle.

Multi-modal feedback provides feedback to two or more of the feedback mechanisms (audio, tactile, visual). Clarke (2003), reports that when compared against single mode feedback a well matched combination of feedback modes is optimum. Audio-tactile signals are an example of multi-modal feedback. Evidence from the most recent empirical research has suggested that the presentation of auditory or vibrotactile warning signals can improve a driver’s responses to potential front-to-rear-end collisions (e.g. Ho, Reed & Spence, 2006; Ho & Spence, 2005; Lee, McGhehee, Brown & Marshall, 2006). The use of non-visual warning has been shown to have important safety implications in terms of its potential for reducing the number of front-to-rear-end collisions.

3.1.3 Reaction times

A review of the literature suggests that limited work has been conducted to explore how quickly people react /reaction times and types. Ho, Reed and Spence (2007) used a simulator to assess the relative utility of auditory, vibrotactile and combined audiotactile in car warning systems. The effectiveness of the signals was assessed in the both the presence and absence of background radio and lead car brake light signals. The following dependent variables were measured:

- Response time (defined as the time after the onset of a critical event at which the participants initiated a braking response by depressing the brake pedal)
- The shortest distance headway, and
- The percentage of collisions

In terms of reaction times, Figure 5 (reproduced from Ho, Reed & Spence, 2007) shows that participants responded significantly more quickly to the audiotactile warning signal than the auditory or vibrotactile warning system.

Again, limited evidence could be found which related to age, alcohol and tiredness and the interaction with warning systems. The only source of information identified was that the introduction of a multi-sensory in-car interface holds great promise in terms of effectiveness for the aging driver population (Laurienti, Maldjian & Wallace, 2006).

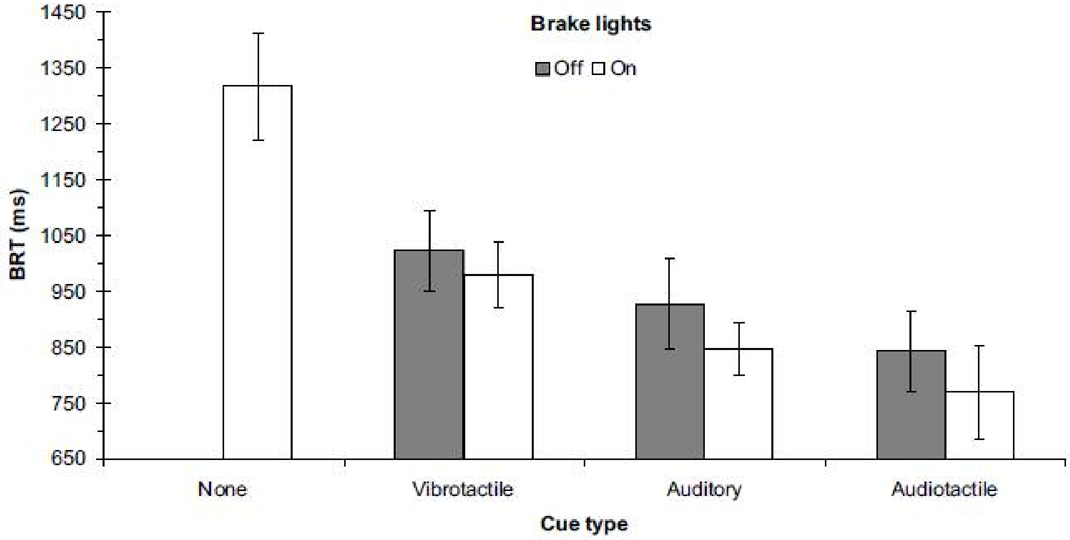

Figure 5. Mean braking time response times in milliseconds as a function of cue type and brake lights condition[6]

3.2 Passenger car AEBS

In 2007, TRL undertook a study of AEBS on behalf of the EC (Grover et al, 2008). As part of this work, analysis was undertaken to establish both target population and effectiveness when fitted to cars with the aim of producing results that would conform with a high burden of proof (although the concept had not been formalised at that time). The target population was well defined within Stats19 data, although there was no attempt to separate systems that reacted to stationary objects and those that did not. A study of effectiveness was undertaken based on data from the UK On-The-Spot (OTS) study. However, this study proved inconclusive because the sample size was too small. The main problem was that information on the travel and impact speed is required for both vehicles involved. In accidents involving passenger cars, information on speed is typically derived either from witness evidence or from the reconstruction of skid marks. The main benefit of AEBS is in accidents where the driver does not brake and of course the lead vehicle may not brake at all. Thus in many cases speed information was only available where no significant benefit of AEBS would be expected because the driver had already braked to maximum. In cases where the driver did not brake, there was rarely sufficient information on speed. This combined with filtering out the accidents where the system would not work (e.g. heavy rain/fog etc) and the relatively low severity of the accident type meant that almost no serious cases were available for analysis.

In the study by Grover et al (2008) the effectiveness for trucks was evaluated using similar methods but based on data from the HVCIS fatal accident database, which was much more successful. The reasons for this success were that:

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[6] The error bars indicate the standard errors of the means. Brake lights on/off refer to those of the vehicle in front. Response times are slightly longer if the brake lights are off, regardless of cue type.

- All were fatal accidents which were investigated in detail by the police and thus, there was often considerably more witness evidence available than in the typically lower severity OTS accidents;
- Trucks are equipped with tachographs, providing much more reliable speed information independently of skid marks for at least one of the vehicles involved.

The study of effectiveness for cars, therefore, became a target population study that was refined by assuming that the effectiveness was comparable to that derived for heavy vehicles. Thus, it did not achieve its intended burden of proof level and could be considered low to medium. What was clear from the target population analysis alone was that front to rear shunt accidents involving passenger cars as the vehicle suffering the frontal impact was a very frequent accident type, but not a very severe one with relatively few fatalities.

No major new studies of the effectiveness of AEBS have been identified for this current study, through the Technology Watch project, and a literature review has not identified any material sufficient to estimate the likely effectiveness for this system with a medium to very high confidence level. A new analysis was thus undertaken specifically for this project.

The generic methodology (see Figure 4) suggests that a retrospective study would offer the highest potential burden of proof, but requires sufficient market penetration to achieve a robust sample size. Since the time of the previous study, more manufacturers are fitting AEBS. Thatcham are in the process of compiling data about the level of fitment of various new technologies. The results are not yet publicly available, but in discussions as part of this study they estimated that there may be very approximately around 11 models currently available with AEBS. It is considered likely that many, if not all, of these will have it available as an option rather than standard fit. It was therefore considered unlikely that there will be sufficient numbers of equipped vehicles in existence to provide a statistically robust sample for a retrospective study.

This left a predictive study as the main method remaining that was feasible in the time frame permitted for this work. Since TRL’s previous AEBS study, the sample available in OTS has grown, however there is still insufficient data on serious accidents of the relevant types to provide reliable analysis. CCIS data has therefore been used in conjunction with the OTS data in order to understand the effect of AEBS on serious and slight casualties.

In order to address the issue of so few fatalities in the OTS and CCIS databases for this analysis, an additional sample was created based on police fatal files. While the police fatal files do not overcome the fundamental limitation about the speeds being less available in the relevant accidents where drivers do not brake, the increased sample size and increased quantity of witness evidence allowed a sufficiently robust sample to be generated. The actual burden of proof would be expected to be medium or better but will depend on how much supporting evidence is available from the literature. Given the inherent uncertainties and variations in how individual drivers react to warnings, it was concluded that the information contained within OTS, CCIS and the police fatal files is insufficient for an objective, case-by-case, robust estimate to be made of whether the driver involved would have reacted to a warning, nor can it indicate how effective that reaction would have been at altering the outcome of the accident or preventing it altogether. The in-depth analysis was thus restricted to only considering the speed reduction capabilities provided by the autonomous braking system, and so assuming that the driver involved would not have reacted to any warnings provided before the brakes were applied on his/her behalf.

To estimate the overall (rather than case-by-case) effectiveness of the forward collision warning function of the AEBS, the results of some field operation trials were used (Nodine et al, 2011). These trials relate to a relatively small scale, US trial (108 drivers monitored for 6 weeks of driving, 2 weeks without the safety systems activated and the last 4 weeks with it in operation). The results, though, relate to real world effectiveness of an actual FCW system, and are thus sufficient to provide at least a medium burden of proof for the purposes of the EASS study.

3.2.1 STATS19 analysis (target population estimates)

STATS19 data from 2007 to 2009 were analysed, and accidents were selected which involved two vehicles and no pedestrians and where the front of a car hit the rear of another vehicle (excluding TWMV and pedal cycles). This was split by the severity of all the occupants involved in the accident and an average number of each casualty in this type of accident per year was calculated, as shown in Table 2.

In order to match the samples analysed as closely to the national sample as possible, those accidents where the systems would not have been effective were also identified as well as possible in STATS19. This involved eliminating accidents without good weather (Table 3).Table 3The STATS19 target populations for reported casualties for passenger car AEBS are thus:

Fatalities: 32 Serious: 620 Slight: 24,558

Adjusting for under-reporting, by applying factors of 2.7 (lower) and 3.3 (upper) to the non-fatal casualties gives the following overall (all casualties) annual target population estimates:

Fatalities: 32 Serious: 1,674 – 2,046 Slight: 66,307 – 81,041

Table 2. Averaged reported casualties involved in front to rear collisions per year, split by vehicle impacted.

Vehicle 1	Vehicle 2	V1 impact side	V2 impact side	Fatal	Serious	Slight	Total
Car/taxi	Car/taxi	Front	Rear	18	606	29053	29677
Car/taxi	LCV	Front	Rear	3	43	1008	1053
Car/taxi	HGV	Front	Rear	15	70	544	629
Car/taxi	LPV	Front	Rear	1	10	263	274
Car/taxi	Other	Front	Rear	1	13	205	219
Car/taxi	Minibus	Front	Rear	0	5	154	159
Car/taxi	Agric	Front	Rear	2	9	51	62
TOTAL				*39*	*755*	*31279*	*32072*

Table 3. Averaged reported casualties per year by weather conditions

Conditions	Fatal	Serious	Slight	Total
Good weather	32	620	24558	25210
Bad weather	7	135	6721	6862
Total	*39*	*755*	*31279*	*32072*

3.2.2 Specification of a generic system

In practice, different vehicle manufacturers and component/system suppliers will have different specifications for their AEB systems, so no two systems are likely to be identical in their precise configuration, nor, for this reason, in their overall effectiveness. For the purposes of this predictive study, though, it was necessary to simplify the potential operational variations and pretend that a single, generic system was fitted to all the cars involved in the accidents studied.

Grover et al (2008) described recent TRL work for the European Commission on the costs and benefits of passenger car AEBS. This work included a thorough review of systems then on the market or under development and close to market. This analysis has been used for this current study to define a generic AEBS system for passenger cars.

The main characteristics of current systems, used to define a generic system, can be summarised as:

- Sensor range ahead of vehicle up to 200m for long range sensors and circa 30m for short range;
- Horizontal field of view 9-16° (long range) and c. 80° (short range);
- Sensor scanning rate of 10-25 Hz;
- Aimed at detecting front to rear shunt collisions on straight roads and gentle, high radius curves;
- Able to recognise all moving vehicles except pedal cycles and small motorcycles, travelling centrally in the same lane as the vehicle to which the system is fitted;
- Operative at all speeds above about 10 km/h (absolute and relative), but only able to recognise similarly positioned stationary vehicles at closing speeds of less than or equal to 40 mile/h;
- Collision prediction algorithm updated at approximately 50 Hz;
- Warning given to driver when likely impact detected, but without autonomous braking at that stage (2.6s before impact);
- If driver does not apply the brakes, or is not applying the brakes as hard as the system feels is necessary (and has not taken avoiding steering action), 0.3g braking is applied autonomously at 1.6s before impact;
- Braking applied up to maximum achievable when impact imminent and unavoidable by steering action (0.6 seconds before impact);
- The system is capable of avoiding a collision altogether, through application of the brakes alone, if the relative speed at initial brake application (1.6s before impact) is less than about 25 mile/h (40 km/h);
- The systems are unlikely to be effective when:
    - There is rain, snow or fog, due to the scattering of light and radar signals by water droplets.
    - There is a sudden encounter such as a vehicle cutting immediately in front, such that the detection algorithm does not have sufficient time to track the vehicle ahead;
    - The vehicle is accelerating;
    - On curves or where the vehicle is drifting out of its lane towards an oblique angled impact with a vehicle in the adjacent lane.

3.2.3 Fatal files analysis

A batch of 100 fatal files was selected from the TRL fatal file archive which involved the front of a car impacting the rear of another vehicle. These 100 files, involving 105 fatalities, were then analysed to assess the benefit of fitting AEBS to the car.

