Techniques for assessing the effectiveness of vehicle primary safety features using accident data

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TECHNIQUES FOR ASSESSING THE EFFECTIVENESS OF VEHICLE PRIMARY SAFETY FEATURES USING ACCIDENT DATA

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## CONTENTS

 Executive summary i  

1 Introduction 1  

2 Research methods 1  

3 Current accident analysis techniques 1  

   3.1 Background to the problem 1  
   3.2 Accident causation studies 3  
   3.3 Predictive analyses 6  
   3.4 Retrospective analyses 8  
   3.5 Specific research studies 14  

4 Potential methods for improving current techniques 15  

   4.1 Improvements to pre-crash data 15  
   4.2 Enhanced exposure data 17  
   4.3 Vehicle performance data 18  

5 The role of human factors research 20  

6 Discussion 23  

   6.1 Analysis using current sources of accident data 23  
   6.2 Study quality 23  
   6.3 Improvements to currently available data 26  
   6.4 Proposals for future research 27  
       6.4.1 Research to meet short term objectives 27  
       6.4.2 Development of new data sources and analytical techniques 28  
       6.4.3 Development of research tools 32  

7 Conclusions and recommendations 32  

Acknowledgements 33  

References 33
Executive summary

In recent years there has been a tremendous improvement in secondary safety features of vehicles such that much higher levels of protection are offered to occupants when they become involved in a crash. Although there is still scope for substantial and worthwhile additional improvements in secondary safety, some researchers (e.g. Colinot & Lecher, 1991; Chenisbest et al., 1998; Perron et al., 2001; Becker et al., 2004) have suggested that there are limits to what can be achieved with secondary safety alone and have suggested that, in future, more cost-beneficial gains in safety may be achieved through primary safety measures and the integration of primary and secondary safety features into an intelligent safety system package. Other researchers (Rieger et al., 2005) go further and state that the future development of vehicle safety will be driven by accident avoidance much more than injury mitigation, citing the philosophy that accident avoidance is always the better solution.

At the same time as this, there is a political climate that requires rigorous cost benefit analysis to demonstrate the benefits of new systems, tests or regulations before they can be imposed on industry. This is intended to ensure that the most cost-effective solutions are prioritised such that useful safety gains can be made while minimising the burden on industry and the wider economy.

One of the main tools used in deriving such cost benefit analyses is the use of accident data to quantify the casualty reduction benefit of safety measures. However, traditional sources of accident data can be very limited in terms of their ability to accurately quantify the effects of primary safety features.

In April 2006, the TRL Academy agreed to sponsor a small project that aimed to establish current best practice in terms of using accident data to evaluate primary safety features of vehicles and to recommend ways to improve these analyses using different or new sources of data and or new improved analytical techniques such that more robust cost-benefit analyses can be achieved. In October 2006, the UK Department for Transport (DfT) also sponsored TRL and others to consider ways of improving the quantification of the benefits of primary safety features. This report describes the overall findings from both the TRL Academy and DfT sponsored research and, as such, was approximately two-thirds funded by the TRL Academy and one-third by the DfT. The work was completed in December 2006.

The main emphasis of the analysis carried out was on accident data but the role of physical and human factors tests and experimentation were also briefly considered. The work was based on a review of scientific literature and consultation with organisations that hold existing and potential new sources of data. The main conclusions and recommendations are reproduced, below.

1. The literature reviewed was in general agreement that the relative importance of primary safety research was increasing and that this type of research had different needs for accident data that were not currently fully considered in existing databases.

2. Most of the literature identified that there were a range of difficulties and limitations in the analyses carried out. However, appropriate analytical techniques were able to overcome many of these difficulties and there were many high quality robust analyses of primary safety features in existence.

3. It was found that the quality of analyses in the field was quite variable. Some of this variation was directly attributable to limitations in the data sources but a number of studies were found that contained questionable assumptions or failed to account for potentially important confounding factors.