As suggested from the literature reviews, these systems may not work in fog/rain/snow, so in these situations it was assumed that the fitment of the system would not have had an effect on the severity of the accident (leaving 90 cases, 94 fatalities – which are within the STATS19 target population). It was also assumed that the system would not have had an effect if it was recorded that the driver had applied heavy braking at least 1 second before the impact occurred, because the driver would then already be doing what the system could do (the breakdown of these files can be seen in Figure 6). After applying these criteria, there were a further 39 cases where the system would not have been effective due to the accident type and other complicating factors as follows:

- 18 drifted or swerved out of their lane. These systems may not work in this situation due to the low approach angle or lack of time to detect an imminent collision and take appropriate mitigating action. The system would not be able to differentiate between a vehicle changing lane into a lane next to a vehicle and drifting into that vehicle.
- 10 were weaving in and out of lanes or otherwise driving recklessly, which would have the same effect as above.
- 11 had other complicating factors such as:
  - Death possibly due to natural causes;
  - Collision on a bend or slippery road surface;
  - Shunted vehicle not fully in carriageway (highly offset rear collision);
  - Following too closely to the vehicle in front for the system to be able to react in time.

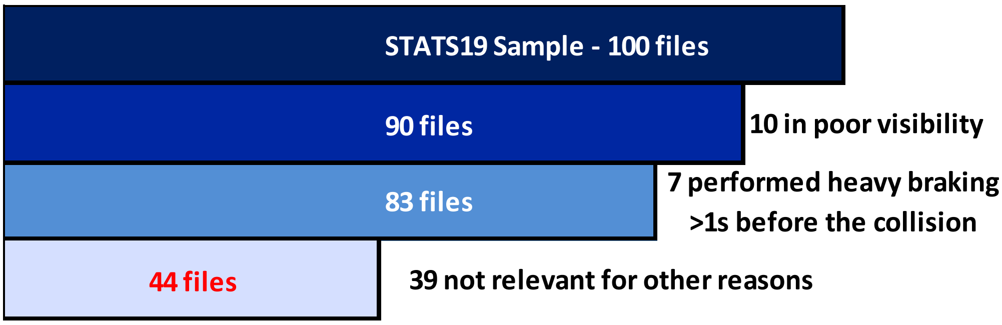

Figure 6: Selection process for accidents that may be affected by the installation of AEBS

This left 44 files for further analysis, involving 48 fatalities, where the driving speed and impact speed of the vehicles were assessed, and the impact speed was then re-calculated to emulate what would occur if AEBS was fitted. The specifications assumed for this system were that the car would begin braking 1.6 seconds before it expects a collision, with 0.3g braking force, and then 0.6 seconds before impact with 0.6g braking force. Calculations show that this is a broadly overall equivalent effect of braking for 1.6 seconds with 0.4g braking force. The 0.6g "full braking" figure was chosen as being representative of the average available friction coefficient, as measured by police accident investigators at the accident scenes and reported in the fatal accident files.

This method was chosen as the stakeholder consultation found that it is undesirable for the system to apply full braking too early, as false positives may cause the driver to disable the system if the braking is too harsh. Once this new impact speed was calculated, an assessment was made as to whether or not the severity of the fatalities involved would have been reduced and, if so, by what extent; taking into account other factors that might affect the severity such as age, belt use and the extent of the (fatal) injuries sustained.

Two AEBS systems were considered, as current AEBS systems can detect all moving vehicles but stationary targets only at low approach speeds (40 mile/h or less). Therefore the first system (AEBS1) was taken to be a current system with this limitation, and a second, (hypothetical future) system (AEBS2) was also considered where all stationary targets could be identified, even at high approach speeds.

For the AEBS1 system, 11 fatalities were reduced to no injury, either by the impact no longer occurring or the impact speed being reduced to a very low level, 10 were reduced to a serious injury and 7 were reduced to a slight (leaving 20 still as fatalities). The AEBS2 system was judged likely to convert 11 fatalities into no injury, reduce 17 to serious and 7 to a slight casualty, with the remaining 13 cases left unaffected.

Relating these savings back to the original Target Population (94 fatalities) gives effectiveness estimates for the autonomous braking systems as follows:

AEBS1: 12% no injury, 11% reduced to serious and 7% reduced to slight (70% remain as fatalities);

AEBS2: 12% no injury, 18% reduced to serious and 7% reduced to slight (63% remain as fatalities).

The final step in the analysis was to estimate the effectiveness of the warning function of AEBS. The US trials (Nodine et al, 2011) provide a central estimate that FCW systems would prevent 16% of all rear end collisions, with the 95% confidence limits being 2-30%. Based on STATS19 data, this is equivalent to an effectiveness range of 3-38% in good weather conditions (assuming 0% effectiveness in bad weather), and this range is thus applicable to the target population casualty numbers. The calculated overall casualty savings from AEBS start by assuming that between 3 and 38% of the Target Population casualties would be prevented altogether through appropriate driver response to the warning. The additional savings provided by the autonomous braking, relevant in the remaining cases, were calculated assuming the same proportions of severity reduction/prevention as found from the in-depth fatal file analysis. There were assumed to be no differences between the effectiveness of the warning function between AEBS1 and AEBS2 (i.e. no additional warning capabilities were assumed for the hypothetical AEBS2 over and above those provided by current systems, and as assessed by Nodine et al, 2011).

These were then weighted to the national level of 32 fatalities per year, the results of which are shown in Table 4 where the AEBS1 system reduced the number of fatalities by 10-18 (to 14-22), and the AEBS2 system reduced them by 12-19 (to 13-20).

Table 4. New distribution of fatalities/casualties with AEBS1 and AEBS2

	Assumed FCW Effectiveness	Fatal	Reduced to Serious	Reduced to Slight	Casualties avoided - Uninjured
Original		32	0	0	0
AEBS1	3%	22	3	2	5
AEBS2	3%	20	5	2	5
AEBS1	38%	14	2	1	15
AEBS2	38%	13	4	1	14

In casualty cost reduction terms, the savings (from the fatal accidents only) range from £15m-£28m for AEBS1 and from £18m-£29m for AEBS2.

3.2.4 OTS/CCIS analysis

In order to assess the benefit to serious and slight casualties in passenger car AEBS relevant accidents, the OTS and CCIS databases were used.

Firstly the OTS database was analysed to identify all accidents that involved the front of a car striking the rear of another vehicle, where the driving speed and impact speed were known. This resulted in too few seriously injured casualties to provide a sample size on which valuable analysis could be performed.

As the CCIS database contains a larger number of car accidents, this database was the next step. However, CCIS does not contain the driving speed or impact speed of the vehicles, but does contain ETS (Equivalent Test Speed). In order to estimate the driving speed and impact speed of the collision, an estimate was made using the OTS sample to relate them to ETS. This relationship was then applied to the ETS for each relevant case in CCIS to generate an estimated driving speed and impact speed.

The 390 seriously and slightly injured casualties in relevant accidents in CCIS were split into 5 km/h impact speed groups, then weighted up to STATS19 by severity. The percentage of serious and slight casualties in each of the impact speed groups was then calculated.

For the AEBS system, the system equivalence of a 1.6 second time to collision for initial brake activation was assumed, at which point a deceleration rate of 0.4g was applied until the collision, equivalent to the modelling used for the fatal data. A new impact speed was calculated from the driving speed for all the serious and slightly injured occupants in CCIS. These were then split into the same speed groups using this new impact speed, and the percentages were applied to the new totals. As with the fatal file analysis, two systems were assessed, one that only works if the impacted vehicle is not stationary, or it is stationary but the closing speed was less than 40 mile/h (AEBS1) and the other works irrespective of whether the impacted vehicle is moving (AEBS2).

As CCIS does not specify whether a vehicle was stationary, the OTS sample of relevant accidents was used to find the percentage of accidents where the AEBS1 system would not work. This found 6% of accidents to have involved a stationary vehicle where the closing speed was greater than 40mph. This was combined with data from STATS19 to provide information on the weather/visibility at the time of the accident. This found 21% of accidents to have occurred where visibility was reduced (i.e. for the casualties where the conditions were known, the weather was not fine). Occupants that were not belted were assumed to have no benefit from the fitment of the systems, unless the accident was avoided.

It was not possible from the OTS/CCIS data to identify cases where the systems would not have been effective because, for example, the car was weaving in and out or drifting out of its lane. or the impact was on a bend. To make some allowance for these cases, the appropriate proportion has been taken from the fatal file analysis and applied to the serious and slights – in the fatal file study, 44 cases out of the 90 in the original target population (48.9%) were amenable to AEBS fitment, so this proportion is applied to the serious and slight sample.

Overall, this process found the following effectiveness figures for the autonomous braking systems:

AEBS1: 2.6% of serious injuries prevented and 2.4% of slight injuries;

AEBS2: 2.7% of serious injuries prevented and 2.5% of slight injuries.

The final step is to allow for the likely effectiveness of the warning function, in an identical way to that adopted for the fatal file analysis (i.e. using a range of 3-38% of the target population casualties).

The net result of the analysis is shown in Table 5. Overall, the both AEB systems modelled produce casualty savings of about 90-800 serious injuries and roughly 3,500-32,000 slight injuries.

Table 5. Reductions in serious and slight casualties with the AEBS1 and AEBS2 systems

	Assumed FCW Effectiveness	Serious	Slight
Original Target Population (casualties potentially preventable)		1,674-2,046	66,307-81,041
		Casualties Prevented	
AEBS1	3%	92-113	3,533-4,318
AEBS2	3%	94-115	3,597-4,396
AEBS1	38%	663-810	26,184-32,002
AEBS2	38%	664-811	26,225-32,052

In casualty cost reduction terms, the savings (from the serious and slight accidents only) range from £65m-£584m for AEBS1 and from £66m-£585m for AEBS2.

3.2.4.1 Assumptions/Limitations using this method

Theoretical impact and travel speeds have been calculated from ETS, which will not be the actual speeds of the accident. The effect of this approach is that every case in CCIS has a lower impact speed than travel speed, an average reduction in speed is used. However it is thought that this is the best estimate that can be obtained using the data available.

If any impact occurred the result would be a slight accident, only when the impact was avoided are the occupants counted as uninjured.

3.2.5 Overall effectiveness estimate

The results from the fatal file analysis were combined with the results from the analysis of serious and slight accidents, producing overall reductions as shown in Table 6. Using the costs of casualties as defined in Reported Road Casualties Great Britain (Department for Transport, 2010a), the addition of AEBS that can detect stationary vehicles regardless of closing speed (AEBS2) was found to reduce the overall cost of the accidents by £84-614million. In casualty cost reduction terms, both systems would have an overall effectiveness of about 6-40% (i.e. 6-40% of the target population casualty costs are likely to be avoided).

Table 6. Overall effectiveness estimates

	Fatalities	Serious	Slight	Cost (£m)	Saving (£m)
original	32	1,674-2,046	66,307-81,041	£1,260-1,529m	0
		Casualties Prevented			
AEBS1	10-18	90-807	3,532-32,000		£80-612m
AEBS2	12-19	90-806	3,597-32,050		£84-614m

3.2.6 System cost analysis

A wide range of costs for AEBS was found from data on the Techwatch website (Techwatch 2011); costs for passenger car AEBS ranged from €250 per vehicle to €1000 per vehicle (£200-£850). It is likely that these are full market costs to consumers as optional extras and are thus subject to quite high mark-ups. It is also reasonable to assume that if such systems (which are currently only available on quite a small number of vehicles) were ever mandatory fitment items to all new vehicles, the production costs would tend to be somewhat lower than the current situation, through economies of scale and product innovation. For the purposes of this study, therefore, a future likely actual cost (to manufacturers) range of £100-£500 per vehicle is used in the cost-benefit analysis.

This applies to AEBS1, which is the generic system most closely matched to current technologies. For AEBS2, with additional functionality to be able to mitigate accidents involving stationary target vehicles at high closing speeds, it is reasonable to assume some additional system costs. AEBS1 systems are already assumed to be able to mitigate accidents with stationary vehicles at closing speeds up to 40 mile/h, so to develop those systems for impacts at, say, up to 70 mile/h, should not be hugely complicated. A total system cost range for AEBS2 is thus assumed to be £125-£550.

3.2.7 Cost benefit analysis

Applying the per vehicle system costs (£100/125-£500/550) to the 2.2million assumed new car registrations per year in Great Britain produces an annual implementation cost of £220-1,100million for AEBS1 and £275-1,210million for AEBS2. Combining these data with the casualty savings estimates generates ranges of benefit-cost ratios, as shown in Table 7. The lower ratios shown are based on the upper cost estimates and lower casualty savings estimates, while the upper ratios are based on lowest assumed implementation costs and highest savings estimates.