4. There are a number of inherent limitations in currently available data that make the evaluation of primary safety features difficult. It is important that these limitations are acknowledged and accepted by all involved in the work and where the burden of proof required is high then it may be necessary to compile a body of evidence comprising predictive accident analysis, physical tests, evaluations of the effect on driver behaviour and retrospective statistical analysis in order to gain confidence in the conclusions.

5. A range of possible research to fill gaps in knowledge has been proposed:
a. Predictive and retrospective analyses of the current range of proposed primary and e-safety systems using current data and the best of the available analytic techniques. This should have twin aims of providing an objective quantification of the benefits and relative importance of the range of safety features to the highest standard currently possible, accepting the limitations of the available data, and enabling comparison and development of increased understanding of the data and analytical techniques that can be used. This research could include:

   i. Predictive analyses of a range of new and existing measures using different techniques.

   ii. Human factors experiments aimed at validating the assumptions about driver behaviour in relation to new technologies made in earlier predictions and seeking to identify any unintended consequences in terms of distraction or behavioural adaptation.

   iii. Retrospective analyses of statistical data regarding new safety measures already on the market and comparison with the accident predictions and human factors experiments to establish whether the approaches agree on the benefits and what lessons can be learned, what new techniques or information may be required to improve predictions.

b. Investigation of the potential role of EDRs in the UK, based on the progress in the USA

c. Assessment and development of improved vehicle and exposure information

d. Naturalistic driving studies

   i. Analysis of accidents and exposure within fleets of vehicles currently equipped with after-market EDRs

   ii. Tailored accident and exposure studies based on specifically instrumenting fleets to a controlled design

e. The development of research tools such as quality assessment guidelines.
1 Introduction

In recent years there has been a tremendous improvement in secondary safety features of vehicles such that much higher levels of protection are offered to occupants when they become involved in a crash. Although there is still scope for substantial and worthwhile additional improvements in secondary safety, some researchers (e.g. Colinot & Lecher, 1991; Chenisbest et al, 1998; Perron et al, 2001; Becker et al, 2004) have suggested that there are limits to what can be achieved with secondary safety alone and have suggested that, in future, more cost-beneficial gains in safety may be achieved through primary safety measures and the integration of primary and secondary safety features into an intelligent safety system package. Other researchers (Rieger et al., 2005) go further and state that the future development of vehicle safety will be driven by accident avoidance much more than injury mitigation, citing the philosophy that accident avoidance is always the better solution.

At the same time as this, there is a political climate that requires that a rigorous cost benefit analysis demonstrates the benefits of new systems, tests or regulations before they can be imposed on industry. This is intended to ensure that the most cost-effective solutions are prioritised such that useful safety gains can be made while minimising the burden on industry and the wider economy.

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2 Research methods

The research was based predominantly on a review of scientific literature but has also involved consultation with organisations and experts involved in accident analysis for primary safety and with those that may hold data with the potential to enhance the techniques currently used.

3 Current accident analysis techniques

3.1 Background to the problem

It is well documented that using existing accident data to assess the effectiveness of a primary safety (accident avoidance) feature can be very difficult (e.g. Sandin & Ljung, 2005; Paulsson, 2005). At a simple level this is because when a primary safety feature is fully effective then there is no accident and, thus, no data for comparison (Fenaux, 2003). Research has also suggested that most available accident databases are focussed on the technical and medical description of the accident outcomes and have insufficient data on accident cause (Becker et al, 2004). A variety of methods are, therefore, used to try to overcome this fundamental difficulty and each method has strengths and weaknesses.
There are no current methods that are considered perfectly accurate and reliable and all methods have strengths and weaknesses. Generally, analyses can be broadly divided into four categories:

- **Causation studies** – these examine real world accidents to try to identify what factors in combination caused the accident. This information is usually used to highlight problem areas with the largest scope for improvement and to inform the design and development of features that could be used to avoid or mitigate the severity of the accidents.

- **Predictive studies** – these build upon causation studies by examining accidents where vehicles were not equipped with the specific feature under consideration and making calculations and/or judgements to assess whether the accident would have been avoided or mitigated if the safety feature had been present.

- **Retrospective studies** – these 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.

- **Specific research studies** – principally questionnaire surveys of drivers of vehicles, some of which are equipped with a particular safety feature, in order to compare the accident involvements of equipped and unequipped vehicles and estimate the relative risk of equipped vehicles.

Typically, predictive studies have the advantage that they can be used to predict benefits before the measure has been introduced into the vehicle fleet and can be relatively straightforward to carry out. However, in order to be accurate, there must be a detailed knowledge of how each system will perform in every accident within the dataset, including how they interact with driver behaviour. This usually means that a broad range of assumptions is required and the size of the predicted benefit will depend heavily on those assumptions. Analyses can be further limited by the range and quality of data available in the accident data source because there is often insufficient information relating to events immediately prior to impact to make accurate calculations or assessments. It can also be very difficult to take account of unintended consequences of systems, for example, where a feature changes the type of accident from the one it was intended to prevent to some other type of accident such that net benefit is reduced. Some authors (e.g. Sferco *et al.*, 2001) acknowledge that such methods tend to produce an over-estimate of benefits because of these problems.

Retrospective studies of accident data using statistical methods to allow for potential confounding factors should produce more reliable estimates of actual benefits. This is because they are directly comparing accident risk with and without the system in the real world with real drivers, thus taking account of human factors issues and any unintended consequences. However, there are a large number of factors that can contribute to the risk of involvement in an accident for a particular vehicle, such as the:

- Presence of the safety feature under consideration
- Presence of other safety features that may influence accident or injury risk
- Number of that vehicle model registered
- Mileage driven each year
- Use of different classes of road relative to other vehicles
- Age of the vehicle
- Age population of the drivers of that model
- Behavioural characteristics of the drivers (e.g. do sportier models attract higher risk drivers etc.?)

Previous research, e.g. Maycock *et al* (1991) has shown that these factors affect accident risk in a complex fashion; for example, risk is proportional to (annual mileage)^x where x is considerably less than 1. Nevertheless, statistical techniques exist which will take account of these interactions while
estimating the relative risk attributable to the presence of the system. Broughton and Baughan (2000) is one of many reports that exemplify how this may be achieved.

An inescapable limitation of retrospective studies to assess safety systems is that large numbers of equipped vehicles must be in use to provide the volumes of data that allow statistically robust estimates to be prepared. Thus, they cannot provide a priori evidence that a system will be effective and should be approved for use on the road.

The above is far from a definitive list and, to provide a perfectly accurate assessment all of these other factors must be eliminated, or compensated for, in the analysis. While it will never be possible to entirely eliminate the influence of such factors, suitable statistical methods can compensate for significant influences of factors that can be quantified. It can be difficult to identify the presence of safety features on the vehicles in the accident database and the data available in relation to exposure to risk (i.e. distance travelled on what roads, driver age and behaviour etc.) are limited. In addition to this, studies that attempt to eliminate as many variables as possible often end up with small sample sizes that are insufficient to provide statistically significant results. A range of assumptions and approximations are usually also applied in these analyses to try to overcome these problems. When these are combined with appropriate statistical techniques successful analyses are possible.

3.2 Accident causation studies

In the UK there are several major accident databases in existence and each has different priorities, strengths and limitations. These are:

- STATS 19 – GB national accident database including all injury accidents reported to the Police
- Co-operative Crash Injury Study (CCIS) – Detailed database examining car occupant injury in defined sample areas.
- UK On-the-spot (OTS) – Detailed accident database based on investigations at the scene in two defined sample areas.
- Police fatal database – A database compiled based on coding of Police fatal accident reports.
- HVCIS fatal database – A more detailed vehicle-oriented database based on police fatal accident reports but considering only accidents involving heavy vehicles.

Of these major databases, the CCIS has only a text description of the accident circumstances that can be related to the cause because it is strongly focussed on information related to the cause of occupant injury. Each of the remaining data sets has varying levels of information related to the cause of accidents. All depend upon the skill of those who investigated the accidents in reconstructing the preceding events and inferring the principal causes.