Table 7. Estimated benefit-cost ratios for passenger car AEBS

	Per vehicle costs	Total annual costs	Total annual savings	Benefit:cost ratio
AEBS1	£100-£500	£220-1,100m	£80-612m	0.07-2.78
AEBS2	£125-£550	£275-1,210m	£84-614m	0.07-2.23

With the high assumed system costs and low casualty savings assumptions, the ratios are well below unity, implying that the systems are unlikely to be cost effective, but the systems would be cost effective if the costs are at the lower end of the likely range and the casualty savings are at the upper end of their likely range. The break-even costs for the modelled, generic AEBS1 and AEBS2 (the per vehicle costs at which the overall costs and savings would be equal) can be calculated from the data shown in Table 7 to be £36-£278 and £38-£279 respectively, if effectiveness remained unchanged.

The break-even effectiveness (the proportion of overall target population casualty costs that would need to be prevented to equalise the costs and savings) can be calculated to be 14-17% for AEBS1, at the lowest assumed system cost of £100, rising to 72-87% at the high cost of £500 per vehicle. The corresponding figures for AEBS2 are 18-22% at £125 and 79-96% at £550 per vehicle. The calculated effectiveness of both the modelled generic systems, based on the analyses described earlier, is around 6-40%. It should be noted, however, that these figures retain the assumption that systems would not be able to avoid or mitigate accidents occurring in poor weather conditions – if the effectiveness improved to allow some capability in these conditions, the overall target population costs would increase, and the break even effectiveness would not be as high as the above calculations suggest.

3.3 Pedestrian AEBS

Very few existing studies of the likely effectiveness of a pedestrian AEB system have been identified and since only one system is as yet available on the market, very little is known about the likely technical specifications.

A predictive study was therefore completed, employing a similar methodology to that for passenger car AEBS. This involved a combination of OTS and fatal file studies. An important difference, though, is that no attempt has been made to estimate the effectiveness of any pre-collision warning functionality of pedestrian AEBS. This is firstly because no evidence was found in the published literature that would allow an estimate to be made. Secondly, it is unlikely that a warning system could be as effective in pedestrian impacts as with car rear end collisions, largely because by their nature the pre-impact movements of the pedestrians are much more difficult to predict and they are likely to be on the pavement for much of that time, rather than in the roadway. While this means the casualty saving estimates made for pedestrian AEBS are based solely on the autonomous braking capabilities of the systems, and thus may under-estimate the full benefits, it is likely that any additional savings from the warning system would be relatively small and thus have a similarly small effect on the calculated benefit-cost ratios.

3.3.1 STATS19 analysis (target population estimates)

STATS19 data from 2007 to 2009 were analysed, and accidents were selected which involved one car striking a pedestrian, and where the front of that car hit the pedestrian. These were further split by the severity of all the occupants involved in the accident, by the weather conditions at the time, to eliminate any occurring in rain, snow or fog, and by lighting conditions, to eliminate any on an unlit road at night. Table 8 shows the resulting data, in the form of annual averages.

Table 8. Averaged annual reported casualties from car front to pedestrian accidents, by weather and visibility conditions.

Conditions	Fatal	Serious	Slight	Total
Good weather/visibility	174	2150	7638	9962
Bad weather/visibility	88	592	1905	2585
Total	*262*	*2742*	*9543*	*12547*

The STATS19 target populations for reported casualties for pedestrian AEBS are thus:

Fatalities: 174 Serious: 2,150 Slight: 7,638

Adjusting for under-reporting, by applying factors of 2.7 (lower) and 3.3 (upper) to the non-fatal casualties gives these (all casualties) annual target population estimates:

Fatalities: 174 Serious: 5,805 – 7,095 Slight: 20,623 – 25,205

3.3.2 Specification of a generic system

A generic system, based on the following specifications, has been used to evaluate the effectiveness in this report. It should be emphasised that the generic system is not intended to be an exact replica of the Volvo system currently available as an optional extra, but instead to be representative of the broader range of systems potentially under development and/or to be introduced to the market over the coming few years:

- There are a number of conditions, at least for likely first generation technologies, where the systems would be unlikely to be fully effective:
    - Poor visibility – systems would potentially only operate in good light conditions so consideration was only given to accidents that occurred in daylight or suitable artificial lighting conditions.
    - Adverse weather (fog, snow or rain). Rain, snow and fog may compromise the ability of the system to recognise pedestrians, due to the scattering of light and radar signals by water droplets. Only accidents in dry, clear conditions, or known to be with only very light rain, are considered suitable for the system to work.
    - Cluttered carriageway. It is proposed that the system will need a finite time to decipher the path of the pedestrian and simplistic early models may get confused in a cluttered environment, i.e. one that contains lots of moving and/or stationary objects in the roadway, all of which need to be independently monitored by the system. Therefore only accidents occurring in an un-cluttered environment are considered.
    - Curvature of the road. Again, early systems would need a finite time to decipher a threat and configure a likely path, so it is assumed that the added complexities of a curved vehicle path exceed their capabilities.
- Unless commented upon in the Accident Investigator’s (AI) report, a reaction time for a human was assumed to be between 0.75 seconds and 2.0 seconds.
- There is an infinite range of possible options for pedestrian AEBS with regard to how far before a likely impact the system is set to activate the brakes, and how hard it applies the brakes. In general the earlier a system applies the brakes, and the harder it does so, the higher chance there is for the accident to be avoided altogether, or for the impact speed to be substantially reduced, However, the earlier the system is set to intervene, the higher also is the potential for “false alarms”, i.e. activation of the brakes when an impact was not actually going to occur, e.g. because the pedestrian had seen the car approaching and was about to take appropriate avoiding action. System designers could, therefore, decide to only mitigate unavoidable impacts by leaving the brake application to the last possible moment, or could aim to prevent more collisions, but accept a certain number of false alarms, by earlier brake activation. To cover the full likely range of options, three separate systems have been modelled for this study:
    - System 1 would act at a maximum 2 seconds prior to impact. This would give the maximum opportunity for impact speed reduction or collision avoidance, but have the highest propensity for false alarms.
    - System 2 would act at a maximum of 1 second prior to impact. This would be less susceptible to false alarms but would, in consequence, provide less impact speed reduction and a reduced likelihood of collision avoidance.
    - System 3 is seen as a mitigation-only system and would only act at 0.6 seconds prior to impact. This would slow the impact speed a little but would not give sufficient time for avoidance manoeuvres, though it would be the least prone to false alarms.
- All of the brake times consider the time to collision (TTC) at the point of brake activation. TTC is the time to impact if the vehicle travels at a constant speed. All the above systems also are modelled on the assumption that the brakes are applied instantaneously up to the maximum adhesion level available from the road surface (usually as reported by the AI).
- The generic system is assumed to be operational at all car speeds. System designers may wish to limit the potential for “false alarm” heavy braking from

high speed by only activating the brakes at relatively low vehicle speeds. The Volvo system, for example, is aimed at urban accidents and is believed to only apply the brakes at speeds below about 30-35 km/h.

- The above systems are all modelled such that the impact point between the car and the pedestrian is fixed, i.e. the analysis does not allow for changes in the impact geometries resulting from the pedestrian having more time to move out of the way, or at least continue walking/running, because the system has acted to slow the vehicle (meaning it takes longer to get to the impact point). In practice, however, this relative motion might be important, particularly if the pedestrian is crossing perpendicular to the path of the vehicle and for systems activating the brakes at higher TTCs.
- The braking stage has been assumed as either 'off' or fully 'on', i.e. there is no allowance for 'ramping up' of the brake pressures. In practice, modern vehicle braking systems allow for very rapid brake pressure rises (less than 0.2 seconds), so this assumption is reasonable, as well as making the modelling calculations very much simpler.

3.3.3 Fatal files analysis

58 fatal files representative of single vehicle, car to pedestrian accidents in STATS19 were taken from the database, having been coded for a previous project, which included a short description of each incident. This allowed rapid identification of those cases likely to be within the target population for pedestrian AEBS. Figure 7 shows the steps taken to identify the relevant cases. 5 cases were found not to involve a frontal impact, 11 were on dark, unlit roads and a further 5 were in poor weather (rain, fog or snow), leaving 37 cases as being potentially relevant to pedestrian AEBS fitment and falling within the target population. A further 19 cases were eliminated because of a cluttered carriageway environment, being on a bend, or because of some other deliberate or malicious act that would render an AEBS non effective, leaving 18 cases as still potentially relevant.

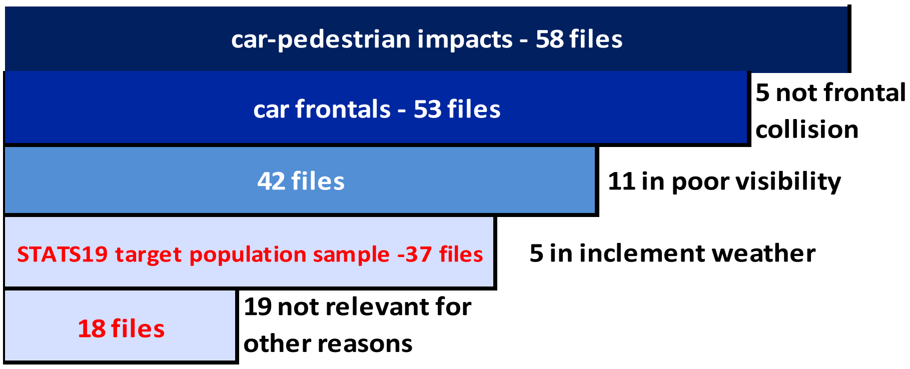

Figure 7: Files not included in the analysis of the Pedestrian AEBS system.

18 files were thus identified for more detailed reconstruction, to fully evaluate if, and to what extent, the generic pedestrian AEB system defined for this study could mitigate the fatal injuries sustained by each pedestrian.

In a few cases it was possible to gain the information required from the Police Accident Investigator's report but in general the details required to make a judgement on a successful activation of pedestrian AEBS were as follows:

1. Scene plan: - to establish the curvature of the road and/or how cluttered the environment was at the time of the accident.
2. Details on any evasive manoeuvres taken by the driver, braking / steering etc - it is important to know if the driver braked prior to impact and for how long.

3. The level of grip at the scene: normally stated in the AI report, the coefficient of friction is important for use in the calculations.
4. Initial speed prior to any avoidance manoeuvres: in order to establish a distance in which the system would react.
5. Impact speed: this may be the same as an initial speed if no braking has taken place, this is used to assess the likelihood of fatality.

During reconstruction of the 18 accidents it was found that a further 7 accidents were inconclusive from the data given in the file, such that a full reconstruction was not possible due, for example, to uncertainties over speeds or trajectories. These 7 cases have therefore been split proportionally according to the results obtained from the remaining 11 cases analysed.

In assessing the potential effectiveness, no allowance was made for drivers making evasive manoeuvres, either as a result of some form of system warning or through the sudden autonomous application of braking alerting the driver to the impending hazard. It is only the speed reduction that was used to judge the system effectiveness.

Where the accident was not avoided completely, the speed may have been reduced and therefore the injuries may have been mitigated. Injury severity at impact speed has been calculated using data based on the risks calculated in Richards, 2010. There are a number of limitations while using this method however, by using these formulae a likelihood of severity at each impact speed of the 11 analysed has been assessed and the results extrapolated to STATS19 level. The results are shown in Table 9.

Table 9. New distributions of fatalities/casualties for the three pedestrian AEB systems

	Fatal	Reduced to Serious	Reduced to Slight	Accident avoided - Uninjured
Original Target Population	174			
0.6s system	122	14	38	0
1s system	103	14	33	24
2s system	89	0	0	85

3.3.4 OTS/CCIS analysis

In order to assess the benefits for serious and slight casualties in pedestrian AEBS relevant accidents, OTS data were used, specifically accidents which involved the front of a car hitting a pedestrian. The original impact speed and driving speed were extracted from each case, along with the severity of the pedestrian's injuries. From the driving speed of the vehicle, a new impact speed (v) was calculated using the following equations, with a 2 second, 1 second and 0.6 second system reaction time (t) for the two avoidance systems and the mitigation system, as with the fatal file data. In the equation u is the original driving speed, a is the acceleration and t is the braking time of the system taking the coefficient of friction (μ) to be 0.7, and g as 9.81ms^{-2}.

$$v = \sqrt{u(u + 2at)}$$
$$a = \mu g$$

The accident risk curves were then used to calculate the original risk of serious injury to the pedestrian, and relate this to the risk of serious injury at the new speed. This information was used to calculate the severity reduction of the casualties and weighted up to the STATS19 target population, in the same way as was done for the fatal file analysis. Accidents which were in the dark with no streetlights, or in bad visibility weather (i.e. the weather was not recorded as fine) were accounted for, with no change to their severity, as the system would not have had an effect in these cases (as discussed previously). It was not possible from the OTS data to identify cases where the systems would not have been effective because, for example, the pedestrian only became "visible" to the car at the last moment, or the impact was on a bend. To make some allowance for these cases, the appropriate proportion has been taken from the fatal file analysis and applied to the serious and slights – in the fatal file study, 18 cases out of the 37 in the original target population (48.6%) were amenable to AEBS fitment, so this proportion is applied to the serious and slight sample.

Table 10 shows the resulting reduction in the number of casualties for each system.