Broughton et al (1998) published a method for recording contributory factors in road accidents. This was intended for national use by the police and was designed such that it could be reliably applied by any police officers attending road accidents, including those with little or no training in accident investigation. A hierarchical system was employed where a series of precipitating factors described what happened in the accident, for example the driver failed to stop at a mandatory sign, and a larger series of contributory factors described why this failure had occurred, for example, impairment due to alcohol.

The method lists several contributory factors that are directly related to the vehicles role in the accident. Most of these factors are related to vehicle defects such as incorrect tyre pressures or defective brakes. Only one code exists that relates directly to vehicle design, which is a failure to see a pedestrian or vehicle in a blind spot. However, many of the other factors listed can be used to help identify accidents where improved vehicle design may have had the potential to avoid the accident. For example, accidents where the precipitating factor was “loss of control” could possibly have been prevented by improved handling or fitting an electronic stability control (ESC). In the pilot study
(Broughton et al, 1998), loss of control was the most frequently recorded precipitating factor being coded in 22% of the accidents.

The ‘TRL coding system’ described by Broughton et al (1998) was adopted in 1999 by 12 of the 51 British police forces to record Contributory Factors1, and became part of their routine collection of STATS19 data; 3 further forces followed in the next 2 years. Various analyses of these data have been published, e.g. Broughton and Buckle (2006). None of these related directly to specific aspects of vehicle safety, although the latter report showed that 70% of car occupant deaths in 2004 occurred as a result of loss of control.

From 2005, the STATS19 data collection was expanded to record accident causation, using a system that is based on the TRL system but differing in certain details. Thus, a consistent subset of the national STATS19 data with Contributory Factors is available from 1999 to 2004, the full national set of STATS19 data with the new Contributory Factors is available for 2005 and will continue to be collected.

The TRL system was also used to record causation in Police fatals database and the UK OTS project. However, the coding of the Police fatal database ceased in 2002.

The TRL coding system originated in a project carried out in 1994-95 as part of the LINK research programme by TRL, Ford and the General Accident insurance company (Broughton and Markey, 1996). Its aim was to provide guidance to motor manufacturers about which types of in-car equipment are most effective in helping drivers to avoid accidents. A system for coding accident causation was drawn up, and applied to 2 samples of accidents, 1,048 fatal car accidents from the TRL Police fatal database and 1,548 non-fatal accidents reported in insurance claims submitted to General Accident.

The potential effectiveness of generic types of in-car equipment for avoiding accidents was estimated by analysing the causation data that had been assembled.

The HVCIS project collects information on accident cause (Knight & Whitehead, 1999) related to the driver, environment and vehicles and does record pre-crash information from accident reconstruction. The behaviour factors coding is relatively simplistic compared with some other causation studies and, again, the vehicle factors relate mainly to vehicle defects.

A new method of recording the causes of accidents was also developed for the UK OTS project (Hill & Cuerden, 2005). Each road user that was “active” in the accident is assigned a series of interaction codes that define how that road user has interacted with others involved in the accident. These codes are grouped into seven sub-categories:

- **Legal** - e.g. disobeyed signs or road markings or was legally unfit to drive due to alcohol consumption
- **Perception** – Expecting, looking, planning (e.g. did not look for other vehicle or saw but did not perceive a hazard)
- **Judgement** – understanding, deciding, planning (e.g. interpreted information from a road sign incorrectly or followed too closely)
- **Loss of vehicle control** – e.g. due to excessive braking or excessive cornering
- **Conflict** – interpersonal communication (e.g. adopted a path conflicting with that of another road user or behaved aggressively toward another)
- **Attention** – e.g. suffered a distraction due to a mobile phone or was distracted by another road user.
- **Impairment** – e.g. suffered illness or impairment due to fatigue.

The detailed interaction codes in OTS have been used in some simple analyses but, as yet, are largely untested in a large scale analysis of accident causes. However, they may prove to be an informative

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1 The term traditionally used by the British police
source of information for the identification of problems that vehicle primary safety features could solve.