Table 10. Reductions in serious and slight casualties with the pedestrian AEB systems

	Serious	Slight
Original Target population casualties	5,805-7,095	20,623-25,205
	Casualties Prevented	
0.6s system	1,261-1,541	1,699-2,077
1s system	2,492-3,045	8,697-10,629
2s system	2,821-3,448	10,023-12,250

3.3.4.1 Assumptions/limitations using this method

There are a number of limitations when using the risk curves, as discussed in Richards (2010), such as the large variability in the risk of injury, as it depends on many other factors as well as impact speed. Age, gender, biomechanical tolerance, the part of the vehicle hit, and many other variables are all related to the risk of pedestrian fatality. It should also be noted that the curves give the risk of fatality provided that the pedestrian has been injured, as the national statistics do not include information on uninjured pedestrians. In our estimations, only those where the accident would have been avoided with the addition of the system are counted as "uninjured" if any impact occurred at all, the pedestrian was assumed to have been at least slightly injured. However, it is a good assumption that the vast majority of pedestrians hit by the front of a moving car will receive at least a slight injury.

3.3.1 Overall effectiveness estimate

The results from the fatal file analysis were combined with the results from the analysis of serious and fatal accidents, producing overall reductions as shown in Table 11. Using the costs of casualties as defined in Reported Road Casualties Great Britain, the addition of pedestrian AEBS was found to reduce the cost by between £327million and £917million, depending on the particular system.

Table 11. Overall effectiveness estimates

	Fatalities	Serious	Slight	Cost (£m)	Saving (£m)
Original	174	5,805-7,095	20,623-25,205	£1,593-1,886m	0
		Casualties Prevented			
0.6s system	52	1,247-1,527	1,661-2,039		£327-383m
1s system	71	2,478-3,031	8,666-10,596		£673-798m
2s system	85	2,821-3,448	10,023-12,250		£775-917m

In casualty cost reduction terms, the modelled systems would have overall minimum effectiveness ranging from 20% (i.e. 20% of the target population casualty costs are likely to be avoided) for the 0.6s system to 49% for the 2s system, with the 1s system at 42%. These are minimum values because of the assumption that any pre-collision warnings would have no effect over and above those provided by autonomous braking.

3.3.2 System cost analysis

From a stakeholder consultation and literature review, it was estimated that a system of this type would cost somewhere between £1,000 and £1,500 as an optional extra to the customer (the Volvo system cost £1,380 at the time of writing this report). These are full market costs to consumers as optional extras and are thus likely to be subject to quite high mark-ups. It is also reasonable to assume that if such systems (which are currently only available on a very small number of vehicles) were ever mandatory fitment items to all new vehicles, the production costs would tend to be somewhat lower than the current situation, through economies of scale and product innovation. For the purposes of this study, therefore, a future likely actual cost (to manufacturers) range of £400-£800 per vehicle is used in the cost-benefit analysis.

There is assumed to be no variation in the system costs between the three generic systems modelled, because the hardware and software would be the same in each case. The only characteristic that varies between the three generic systems is the time to collision at which the brakes are applied, which it is assumed would be implemented through variations in the control system programming only.

3.3.3 Cost benefit analysis

Applying the per vehicle system costs (£400-£800) to the 2.2million assumed new car registrations per year in Great Britain produces an annual implementation cost of £880-1,760million. Combining these data with the casualty savings estimates generates ranges of benefit-cost ratios, as shown in Table 12. The lower ratios shown are based on the upper cost estimates and lower casualty savings estimates, while the upper ratios are based on lowest assumed implementation costs and highest savings estimates.

Table 12. Estimated benefit-cost ratios for pedestrian AEBS

	Per vehicle costs	Total annual costs	Total annual savings	Benefit:cost ratio
0.6s system	£400-£800	£880-1,760m	£327-383m	0.19-0.44
1s system	£400-£800	£880-1,760m	£673-798m	0.38-0.91
2s system	£400-£800	£880-1,760m	£775-917m	0.44-1.04

With the assumed system costs, the ratios are well below unity for the least effective (0.6s braking) system, implying that such systems are unlikely to be cost effective. System developers would either need to substantially improve their capability, so that they prevent a higher number of casualties, or reduce the system costs, or both. As an illustration of the scale of this challenge, the break-even costs for the modelled, generic 0.6s system (the costs at which the savings and benefits would be equal) can be calculated from the data shown in Table 12 to be £149-£174.

The more effective 1s system has correspondingly higher calculated benefit-cost ratios, approaching unity if the upper estimate casualty savings and lower estimate per vehicle costs are used. Its break even cost is £306-£363.

The most effective (2s) system would be cost effective at the low end of the assumed cost range and upper end of the estimated savings range. Even at the lower end of the savings range, cost effectiveness would be possible if the system costs were £350.

The break-even effectiveness (the proportion of overall target population casualty costs that would need to be prevented to equalise the costs and savings) can be calculated to be 47-55% at the lowest assumed system cost of £400, rising to 93-110% at the high cost of £800 per vehicle (this means that if the lower end of the estimated casualty costs range is used, £800 systems could never be cost effective because effectiveness cannot exceed 100%). It should be noted, however, that these figures retain the assumption that systems would not be able to avoid or mitigate accidents occurring in poor weather or visibility conditions – if the effectiveness improved to allow some capability in these conditions, e.g. in rain or on unlit roads at night, the overall target population costs would increase, and the break even effectiveness would not be as high as the above calculations suggest.

It must also be emphasised that in reality, systems would issue a pre-collision warning to the driver and in a proportion of cases that driver would take appropriate avoiding action, and thus the true system effectiveness and benefits would be at least a little higher than indicated by these calculations. The effectiveness of a pedestrian warning system is likely to be less than the equivalent for passenger car AEBS (rear shunt collisions), because, for example, of the inherent difficulties in predicting pedestrian movements and the often very short period of time during which they are in the roadway (and off the pavement). If, by way of illustration, it assumed that a pedestrian warning system is half as effective as a car AEBS system then it would prevent 10% of the target population casualties (car AEBS warning systems were centrally estimated to prevent 20% of the relevant target population casualties). For the 0.6s system, this would mean the overall effectiveness rising from 20% to 28%, and the BCRs to between 0.25 and 0.60 (from between 0.19 and 0.44). The scope for a warning system to be effective would tend to reduce for the 1s and, even more so, 2s system because of the difficulties in making accurate predictions even further ahead of the impact.

3.4 LDWS

3.4.1 STATS19 analysis (target population estimates)

For LDWS, the data have been analysed to identify three separate target populations (Table 13), those where the car ran off the road, perhaps as a result of lack of attention/fatigue and had a single vehicle accident, and those that crossed the lane boundary to suffer either a head-on collision with an oncoming vehicle or a side to side collision with a passing vehicle. These target populations are equivalent to those used in TRL's earlier research for the EC.

Table 13. Description of target populations.

Target population reference	Description
A	Head-on collisions - The vehicle of interest leaves its lane unintentionally and collides head-on with oncoming vehicle. These accidents are most likely to occur on single carriageway roads.
B	Leaving roadway collisions – the vehicle of interest drifts out of the travel lane. These accidents are often single vehicle (can include pedestrians) and may involve impacts with roadside furniture. Other vehicles may be involved, however, because they have been required to react to the lane departure of the vehicle of interest.
C	Side-swipe collisions – when the vehicle of interest unintentionally leaves the lane in which they are travelling on a road with multiple lanes, the side of the vehicle of interest could collide with the side of a vehicle that is travelling in an adjacent lane. There is also a possibility of an impact between the front of one vehicle and the rear of the other.

The three accident scenarios are mutually exclusive, so the total casualties (fatal, serious and slight) in each are added together to arrive at the overall target population for reported casualties (Table 14).

Table 14. Averaged 2007-2009 annual reported casualties by impact scenario

Scenario	Fatalities	Serious	Slight	All casualties
A – Head-on	64	474	2,030	2,568
B – Leaving roadway	142	1,023	3,966	5,131
C – Side-swipe	3	37	280	320
Totals	209	1,534	6,276	8,019

The STATS19 target populations for reported casualties for LDWS are thus:

Fatalities: 209 Serious: 1,534 Slight: 6,276

Adjusting for under-reporting, by applying factors of 2.7 (lower) and 3.3 (upper) to the non-fatal casualties gives the following overall (all casualties) annual target population estimates:

Fatalities: 209 Serious: 4,142 – 5,062 Slight: 16,945 – 20,711

3.4.2 Retrospective study data

The original aim was to undertake a retrospective analysis of STATS19 data comparing cars fitted with LDWS and those without, based on the number of vehicle registrations to control for exposure. However, following a detailed review of new GB car sales for 2009 correlated with STATS19 involved accident vehicles, it became clear that the sample size for cars fitted with LDW systems was too small for a retrospective analysis to yield any meaningful results. The findings with respect of the vehicle make model sales with and without LDWS for 2009 are included in Appendix A and Appendix B for reference.

3.4.3 Literature review

Having established that a retrospective study of LDWS effectiveness in the UK was not yet feasible, the methodology was switched to a predictive study. The initial step was to carry out a literature review, to identify any recent relevant studies that could be used to provide the required burden of proof level (at least medium).

Two recent publications from the USA provide evidence on the effectiveness of LDWS that was not available at the time of the 2008 EC study (Visvikis et al, 2008). One involves a predictive study based on a detailed review of national accident statistics and the other reports the results of a major field operational trial. Together, although they relate to the USA, their results can be applied in the GB context sufficiently to provide at least the medium burden of proof level required.

Jermakian (2010) identified the three basic accident scenarios relevant to LDWS and systematically excluded cases from each that would likely not be relevant, e.g. because of road defects, loss of control, avoidance manoeuvres, low speed, snow on the road way, etc. Finally, she split those left, and thus potentially relevant to LDWS fitment, into those where the car was not speeding, which she defined as definitely relevant to LDWS, and those where the car was speeding, which were defined as possibly relevant. The analyses were further split into fatal crashes, non-fatal injury crashes and all crashes. Effectiveness ranges (the proportions of each casualty group that might be preventable by LDWS) can thus be deduced for each target scenario and for both fatal and non-fatal injury accidents (Table 15).

Table 15. Effectiveness ranges by impact scenario (from Jermakian, 2010)

Scenario	Fatalities	Non-fatal injuries
A – Head-on	35-41%	24-31%
B – Leaving roadway	7-10%	17-31%
C – Side-swipe	30-39%	27-33%

Nodine (2010) presents a summary of the results of field operational trials on 16 prototype cars, shared by 108 drivers doing in total 219,000 miles. Each driver had the car for 40 days, the first 12 of which without LDWS fitted and the remaining 28 days with the system in-use. The precise details of the system fitted are not presented, but the results show a 21% decrease in unintended lane excursions for all drivers. Nodine then provides a projection of the potential overall safety benefits, in the form of overall effectiveness percentages, broken down by impact scenario but not by severity (the analysis covers all crashes). The results are shown in Table 16.

Table 16. Effectiveness by impact scenario (from Nodine, 2010)

Scenario	All crashes
A – Head-on	7%
B – Leaving roadway	23%
C – Side-swipe	40%

Combining the Nodine and Jermakian effectiveness estimates is not straightforward, particularly because neither study breaks them down by fatal, serious and slight, and although the Nodine study is from a field operational trial (which would normally give a high burden of proof), it only involved a small number of cars and possibly an even smaller number of different LDW systems, perhaps only one. The ranges used for this current study, deduced from the two US studies, are shown in Table 17.

Table 17. Effectiveness ranges used, by impact scenario

Scenario	Fatalities	Serious	Slight
A – Head-on	7-41%	7-31%	7-31%
B – Leaving roadway	7-23%	17-31%	17-31%
C – Side-swipe	30-40%	27-40%	27-40%

These figures are broadly in line with those derived as part of the 2008 analysis for the EC, based on mainly predictive European studies published up to that time.

3.4.4 Overall effectiveness estimate

Combining the overall (all casualty) target population estimates with the effectiveness estimates (Table 17) allows estimates to be made of the likely casualty savings were LDWS fitted to all GB cars. Table 18 presents the estimated casualty savings and values.

Table 18. Overall effectiveness estimates, by casualties and value

Scenario		Fatalities	Serious	Slight
A – Head-on	Target population	64	1,280-1,564	5,481-6,699
	Casualties prevented	4-26	90-485	384-2,077
B – Leaving roadway	Target population	142	2,762-3,376	10,708-13,088
	Casualties prevented	10-33	470-1,047	1,820-4,057
C – Side-swipe	Target population	3	100-122	756-924
	Casualties prevented	1	27-49	204-370
Totals	Target population	209	4,142-5,062	16,945-20,711
	Casualties prevented	15-60	587-1,581	2.408-6,504
	Value (£m)	**24-95**	**105-282**	**33-89**

In total, the estimated overall annual benefit from LDWS fitment to all cars in Great Britain is in the range £162-466m, compared to the overall target population costs of £1,302-1,518m; an overall effectiveness (in casualty cost reduction terms) of 12-31%.