In Germany, the German in-depth investigation accident study (GIDAS) (Otte et al, 2003) is similar to the UK OTS project. It aims to provide in-depth information associated with both accident and injury causes and outcomes and does collect detailed information on the pre-crash phase of the accident.

Paulsson (2005) describes the development of a method for an in-depth accident causation data study as part of the EC SafetyNet project. The project aims to develop a European causation database and data will be contributed from the UK, Finland, Sweden, The Netherlands, Germany and Italy. The data will be based on in-depth studies at the scene of accidents immediately after it has occurred, near time investigations, which may include scene information retrieved shortly after the accident, and retrospective investigations which take place a few days after the accident. The UK OTS data will be provided by Loughborough University.

The methodology for attributing causation factors to the accidents will be based on a method known as DREAM (Driving Reliability and Error Analysis Method). This method is intended to capture information from a Human-Technology-Organisation perspective and is based on identifying critical events and linking those to contributory factors that are divided into general causes and specific causes. The contributing factors are divided into those related to the road user, the vehicle, the organisation and the infrastructure. The vehicle related contributory factors vary substantially from those described by Broughton (1996) and Hill & Cuerden (2005) in that they do contain contributory factors related to the design of the vehicle and not just to maintenance defects. Information on contributory factors related to vehicle design includes inadequate HMI, ergonomics, design of communication devices, and inadequate construction (e.g. headlamps provide insufficient light). However, there is also a category for unpredictable system functions or characteristics. This code could potentially be used to identify accidents where a driver negotiated a bend at speed and unpredictable handling led to a loss of control. In most causation factors system this would get attributed solely to the driver because of the legal perspective that states that a driver has the obligation to drive within the limits of the vehicle. However, a different vehicle with different handling properties would not have had an accident when subjected to the same inputs.

A Swedish project called the Factors influencing the Causation of Accidents and Incidents (FICA) also bases its causation methodology on the DREAM method applied to in-depth accident cases.

Chenisbest et al (1998) describe the development of the European Accident Causation Survey (EACS) database. This project collected data from in-depth at the scene accident investigations in France, Germany, Finland and Italy using a common set of forms and coding protocols. Spain was added to the programme and in Phase 3 The Netherlands was due to be added (Sferco et al, 2001). The aim of the study was to focus on the vehicle kinematics and driver behaviour in the immediate pre-crash phase of the accident and to populate the database with 2,000 accidents where this information was available.

Toth et al (2003) describe the development of a causation study for accidents involving large trucks in the US, within the framework of the National Automotive Sampling System (NASS). This is also based on an at-the-scene methodology and contains a system for recording accident causation using a critical events methodology that has elements in common with the DREAM method described for other studies, although the only vehicle factor described in the paper was a generic “vehicle condition related factor”. NHTSA have now also implemented a new causation study, the National Motor Vehicle Crash Causation Survey (NMVCCS), which will build on the truck causation survey methods to survey 5,000 crashes per year over a six year period using driver interviews and at the scene investigation.
3.3 Predictive analyses

Predictive studies are essentially an extension of causation studies that use the causation data and detailed accident circumstances to estimate the effect that a particular safety system would have had if it had been fitted to relevant vehicles in the accident. This analysis can take place at a number of levels. Langwieder et al (2005) present an analysis that identifies the number and proportion of accidents involving cars where skidding occurred in order to highlight the maximum number of accidents where ESP had the potential to avoid an accident. However, this study made no estimate of how many of those cases would actually have been avoided or mitigated by the presence of ESP. An analysis of accidents involving trucks was also carried out by the same authors where an assessment of whether ESP would have been of influence was made on a case-by-case basis, in order to come up with a more definitive estimate.

Sferco et al (2001) carried out a predictive analysis of the effect of ESP based on the EACS database. This analysis also relied on a case by case analysis of the data and a subjective expert opinion on whether the presence of ESP would have definitely not, maybe, probably or definitely influenced the accident or whether it would have definitely avoided it. Although it was not entirely clear in the paper it appeared that the final estimate of benefits was made by assigning a probability weighting to the various confidence categories.

Becker et al (2004) embodied the concept of different levels of analysis in the definition of a “field”, an “effectiveness” and an “expected benefit”. The field was defined as all accidents and casualties that a given safety feature could potentially affect. The effectiveness was defined as the proportion of the field that the system was actually predicted to prevent and the expected benefit was the product of the two. Given that any particular safety feature will not prevent or mitigate every accident to which it is relevant, the expected benefit will always be less than its field. In this context, Langwieder’s analysis (2005), described above, defined the field of application for ESC, while Sferco et al (2001) attempted to define the expected benefit. Becker et al (2004) note that the procedure is suited to gaining fast and inexpensive results, which can be used in earlier conceptual studies before significant numbers of vehicles equipped with the safety system are on the market. The authors also noted that while the identification of the field of application could be carried out very precisely, accurately determining the effectiveness can be very difficult and can be carried out using engineering judgement, tests using a simulator etc. Becker et al (2004) recommend basing the estimated benefit on more than one method of determining effectiveness in order to provide a range of predicted benefits that reflects the potential variation in the methods.

Rieger et al. (2005) used GIDAS data to predict the change in accident distribution that may occur when ESP systems become prevalent in the vehicle fleet. The analysis is based on previous findings suggesting that ESP could prevent 80% of all skidding accidents. The GIDAS data is used to identify the circumstances of skidding accidents and the proportion prevented by ESP were applied to predict the changes in accident types that would occur. The paper stated that the advantage of this approach was that it enabled the future priorities in safety to be predicted at a time when the numbers of vehicles in the fleet actually equipped with all modern safety features was still very low. A key point in the paper was the prediction that lateral pole impacts would be greatly reduced by ESP, thus meaning that measures to improve occupant protection in such crashes were of lesser importance than analysis of current accident statistics would suggest.

Millington et al. (2006) investigated the effect of ‘A’ pillar obstruction on the causes of accidents using a predictive approach based on UK on-the-spot data. The OTS database was analysed to identify specific accident types where “looked but did not see” was considered to be a contributory factor and criteria were defined for selecting cases where ‘A’ pillar obstruction could have been a factor. Where new accident cases met these criteria, additional investigations were carried out to gain data for a detailed study. These selected cases were then fully reconstructed into a three-dimensional computer visualisation of the accident. This involved identifying driver eye positions whilst at the scene and then digitising the front section of vehicles identical to those involved in the accident in order to accurately measure the obstruction caused by the pillars. Running the visualisations with the predicted blind spot enabled a measurement of how long collision partners would be obstructed by the
‘A’ pillar for in the period immediately prior to a collision. Although the study showed that ‘A’ pillar obstruction had the potential to contribute to the cause of some accidents the report highlighted the difficulty of rigorously proving that this was the cause because it was impossible to take into account all of the human interactions that could have occurred, such as moving the head to look around the pillar. The report also highlighted the problems of small sample size, which frequently occurs when working at the level of detail that is required for accurate reconstruction of pre-crash movements.

Page et al. (2005) present a predictive study of the benefits of brake assist systems for passenger cars. This analysis makes a set of assumptions about how brake assist will affect braking behaviour in the lead up to an accident. Information from an accident database was then used to identify cases where brake assist may have influenced the outcome. The cases selected were those where brake assist was not fitted and skid marks were left on the road surface at the scene. For all these cases the assumptions are used to re-calculate what the collision speed would have been if brake assist had been fitted. Injury risk functions are then used to estimate the casualty reduction effect of the reduced collision speeds.