3.4.5 System cost analysis

An investigation was undertaken into LDWS fitted to vehicles manufactured in 2009. Costs for the fitment of LDWS alone were found for 22 makes and models. These costs ranged from £305 to £500. These are full market costs to consumers as optional extras and are thus likely to be subject to quite high mark-ups. It is also reasonable to assume that if such systems (which are currently only available on a small number of vehicles) were ever mandatory fitment items to all new vehicles, the production costs would tend to be lower than the current situation, through economies of scale and product innovation. For the purposes of this study, therefore, a future likely actual cost (to manufacturers) range of £100-£300 per vehicle is used in the cost-benefit analysis.

3.4.6 Cost benefit analysis

Applying the per vehicle system costs (£100-£300) to the 2.2million assumed new car registrations per year in Great Britain produces an annual implementation cost of £220-660million. Combining these data with the casualty savings estimates generates ranges of benefit-cost ratios, as shown in Table 19. The lower ratios shown are based on the upper cost estimates and lower casualty savings estimates, while the upper ratios are based on lowest assumed implementation costs and highest savings estimates.

Table 19. Estimated benefit-cost ratios for LDWS

Per vehicle costs	Total annual costs	Total annual savings	Benefit:cost ratio
£100-£300	£220-660m	£162-466m	0.25-2.12

With the lower assumed system costs, and higher casualty savings estimate, the ratio is well above unity, implying that the systems could be cost effective. If system developers either further improved their capability, so that they prevent a higher number of casualties, or reduced the system costs, or both, this cost-effectiveness would be further improved. The break-even costs for the modelled, generic systems (the costs at which the savings and benefits would be equal) can be calculated from the data shown in Table 19 to be £74-212.

The break-even effectiveness (the proportion of overall target population casualty costs that would need to be prevented to equalise the costs and savings) can be calculated to be 14-17% at the lowest assumed system cost of £100, rising to 43-51% at the high cost of £300 per vehicle. These figures compare to the overall effectiveness of current systems, deduced from the research literature and accident studies described above, of 12-31%.

3.5 Youth key

The 'Youth Key' system evaluated for this study has the following functionality:

- Persistent seat belt reminder with audio mute for all seats. The reminder will provide a constant six-second chime until all occupants have fastened their seat belts correctly. The audio system is also muted until all the seat belts are buckled. A message centre display, "Buckle Up to Un-mute Radio," also appears on the instrument cluster.
- A speed alert chime at 35, 45, 55 or 65 mph.
- Limited top speed of 70 mph.
- Traction control cannot be deactivated.

This is a relatively conservative approach, because the system aims to 'nudge' or encourage the car occupants to wear their seat belts, rather than to insist upon it, and will only warn or advise the driver when s/he reaches certain speeds. The only limit is applied to the maximum speed of the car. The technology has been assumed to be available to 17 to 24 year old novice drivers.

The same technology could be applied to enforce certain car performance characteristics and to remove the element of choice from the driver and passengers. Examples of this enforcement approach could include preventing the engine from starting until all the occupants are seat belted, restricting the number of passengers or times of day when the car can be used (with ignition-locks), reducing the power and acceleration rate of the car, or using speed limiting devices. However, the enforcement option encompasses a number of existing stand-alone primary safety systems, which are documented in the literature, and would represent a significant step away from the current situation.

Therefore, a more conservative version of the Youth Key concept is believed to be more realistic and practicable for the UK (and wider European) market place in the short to medium term. The characteristics of young novice drivers are reviewed in the following sections, and the potential advantages and limitations of the proposed Youth Key technology are discussed.

3.5.1 Literature review – Characteristics of young, novice driver accidents

3.5.1.1 Accident risk – Age and experience

New drivers, especially young new drivers, are over-represented in road collisions. The risk of involvement in a crash during the first year of driving decreases substantially, this is true for all ages of new and novice drivers, but the younger the driver the more pronounced the reduction in accident propensity as they acquire on road experience.

TRL research in the 1990s (Maycock *et al*., 1991) included a study of self reported accidents from a sample of 13,500 drivers. The programme found that mileage-adjusted accident liability decreased with respect to the age at which the driver passed their driving test. Male drivers have higher accident liabilities than females, but age and experience when combined produced very steep declines in accident propensity during the early period of unsupervised driving following gaining a driving a licence (Figure 8).

Another British study (Cohort I, Forsyth *et al*., 1995) found similar results and these findings are summarised by Maycock, 2002 (Figure 9). Both show that once the effects of age and experience are separated, the effect of experience is the dominant force behind the lowering of collision risk. The dotted line shows the initial collision rate of a new driver in their first year of driving, depending on the age they pass their test. The solid line shows the way in which collision rate drops with experience for drivers who pass their test at 17. The effect of experience is, as we can see, substantial in those early years of driving, and even the early months.

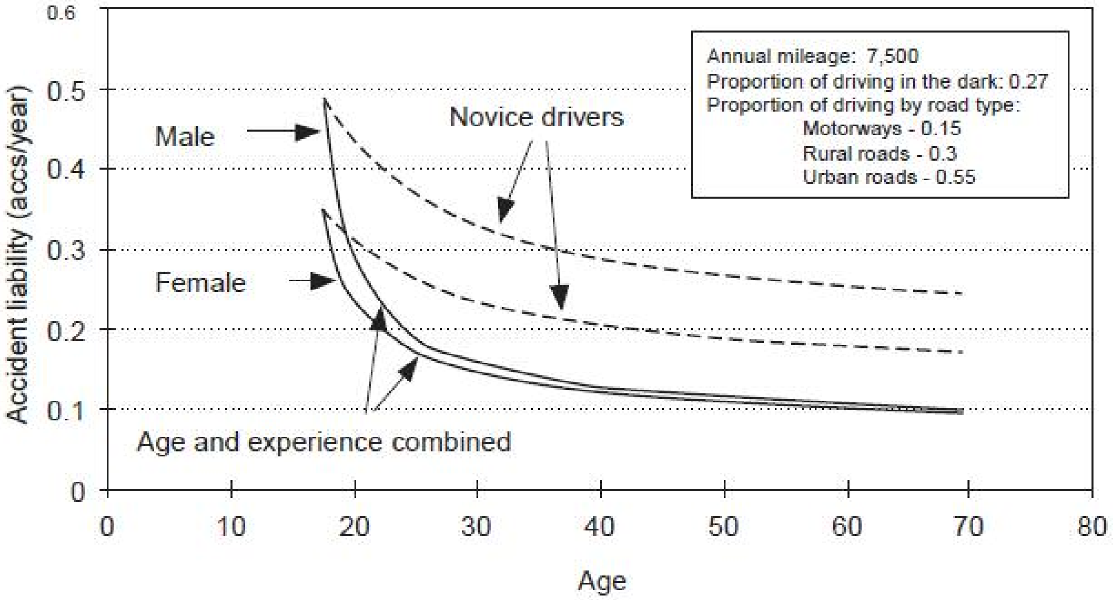

Figure 8. The effects of age and driving experience on collision risk (1991; reproduced from Maycock, 2002).

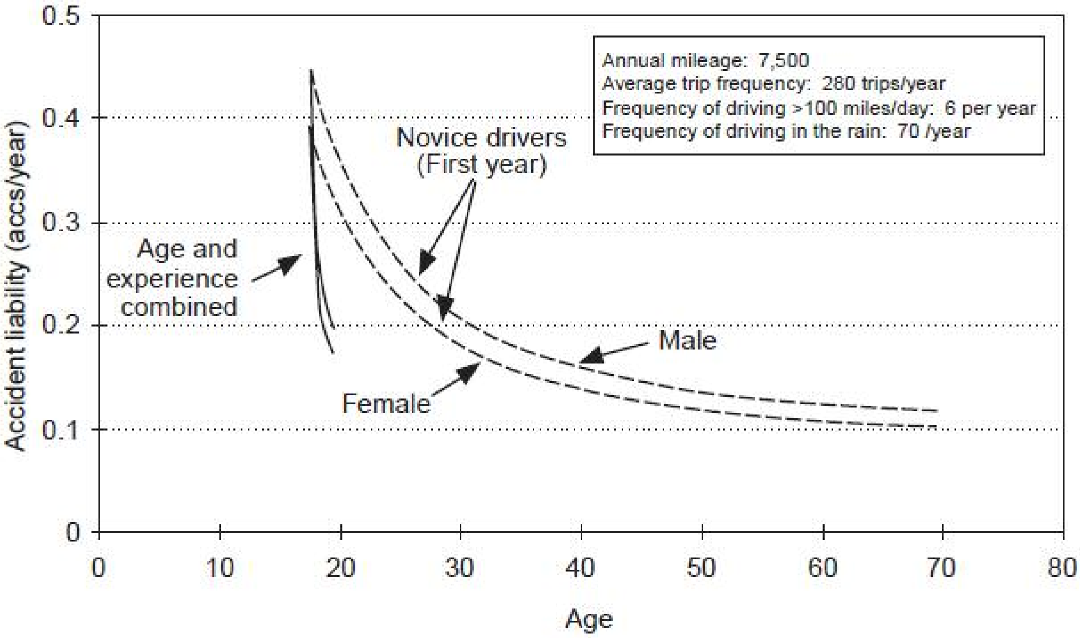

Figure 9: The effects of age and experience on collision risk, from Forsyth *et al.* (1995; figure reproduced from Maycock, 2002)

This British research is substantiated by many other international studies which have all shown that initial very high crash involvement decreases rapidly during the first six months of driving (Mayhew *et al.*, 2000; McCartt et al., 2003; Sagberg *et al.*, 1998).

Youth key technology could potentially aid new drivers by helping them to observe better road safety related behaviours, whilst they acquire important experience on the road which is known to reduce their accident risk.

3.5.1.2 Road casualties and Young drivers

Young drivers aged 17-24 accounted for 12% of driving licence holders in the UK in 2009. In the same year, 26% (over 42,000) of the 163,554 reported personal injury road accidents involved at least one driver aged 17-24. Young drivers appear to be overrepresented in car accidents. A total of 564 fatalities and 5,765 serious injuries occurred as a result of these accidents, with 191 young car drivers killed and 1,835 seriously injured. Males accounted for 71% of the 2,026 KSI young car driver casualties in 2009, and nearly a third of young car drivers involved in accidents were aged 18 or 19 (RoadSafe/DfT, 2009).

3.5.1.3 Use of parent's car

The 'Youth Key' technology would primarily be aimed at young drivers who use a parent's (new) vehicle. It may also appeal to parents who are purchasing their child's first car for them, particularly if the scheme was associated with reduced insurance costs. No data are available on how many drivers use their parent's vehicle, however TRL's OTS (On The Spot) accident database was analysed to find the proportion of accident-involved young drivers (aged under 26) who were driving a car belonging to an 'other relative' at the time of the collision (there was no specific 'parents' group). Of 1,032 accidents recorded, 168 (16%) involved a driver under the age of 26. Of these, 16% of vehicles belonged to an 'other relative' and 70% belonged to the driver. Amongst drivers aged over 26, only 2% of vehicles belonged to a relative, while 75% belonged to the driver, as shown in Table 20. However it is likely that a much smaller proportion of accidents would involve a young driver using a *new* car, and so 16% should be considered a maximum estimate of drivers who could be targeted by the 'Youth Key' in the years after its introduction.

Table 20: Vehicle ownership amongst 1,032 accident-involved drivers (OTS)

	Self	Other relative	Partner/spouse	Friend	Company	Rental/ leasing agent	Stolen	Other	Unknown
Under 26 (n=168)	70%	16%	4%	1%	7%	1%	0%	1%	1%
26 or over (n=864)	75%	2%	7%	1%	10%	2%	0%	1%	2%

3.5.1.4 Seat belt use

In England, there is a scarcity of data relating to seat belt use, but a survey found a seat belt-wearing rate of 94% amongst drivers aged 17-29; this rate was lower for males than for females (DfT, 2010), with young men being particularly associated with low seat belt-wearing rates (Christmas, Young & Cuerden, 2008). Clarke *et al*. (2007) found that among fatally injured drivers aged 17-29, only 60% were wearing a seat belt, with seat belt use increasing with age from about 30 years onwards. A proportion of drivers will be 'inconsistent wearers', wearing their seat belt in certain circumstances only.

It is anticipated that the 'Youth Key' system would encourage higher rates of seat belt use amongst young drivers. Seat belts have been found to be 60% effective at preventing fatal injuries and 32% effective at preventing serious injuries for car occupants (Cuerden *et al*., 1997, 2006).

However a seat belt 'reminder chime' may simply be ignored by a driver, particularly if they are not carrying any passengers. Encouraging seat belt use by preventing the vehicle's audio system from engaging until the seat belt is in use may, in some cases, have an undesirable effect of young drivers deciding to use headphones (connected directly to their personal audio devices) rather than the in-car audio system, thus potentially increasing distraction and decreasing safety, though no evidence has been found to quantify this potential risk. Systems could also be designed or programmed to prevent engine ignition until the seat belt is engaged.

Seat belt interlocks can be bypassed by drivers or passengers choosing to fasten the tongue into the buckle and then sitting on the webbing rather than placing it across their shoulder and pelvic region. On balance, it is likely that more people would comply with such a system than try to circumnavigate it, for example by using other devices to get access to music. This is also the approach taken by Euro NCAP, where cars with seat belt reminder systems are awarded more 'safety points' than those without.

3.5.1.5 Speeding

In Great Britain, 5.1% of all accidents and 15.8% of fatal accidents in 2009 were attributed to exceeding the speed limit. 14,355 injury accidents occurred on motorways or other roads with a 70mph speed limit; 1.8% of these were fatal and 12.1% resulted in a serious injury.

Speeding is more prevalent amongst younger drivers than older drivers. For example Stradling *et al*. (2007) found from a sample of over 1,000 drivers that those aged 17-24, and in particular males, were more likely to report speeding on roads with 30, 60 and

70mph limits, compared to other age groups (for example 89% reported speeding on 30mph roads, compared to 73% of drivers aged 25 or over; for males these figures were 93% and 78% respectively). Clarke *et al*. (2007) found that, of fatal accidents where 'blame' could be assigned, drivers aged under 20 were almost 12 times more likely to have caused a fatal accident than drivers aged 35-65 (compared to being innocently involved in an accident). Speed was a factor in 65% to 75% of 1,185 accidents studied by Ward *et al*. (2007) where the driver was under 25 years old, compared to 50% of all accidents.

By limiting vehicle performance and encouraging safer behaviour, the likelihood of the driver being involved in an accident and, if an accident did occur, of the driver being killed or seriously injured would decrease. The 'Youth Key' system also encourages more economical driving by limiting the top speed. This may reduce harsh acceleration and braking, thus promoting a safer driving style.

3.5.1.6 Engine performance

The majority of accidents involve some form of driver error and therefore driver behaviour is a key factor influencing the risk of being involved in an accident. However, the engine performance of a vehicle and its primary safety factors (such as braking and handling) may influence the choices a driver makes and therefore potential errors and accident risk. For example, if a car has rapid acceleration and deceleration characteristics this may lead to a driver using this wider envelope of performance. However, for novice drivers their skills with respect to vehicle handling and hazard perception may not be fully mature and this combination could exacerbate their limitations and result in more errors and accidents.

The only published reference relevant to this issue identified by this study is a report by the Department of Transport (DfT, 1993). Although somewhat dated now, this compared the rates of involvement in injury accidents, by size of car, performance of car and ownership. The performance of the cars were assessed as 'standard' or 'high', where 'high' included those models '*whose performance is considerably higher than the standard production range*'. Further, the report describes that high performance cars '*typically, though not invariably, have the capability of accelerating from 0 to 60 mph in 10 seconds or less'*.

The measure used for involvement rates was injury accident involvement per 10,000 licensed vehicles in each group. Based on this assessment, privately owned cars registered before 1/01/1991, with a 'standard' performance averaged a fatal or serious involvement rate of 24 compared to 30 for the 'high' performance group. In isolation, this finding **cannot** be used to indicate that 'high' performance cars are more likely to be involved in accidents, as it will also reflect other important differences in the level and type of use of the car and driver behaviour. However, it is known from insurance risk assessments that higher performance vehicles attract higher premiums and there is arguably a common sense relationship which can be made with respect to limiting vehicle performance for novice drivers to prevent accidents.

A Youth Key system which limits engine power in conjunction with preventing deactivation of primary safety systems, such as ESC and traction control, could help reduce the errors novice drivers make and assist them to overcome those they do make. However, this has not been included as part of the specification evaluated in this study.

3.5.1.7 Night time driving

Accidents involving young drivers tend to be caused by young drivers losing control on bends, and were typically in rural areas at night. Clarke *et al*. (2002) found that over 50% of 1,282 accidents where the young driver (aged 25 or under) was to blame occurred in the hours of darkness. Analysis of contributory factors suggested that visibility problems caused by darkness were generally not having much effect on these accidents, but that attitudinal factors were more responsible. ‘Aggressive recklessness’ and accidents involving alcohol were found to peak during the hours of darkness.

The ‘Youth Key’ could include a feature to limit night-time driving, but this functionality has not been included in the Youth Key system evaluated by this study.

3.5.1.8 Multiple accident and injury causation factors

Accidents are complex events and perhaps the combination of some factors could sum together to have a greater benefit than their individual components. An example could be limiting volume or use of the in-car entertainment system and enforcing higher seat belt compliance. This would have the double effect of reducing distraction and accidents, but also (if an accident does occur) of providing additional protection for the young people involved.

3.5.1.9 Cultural and demographic issues

This technology is currently only available in the US marketplace, where a survey found that 75% of parents were in favour of the speed-limiting feature, 72% liked the more insistent seat belt reminder, and 63% liked the audio limiting feature. Although 67% of surveyed teenagers stated that they would not want the ‘MyKey’ features, but this reduced to 36% if use of the MyKey resulted in greater driving privileges.

Whether such a system would receive similar responses in Europe is difficult to predict. There is the possibility that parents may feel that the ‘Youth Key’ acts to undermine their parenting skills or authority, or that their children would feel un-trusted. Also, young drivers engage in risky driving behaviours that would not be mitigated by the ‘Youth Key’, for example phoning or texting while driving, close following, or drink/drug-driving.

3.5.2 Overall effectiveness estimate

An overall effectiveness estimate for Youth Key cannot be based on a retrospective comparison analysis of UK accident data, because this technology has not yet been introduced to the vehicle fleet. Further, a detailed review of the literature specifically relating to the effectiveness of Youth Key, including experience from the USA where this technology is present, did not yield any suitable quantification of the benefits of MyKey or similar technologies at the time of writing. However, significant evidence was identified within the literature with regards to young and novice drivers and their accident involvement rates, the causes of their collisions and the importance of seat belts to mitigate injuries (Section 3.5.1).

A predictive study was considered, which would have involved an in-depth investigation of a representative sample of relevant collisions involving novice drivers, and evaluated whether or not the presence of a Youth Key system, could have prevented them or reduced the severity of the injuries sustained. This approach could have yielded some interesting results, but was discounted for two reasons. Firstly, the scale of the task given the complexity of the evaluation process was beyond the scope and time constraints of this research programme. Secondly, and equally importantly, there are substantial challenges associated with the verification of the accuracy of any predictions based on how individual drivers may have been influenced by factors such as speed alerts, for example would they have slowed down or simply ignored the chime? It is recommended that this methodology be developed and more accurate effectiveness estimates established based on a predictive study, comparing enforcement and encouragement options within the system.

The methodology used to estimate the effectiveness of Youth Key has a low to medium burden of proof.

3.5.2.1 Target Population Age criteria (17-24 year old car drivers)

The primary aims of Youth Key are to prevent road accidents and subsequent injuries by encouraging better road safety behaviours. Table 21 gives a breakdown of the types of casualties associated with reported accidents in GB in 2009 which involved at least one young driver. The table shows that passenger casualties of young car drivers were more often killed or seriously injured in an accident compared to car passenger casualties of older car drivers (25 years or older). In addition, car passengers of young car drivers were more likely to be of the same age and sex as the young drivers.

Table 21: KSI casualties from reported accidents involving car drivers by casualty type, GB 2009 (STATS19)

Type of casualty	Drivers aged 17-24		Drivers aged $\geq$ 25	
	KSI casualties number	% of KSI to all injury casualties	KSI casualties number	% of KSI to all injury casualties
Car driver themselves	2,026	8%	5,260	7%
Car passenger	1,324	9%	2,292	7%
Occupants of other vehicles and pedestrians	2,979	11%	9,232	16%
All KSI casualties	**6,329**	**10%**	**16,784**	**10%**

(Source RoadSafe/DfT, 2009)

The 6,329 killed or seriously injured road users, who were involved in accidents with young drivers in 2009, form the largest possible Target Population that Youth Key could influence (not allowing for under-reporting). There were a total of 26,912 reported KSI casualties in GB in 2009, so Youth Key if universally fitted and activated, could potentially have some benefit for up to 23.5% of all KSI casualties.

However, Youth Key could only **prevent accidents or lessen the injury outcome** if:

- the accident was caused, at least in part, by the actions of the young driver; and
- excess or inappropriate speed was a factor, which would have been prevented by a 70 mph limiter or speed alert chime.

Similarly, the Youth Key seat belt reminder and audio mute system could only **prevent injuries** for those casualties:

- who were in a car driven by a young driver; and
- were not wearing their seat belt, but would have done so if encouraged by Youth Key.

3.5.2.2 Target Population collision mitigation and prevention (speed and accidents)

In 2009, 67% of reported accidents involving young car drivers occurred on roads with speed limits of 40 mile/h or below. These roads accounted for 65% of all casualties and 60% of those who were killed or seriously injured, where the accident involved a young driver. Further, we know from police officers who attended the scene of reported personal injury road accidents, some details with respect to the factors which contributed. Not all accidents in STATS19 have Contributory Factors (CF) recorded, and where they are it is accepted that they may be largely subjective and some factors may be less likely to be assigned than others. However, despite these limitations they offer a good guide as to why the accidents occurred.

From Contributory Factors attributed to cars in STATS19, which were driven by young drivers, we know that:

- 29% had no CF recorded;
- 10% were 'Learner or inexperienced driver/rider';
- 10% were 'Travelling too fast for conditions'; and
- 6% were 'Exceeding speed limit'.

Table 22 provides an estimate of the maximum (reported) Target Population of accidents which could be prevented or result in lesser injuries if all young drivers were in cars fitted with Youth Key, which was operational and they modified their behaviour to prevent any 'speed' related collisions.

Table 22: Derivation of Target Population for Youth Key - accident prevention and injury mitigation (GB, 2009)

Casualty groups	**Casualties associated with accidents involving young drivers**			
	Killed	**Serious**	**Slight**	**All**
All casualties	564	5,765	59,094	65,423
Accidents with CF (71%)*	400	4,091	41,931	46,422
CF1 Exceeding speed limit (6%)	35	356	3,649	4,040
CF2 Travelling too fast for conditions (10%)	57	585	5,997	6,639
Target Population = CF1 + CF2	92	941	9,646	10,679

There are a number of limitations to this approach. Firstly, it has been shown that 'speed' related contributory factors are less likely to be recorded in STATS19 compared to others (Richards *et al*., 2010). Richards *et al*. reported that amongst the six contributory factors which are recorded significantly more often in OTS are "exceeding speed limit" and "travelling too fast for conditions". This could be because road accidents are complex events and often involve multiple factors, frequently attributed to different road users, so preventing one Contributory Factor may not prevent the accident, although with respect to speed it could lessen the injury severity suffered.

The STATS19 target populations for reported casualties for speed-reducing Youth Key are thus:

Fatalities: 92 Serious: 941 Slight: 9,646

Adjusting for under-reporting, by applying factors of 2.7 (lower) and 3.3 (upper) to the non-fatal casualties gives the following overall (all casualties) annual target population estimates:

Fatalities: 92 Serious: 2,541-3,105 Slight: 26,044-31,832

3.5.2.3 Target Population injury prevention (seat belt compliance and accidents)

Cuerden (2006) reported that seat belt use rates vary according to seating position, for injured car occupants. He analysed CCIS data and found that:

- drivers are most likely to be belted, followed by FSPs and RSPs;
- females are more likely to be seat belted; and
- seat belt use decreased with increasing occupant injury severity

Figure 10 shows that for fatally injured car drivers, 29% of males and 16% of females were unbelted at the time of the collision. Approximately 70% of fatally injured male rear seat passengers (RSPs) were unbelted compared to 56% of female RSPs.

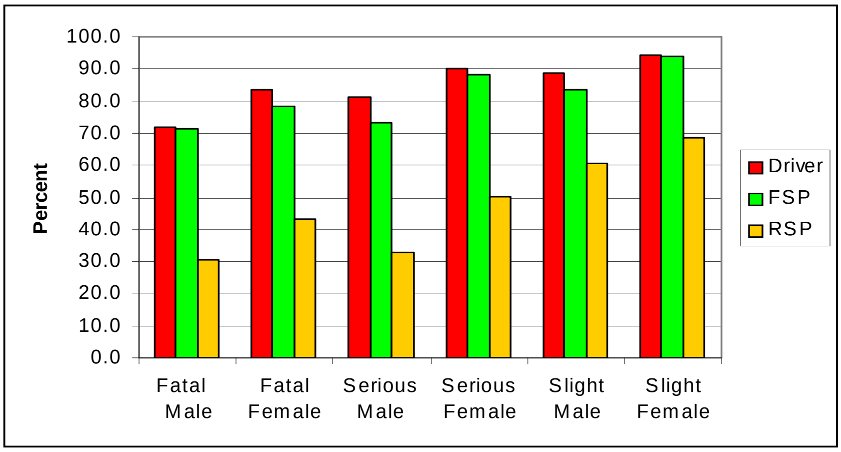

Figure 10: Seat belt use rate by Injury Severity, Gender and Seating Position (Source: Cuerden, 2006; CCIS Data)

The CCIS findings with respect to seat belt rates use were scaled to STATS19 casualties, by injury severity and seating position. Casualties were selected based on all occupants seated in cars driven by 17-24 year old drivers. This allowed estimates to be made of the number of drivers and passengers by injury severity, who were likely to have been unbelted at the time of their accident. These estimates form a (reported) Target Population for the Youth Key system with respect to the injury mitigation potential of increasing seat belt wearing rates for this group of car users (Table 23).

Table 23: Derivation of Target Population for Youth Key - injury mitigation by improved seat belt compliance (GB, 2009)

Casualty Type	**Accidents involving drivers aged 17-24**			
	Killed	**Serious**	**Slight**	**All**
Drivers (KSI = 2,026)	191	1,835	22,963	24,989
Passengers (KSI = 1,324)	144	1,180	12,689	14,013
NB1: Estimate of non- seat belt drivers	48	275	2,296	2,619
NB2: Estimate of non-seat belt passengers	58	413	2,538	3,008
Target Population = NB1 + NB2	106	688	4,834	5,628

The STATS19 target populations for reported casualties for seat-belt Youth Key are thus:

Fatalities: 106 Serious: 688 Slight: 4,834

Adjusting for under-reporting, by applying factors of 2.7 (lower) and 3.3 (upper) to the non-fatal casualties gives the following overall (all casualties) annual estimates:

Fatalities: 106 Serious: 1,858-2,270 Slight: 13,052-15,952

3.5.2.4 Effectiveness of Youth Key collision mitigation and prevention (speed and accidents)

The Youth Key system offers two countermeasures; the first is related to slowing down young drivers and therefore either preventing accidents or reducing the severity of the impacts and the injuries suffered. Quantifying the effectiveness for this element of the system is difficult as it is not well understood how young drivers will behave with a Youth Key system - will they conform? Further, due to the complex nature of accidents it is difficult to predict the precise changes in injury outcome or estimate the number of collisions which may be avoided. For these reasons, an effectiveness estimate has been made for only those casualties who were associated 'speed' related contributory factors and the confidence with respect to the burden of proof is low.

Table 24 assumes that all the vehicles used by young people have Youth Key fitted, but only half are activated. In other words, half of the drivers between the ages of 17-24 have chosen to deactivate the system or drive using a key which allows full performance of the vehicle (parent's permission status). Further, for those young people who do have Youth Key on their cars, only half respect the speed related chimes and adjust their driving accordingly to maintain 'safer' speeds. The final part of the estimation is to assess how many of the remaining drivers, their passengers and other road user casualties would have benefited from the speed related advice Youth Key offered, in terms of preventing collisions or reducing their severity. A range of between 10% and 50% has been assumed, where if the driver conformed the casualties would at best have been prevented or at least their injuries mitigated.

Table 24: Estimation of effectiveness for Youth Key – accident prevention and injury mitigation (GB, 2009)

Casualty groups	**Killed**	**Serious**	**Slight**
All cars fitted with Youth Key (Target Population)	**92**	**2,541-3,105**	**26,044-31,832**
Proportion with activated Youth Key (50%)	46	1,270-1,553	13,022-15,916
Young drivers who respect Youth Key (50%)	23	635-776	6,511-7,958
Conforming prevents accident (10%)	2	64-78	651-796
Conforming prevents accident (50%)	12	318-388	3,256-3,979
Effectiveness range	**2-12**	**64-388**	**651-3,979**

The second potential benefit of Youth Key would be to increase seat belt use rates for young drivers and their passengers and therefore provide them with a greater chance of surviving a collision should it occur. Table 25 gives the effectiveness of seat belts at preventing fatal and serious casualties, calculated using CCIS data (Cuerden, 2006).

Table 25. Seat belt effectiveness for fatal and serious casualties (Source: Cuerden, 2006; CCIS Data)

Injury severity	Seat belt effectiveness, σ
Fatal	61%
Serious	32%

Table 26 assumes that all the vehicles used by young people have Youth Key fitted, but only half are activated. In other words, half of the drivers between the ages of 17-24 have chosen to deactivate the system or drive using a key which allows full performance of the vehicle. Further, for those young people who do have Youth Key on their cars, between 50% and 90% of them respect the seat belt reminder system and fasten their seat belts. The estimated numbers of killed and seriously injured casualties who would have been encouraged to wear their seat belts are multiplied by the seat belt effectiveness figures. This process predicts that between 16 and 29 lives could be saved every year through improved seat belt wearing rates if Youth Key was fitted. The model has assumed that the overall number of casualties would remain unchanged.

Table 26. Estimation of effectiveness for Youth Key – accident prevention and injury mitigation (GB, 2009)

Casualty groups	Killed	Serious	Slight
All cars fitted with Youth Key (Target Population)	**106**	**1,858-2,270**	**13,052-15,952**
Proportion with activated Youth Key (50%)	53	929-1,135	6,526-7,976
Young drivers who conform (50%)	27	464-568	3,263-3,988
Young drivers who conform (90%)	48	836-1,022	5,873-7,178
Effectiveness range	**16-29**	**148-327**	**-**

3.5.2.5 *Overall effectiveness estimate*

There is likely to be a small amount of overlap between the casualties who would benefit from Youth Key encouraging lower driving speeds and those who would benefit from seat belt use. However, it is not possible to accurately quantify this based on the data available and with respect to the casualty saving estimates it is unlikely to change the overall results. Table 27 provides an overall effectiveness estimate, by casualty and value for Youth Key.

Table 27. Overall effectiveness estimates, by casualties and value

Youth Key		Fatalities	Serious	Slight
Accident prevention or mitigation	Target population	92	2,541-3,105	26,044-31,832
	Prevented	2-12	64-388	651-3,979
	Value (£m)	£3-19m	£11-69m	£9-55m
Seat belt compliance	Target population	106	1,858-2,270	13,052-15,952
	Prevented	16-29	148-327	0
	Value (£m)	£25-46m	£26-58m	0
Totals	Prevented	18-41	212-715	651-3,979
	Saving (£m)	£29-65m	£38-127m	£9-55m

In total, therefore, the estimated overall annual benefit from Youth Key fitment to all cars in Great Britain is in the range £76-247m, compared to the overall target population costs of £1,635-1,928m (an overall effectiveness of 5-13%).

3.5.3 System cost analysis

An internet search revealed that Youth Key is currently offered at no extra cost to purchasers of Ford Focus cars in the US. The basic functionality can be expected to be very low cost, with simply a chip in the key that automatically re-programmes various control systems within the vehicle, in much the same way that some cars already cater for different drivers, e.g. by changing the seat position. It is reasonable to assume, however, that fitment to all vehicles would incur some costs for manufacturers. For the purposes of this study, therefore, a future likely actual cost (to manufacturers) range of £10-£50 per vehicle is used in the cost-benefit analysis.

3.5.4 Cost benefit analysis

Applying the per vehicle system costs (£10-£50) to the 2.2million assumed new car registrations per year in Great Britain produces an annual implementation cost of £22-

110million. Combining these data with the casualty savings estimates generates ranges of benefit-cost ratios, as shown in Table 28. The lower ratios shown are based on the upper cost estimates and lower casualty savings estimates, while the upper ratios are based on lowest assumed implementation costs and highest savings estimates.

Table 28. Estimated benefit-cost ratios for Youth Key

Per vehicle costs	Total annual costs	Total annual savings	Benefit:cost ratio
£10-£50	£22-110m	£76-247m	0.69-11.2

With the lower assumed system costs, and higher casualty savings estimate, the ratio is well above unity, implying that the systems could well be cost effective. If system developers either further improved their capability, so that they prevent a higher number of casualties, or reduced the system costs, or both, this cost-effectiveness would be further improved. The break-even costs for the modelled, generic systems (the costs at which the savings and benefits would be equal) can be calculated from the data shown in Table 28 to be £34-112.

The break-even effectiveness for a £10 system is 1-2%. For a £50 system cost, this rises to 6-7%.

4 Discussion & Conclusions

The analyses carried out as part of this study have evaluated the potential casualty benefits, and compared those to the likely system fitment costs, for four separate advanced primary safety technologies:

- Advanced Emergency Brake Systems (AEBS) for passenger cars;
- Pedestrian capable AEBS for passenger cars;
- Lane Departure Warning Systems for passenger cars;
- Youth/Family key.

The nature of the data available to make these evaluations varies between each technology, some involving predictive studies using highly-detailed UK accident records, another using the results of US Field Operational Trials, for example. This variation in data sources inevitably causes variation in the overall burdens of proof achieved.

Effectiveness (defined here in terms of the effect of the safety function on the target population) varies considerably between the four technologies assessed, as do the modelled benefit-cost ratios.

Table 29 shows a summary of the results for the four technologies and, where appropriate, the generic variants modelled. "Effectiveness" in the Table is calculated by dividing the annual casualty savings (in £m) into the overall annual costs of the casualties in the relevant target populations, and is thus defined as the proportion of the overall costs that would actually be prevented.

Table 29. Summary of system effectiveness, costs and benefits, and burdens of proof, for the four technologies

Technology	Overall effectiveness [7]	System costs (per vehicle)	Annual casualty savings (£m)	Benefit-cost ratios	Burden of proof
Car AEBS1	6-40%	£100-£500	£80-612m	0.07-2.78	Medium-High
Car AEBS2	6-40%	£125-£550	£84-614m	0.07-2.23	Medium-High
Pedn AEBS 0.6s	20-21%	£400-£800	£327-382m	0.19-0.43	High
Pedn AEBS 1s	42%	£400-£800	£673-798m	0.38-0.91	High
Pedn AEBS 2s	49%	£400-£800	£775-917m	0.44-1.04	High
LDWS	12-31%	£100-£300	£162-466m	0.25-2.12	High-V. High
Youth Key	5-13%	£10-£50	£76-247m	0.69-11.2	Low-Medium

It should be emphasised here that the burdens of proof are deduced purely from the evaluations of the casualty savings. Just as crucial to the overall benefit-cost ratios are the assumed system costs. For these, an inevitable limitation of this kind of study is that the prediction of production costs (to the vehicle manufacturers) of systems not yet fully developed or in mass production is subject to a high degree of uncertainty. The benefit-cost ratios calculated must, therefore, be treated as indicative only; any inaccuracies in the assumed system costs will alter the ratios, up or down.

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[7] Overall effectiveness = (annual casualty saving)/(overall annual costs of the casualties in the relevant target populations) in £m; calculated for each technology with more details in Section 3.

The conclusions from this study can be summarised as:

- Four generic advanced primary safety technologies have been evaluated, to identify their likely effectiveness in preventing accidents and casualties, their likely fitment costs (if fitted to all vehicles as standard), and the relationships between these two parameters (benefit-cost ratios);
- The study has used a methodology designed by TRL on behalf of the DfT (Smith et al, 2008). The methodology is intended to identify the most suitable and cost effective method of assessing the potential benefits of advanced safety systems, and to allow this assessment to be undertaken in a consistent and objective manner;
- A combination of in-depth accident studies, results of field operational trials, and STATS19 analyses have been used, sufficient to provide for medium to very high burdens of proof regarding the predicted casualty savings;
- For the purposes of this study, given the generally hypothetical nature of the technologies assessed (generic systems are assumed), a simple cost-benefit approach was considered appropriate. This reflects the steady-state ratio once the whole vehicle fleet has been equipped with the system, meaning the full annual casualty savings are achieved, and where the annual fitting costs apply only to new vehicle registrations;
- Advanced Emergency Braking Systems (AEBS) for passenger cars combine sensing of the environment ahead of the vehicle with the automatic activation of the brakes (without driver input) in order to mitigate or avoid rear shunt accidents with vehicles in front. Based on predictive, detailed, in-depth accident studies, overall the predicted effectiveness for these systems was 6-40% of target population casualty costs saved, and the likely benefit-cost ratios ranged from 0.07 – 2.78. The main factor behind this wide range was the estimated effectiveness of the pre-collision warning function of AEBS, with the best available evidence (from US field operational trials) suggesting an effectiveness range equivalent to 3-38% for the warning system. The autonomous braking component was estimated to provide some additional benefit in cases where the driver failed to react appropriately to the warning;
- Pedestrian AEBS incorporates much of the functionality of a first generation AEB system (i.e. one for rear shunts), but with the addition of a video camera to supplement the Laser or Radar systems and thus the ability to track pedestrians. Based on detailed, in-depth accident studies, overall the predicted minimum effectiveness for these systems was quite high (20-49% of target population casualty costs saved), and the likely benefit-cost ratios were similarly higher (0.19-1.04), but still generally below unity, largely because of the relatively high assumed system costs (£400-800); The higher ratios were associated with systems that started to brake earlier in the impact phase (time to collision), but the compromise with these systems would likely be a high frequency of unnecessary brake activations. These are minimum figures because of the necessary assumption that any pre-collisions warnings issued by the system would not have any effect;
- A lane departure warning (LDW) system is an in-vehicle system that provides a warning to the driver of an unintended lane departure. They are limited in their effectiveness, however, because, for example, they would be disabled at low speed (to avoid false alarms as a result of moving passed parked vehicles or pedal cyclists in urban areas) and would not be able to function properly if the lane markings were not clearly visible. Based on accident studies and US field operational trials, overall the predicted effectiveness for these systems was 12-31% of target population casualty costs saved, and the likely benefit-cost ratios were 0.25-2.12, implying that the systems could be cost effective. If system

developers either further improved their capability, so that they prevent a higher number of casualties, or reduced the system costs (to below £100), or both, this cost-effectiveness would be further improved;

- Youth Key technologies are intended to help and encourage teenagers and younger people to drive more safely. The major limitations of these systems include not being likely to mitigate any accidents where the young drivers were not exceeding the speed limit or were already wearing their seat belt, nor where they are driving their own, rather than their parents' car. Based on predictive, STATS19 accident studies, overall the predicted effectiveness for these systems was quite low (5-13% of target population casualty costs saved), but the system's likely very low cost per vehicle (£10-50) produced much higher benefit-cost ratios (0.69-11.2).

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Appendix A Top 100 cars sold in the UK in 2009

Note: Some individual Makes/Models appear more than once in the list – these relate to separate model/trim variants, e.g. petrol and diesel versions.

N	Make	Model	total	2007	2008	2009
1	FORD	FOCUS ZETEC 100	28183	0	9007	19176
2	FORD	FIESTA ZETEC 82	20057	0	3285	16772
3	TOYOTA	YARIS TR VVT-I	16748	0	1	16747
4	FORD	FIESTA ZETEC 96	12099	0	1902	10197
5	FORD	FIESTA STYLE PLUS 80	9488	0	606	8882
6	HYUNDAI	I10 COMFORT	11501	0	2677	8824
7	VOLKSWAGEN	GOLF S	8686	0	6	8679
8	FIAT	500 POP	8380	0	0	8380
9	FIAT	PANDA ACTIVE ECO	8058	0	83	7975
10	FORD	FIESTA TITANIUM 96	9650	0	1755	7895
11	FIAT	GRANDE PUNTO ACTIVE 77	8796	0	986	7810
12	VAUXHALL	CORSA ACTIVE	9347	0	1579	7767
13	HYUNDAI	I10 CLASSIC	9574	0	1862	7712
14	CITROEN	C1 VTR	7349	0	13	7336
15	MINI	COOPER	20273	4483	8610	7180
16	NISSAN	QASHQAI ACENTA DCI	7325	0	273	7052
17	VOLKSWAGEN	POLO MATCH 60	13427	102	6376	6949
18	RENAULT	CLIO EXTREME	6679	0	0	6677
19	VAUXHALL	CORSA DESIGN	22888	6996	8820	6507
20	FIAT	500 LOUNGE	6485	0	0	6485
21	AUDI	A3 E SPORT TDI	6430	0	0	6430
22	NISSAN	MICRA VISIA	6221	0	0	6221
23	HONDA	JAZZ I-VTEC ES	7031	0	865	6166
24	FORD	KA ZETEC	6135	0	54	6081
25	HYUNDAI	I30 COMFORT	6036	0	0	6036
26	VAUXHALL	ASTRA ACTIVE	6103	0	74	6029
27	VOLKSWAGEN	GOLF SE TSI	5987	0	12	5975
28	MINI	ONE	17496	3737	7835	5924
29	FORD	KUGA TITANIUM TDCI	7884	0	1983	5901
30	TOYOTA	AYGO BLUE VVT-I	12467	3236	3418	5813
31	VOLKSWAGEN	GOLF GT TDI 140	5704	0	36	5668
32	FORD	MONDEO ZETEC TDCI 140	15451	3183	6740	5528
33	FORD	KA STYLE	5530	0	57	5473
34	VAUXHALL	CORSA SXI A/C	15761	4838	4891	5350
35	KIA	PICANTO 1	5259	0	0	5259
36	FORD	FOCUS ZETEC 100	8961	2	3701	5258
37	SKODA	FABIA 1 HTP 60	8884	1342	2350	5192
38	TOYOTA	AURIS TR STOPSTART VVTI	5182	0	0	5182
39	VAUXHALL	CORSA SXI	16648	5580	4806	5178
40	VOLKSWAGEN	GOLF SE TDI	5170	0	18	5152
41	HONDA	JAZZ I-VTEC EX	6198	0	1083	5115
42	HYUNDAI	I20 COMFORT	5111	0	9	5102
43	VOLKSWAGEN	GOLF S TDI	5077	0	0	5077
44	HYUNDAI	I20 CLASSIC	5153	0	110	5043

N	Make	Model	total	2007	2008	2009
45	FORD	FIESTA STYLE 82	5476	0	469	5007
46	FORD	KA STUDIO	5029	1	32	4996
47	FORD	FIESTA ZETEC 68 TDCI	5700	0	937	4763
48	VAUXHALL	CORSA SXI A/C	18881	7048	5546	4759
49	PEUGEOT	107 URBAN	4734	2	36	4692
50	PEUGEOT	207 VERVE	4714	0	74	4640
51	VOLKSWAGEN	PASSAT HIGHLINE TDI 140	4773	0	136	4637
52	MINI	COOPER D	11024	1743	4679	4602
53	SEAT	IBIZA SPORT 84	5777	0	1182	4595
54	FORD	FIESTA TITANIUM 90 TDCI	4904	0	642	4262
55	NISSAN	NOTE ACENTA	14396	2952	7184	4260
56	PEUGEOT	107 VERVE	4220	0	0	4220
57	CITROEN	C4 GR PICAS VTR+ HDI EGSA	4436	0	218	4218
58	VAUXHALL	INSIGNIA EXCLUSIV	4199	0	44	4155
59	SUZUKI	ALTO SZ3	4115	0	0	4115
60	MAZDA	2 TS	4995	0	928	4067
61	VAUXHALL	CORSA ACTIVE	4691	0	662	4029
62	HONDA	CR-V EX I-CDTI	13821	5087	4570	4011
63	FORD	FIESTA ZETEC S 120	4653	0	744	3909
64	VOLKSWAGEN	POLO MATCH 80	9671	54	5761	3856
65	MERCEDES	C180 KOMP SE BLUEEFF-CY A	3841	0	19	3822
66	SMART	FORTWO PASSION MHD AUTO	4336	0	526	3810
67	VAUXHALL	CORSA LIFE	14204	5244	4434	3734
68	CITROEN	C1 VT	3738	0	10	3728
69	VAUXHALL	ASTRA SXI	11836	4719	3421	3696
70	FORD	MONDEO TITANIUM TDCI 140	7550	239	3675	3636
71	VAUXHALL	INSIGNIA SRI 160 CDTI	3628	0	4	3624
72	VAUXHALL	INSIGNIA EXCLUSIV 160CDTI	3680	0	57	3623
73	FORD	FOCUS TITANIUM 100	5348	0	1726	3622
74	FORD	FIESTA TITANUM AUTO	3591	0	64	3527
75	MINI	COOPER	3478	0	0	3478
76	PEUGEOT	107 URBAN	3492	0	25	3463
77	SEAT	IBIZA SE	4620	0	1247	3373
78	RENAULT	MEGANE DYNAMIQUE VVT	3496	0	124	3371
79	CITROEN	C3 PICASSO VTR PLUS HDI	3324	0	0	3324
80	FORD	C-MAX ZETEC	13244	3147	6757	3307
81	RENAULT	CLIO DYNAMIQUE 16V	4325	0	1056	3267
82	HONDA	CR-V ES I-CDTI	12175	5338	3519	3263
83	AUDI	A4 SE TDI 6SP	9626	0	6375	3251
84	TOYOTA	YARIS TR VVT-I S-A	3227	0	0	3227
85	MAZDA	2 TAMURA	3212	0	0	3212
86	PEUGEOT	308 S DT	8021	281	4529	3211
87	TOYOTA	PRIUS T SPIRIT VVT-I CVT	3195	0	0	3195
88	FORD	KUGA ZETEC TDCI	4721	0	1532	3189
89	MERCEDES	C220 SPORT CDI A	10335	2146	5059	3130
90	FORD	FOCUS ZETEC TD 115	7498	0	4396	3102

N	Make	Model	total	2007	2008	2009
91	VAUXHALL	ZAFIRA EXCLUSIV	4437	0	1357	3080
92	FORD	FIESTA STYLE PLUS 68 TDCI	3364	0	304	3060
93	VOLKSWAGEN	POLO E 60	9599	2644	3910	3045
94	VAUXHALL	ASTRA DESIGN	4285	253	1023	3009
95	FORD	KA STYLE PLUS	3073	0	70	3003
96	MAZDA	2 TS2	4293	0	1324	2969
97	VOLKSWAGEN	URBAN FOX 55	11981	3737	3254	2960
98	CITROEN	C4 GRAND PICASSO VTR+ HDI	3139	1	180	2958
99	HONDA	CIVIC SE I-VTEC	2956	0	2	2954
100	KIA	PICANTO 12V	3689	1	768	2920

Appendix B Makes and models of cars with LDWS in the UK in 2009

Source: Parkers, www. parkers.co.uk, accessed December 2010.

Make	Model	Variant	LDWS	Costs	Exceptions in the Variant
Audi	A4	All	✓ some exceptions	£450	S, SE, Black edition, Quattro and Technik variants only.
Audi	A5	Coupe	✓	£460	
Audi	A5	Cabriolet	✓ some exceptions	£460	S and SE variants only.
Audi	A5	Sportback	✓ some exceptions	£460	S and SE variants only.
Audi	A5	S5	✓ some exceptions	£450	Not on - S5 Quattro 5d S Tronic
Audi	A6	Saloon	✓ some exceptions	£400	Not the S Line Special Edition
Audi	A6	Avant	✓ some exceptions	£400	Not the S Line Special Edition
Audi	A6	S6	✓	£400	
Audi	A6	Allroad	✓	£400	
Audi	A8	Saloon	✓	£400	
Audi	A8	S8	✓	£400	
Audi	Q5	Estate	✓	£390	
Audi	Q7	Estate	✓	£390	
BMW	5 Series	GT	✓	£380	
BMW	5 Series	Saloon	✓	£380-£415	Standard in the 550SE
BMW	5 Series	Touring	✓	£415	
BMW	6 Series	Coupe	✓	£415	Standard on some models
BMW	6 Series	Convertible	✓	£415	Standard on some models
BMW	7 Series	Saloon	✓	£410	Standard on some models
Citroën	C4	Some variants	✓	£305	With System included: 1.6i 16V VTi Exclusive 5d / 2.0HDi 16V Exclusive (09/08) 5d
Citroën	C5	Some variants	✓		With System included: 3.0HDi V6 Exclusive 5d Auto

Citroën	C6	Some variants	✓		
Citroën	Grand C4 Picasso	Some variants	✓		
Honda	Accord	All	✓	Standard on ADAS models (£2,090) as an option	ADAS (Advanced Driver Assistance System) Vehicles only.
Lancia	Delta		✓		
Lexus	LS		✓	£2,200 Available with pre-crash system	Lexus LS (07 on) 460 SE-L 4.6 V8 4d Auto.
Volvo	S80	All	✓	£343 -£500.	
Volvo	XC70		✓		
Volvo	V70		✓	£500	

Cost benefit evaluation of advanced primary safety systems: Final report

Intelligent vehicles and advanced safety technologies have been the subject of discussion for many years and there is now a large range of production and near-production systems that claim to have significant safety benefits. The Evaluation of Safety System Technologies project took a 'bottom-up' approach, starting with small number of specific safety systems and estimating the target population of casualties and cost benefit information for these systems. This was achieved using primarily in-depth accident data, with the results being scaled up to national level (adjusting for under-reporting). The analyses carried out as part of this study have evaluated the potential casualty benefits, and compared those to the likely system fitment costs, for four separate advanced primary safety technologies:

- Advanced Emergency Brake Systems (AEBS) for passenger cars;
  AEBS1 – potentially able to mitigate/avoid all moving target rear shunts but those with stationary targets only if closing speed 40 mile/h or less;
  AEBS2 – potentially able to mitigate/avoid all rear shunt impacts regardless of whether target (shunted) vehicle is stationary or not;
- Pedestrian capable AEBS for passenger cars;
  0.6s/1s/2s systems – applies full braking 0.6s/1s/2s before a detected, imminent impact with a pedestrian;
- Lane Departure Warning Systems for passenger cars;
- Youth/Family key.

Other titles from this subject area

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