A similar analysis on the effects of brake assist on accidents involving pedestrians was reported by Hannewald and Kauer (2004). This was a predictive study based on GIDAS data using a similar method to that employed by Page et al. (2005). However, in this case the assumptions used were quite different and the validity of those assumptions was questioned by Hardy and Lawrence (2005). Page et al. (2005) assumed that brake assist reduced the amount of time taken for a driver to reach full emergency braking. This meant that in their data set they had recorded the length of skid marks and had calculated collision speed and the speed at the time the tyre marks began. They had then estimated a speed at the start of braking, which was based on an average value of the time taken to reach full braking derived from their human factors research on the subject and an average deceleration of half of maximum was assumed for this time. The main assumption, based on human factors research was that brake assist would reduce the time taken to reach maximum braking by half. A revised collision speed was then calculated based on the reduced time. A key point here was that it was assumed that in the phase where tyre marks were left on the road, brake assist could not increase the deceleration so this always remained the same.

By contrast, Hannewald and Kauer (2004) had assumed the time to reach full braking was the same with and without BAS. The main benefit in their study was derived by using the collision speed, travel speed and distance between the two recorded in the GIDAS database to derive a mean deceleration. Where the mean deceleration was more than a nominal minimum but below a nominal maximum it was assumed that brake assist would increase the deceleration to a maximum. Revised collision speeds were then calculated and compared to injury risk functions to estimate benefits. The problem with this approach was that the collision and travel speeds recorded in the GIDAS data have to be derived from traditional accident reconstruction techniques. In the main, this will mean that they are derived from tyre marks at the scene combined with estimates of tyre road friction to estimate the deceleration. If tyre marks are being left at the scene then it is clear that the vehicle is very close to maximum braking so it is difficult to see how brake assist could improve deceleration any further. This highlights the importance of using clear and visible assumptions in predictive analyses and also the importance of data analysts understanding the limitations of the source of accident data being used. It is also important for those reconstructing accidents and compiling accident databases to understand the needs of the analysts and end-users of the data.

Desfontaines et al. (2001) describe the use of accident data to evaluate the benefits of a safety demonstrator truck developed by Renault in France. They describe an on-the-spot truck accident database, compiled by CEESAR in France, containing 715 in depth accident investigations where trucks were involved. They described a method where relevant accident cases were selected for each safety measure on the truck, highlighting the problem of small sample size in some cases. The crashes were then re-constructed using PC CRASH software for each accident in the sample to determine the most probable scenario leading up to the collision. The parameters of the reconstruction were then modified in a way to reflect the characteristics of the safety system in order to identify the physical changes that this brought about in the crash situation and, thus, to identify the casualty benefits. This analysis was, in some cases, combined with the experience and observation of the analysts.
This type of analysis was carried out for each safety system fitted to the demonstrator vehicle. One problem highlighted by the authors was the difficulty of identifying and quantifying the overlap in predicted benefits between different systems in order to gain an accurate estimate of the overall effectiveness of the package of changes.

Becker et al (2004) also describe the use of modelling when carrying out predictive accident analyses but they divide it into two levels. The first level involves carrying out automated analysis of GIDAS data and then using relatively simple models to automatically simulate the accident outcome if the safety feature of interest had been fitted. The predicted benefit is then the difference between the actual and the simulated outcomes. The report highlights the limits of this approach. The first can be that the accident data available is not always sufficient to enable the desired safety feature to be modelled in an objective way that can be automatically applied. The second is that the actions of the driver cannot be modelled so any safety system whose function depends heavily on driver behaviour cannot be modelled. An example analysis that used this method to assess the benefits of brake assist systems suggested that approximately 200 fatalities could have been prevented by the universal use of brake assist on all passenger cars in Germany in 2003.

A second modelling approach was described by Becker et al (2004). This was essentially a more detailed version of the first, carried out using detailed accident reconstruction software on a case by case basis. This approach allowed more safety systems to be assessed in more detail because arbitrary data on items that were not available in the accident data could be added to the model. However, driver behaviour remains a limitation of the process because the driver’s actions have to be modelled in a detailed analysis. The authors of the report also state that the method cannot be used to assess a representative number of accidents and, thus, cannot be used to predict national benefits. Although not specifically stated in the report, it is assumed that this latter limitation is considered in respect of time and cost constraints.

The HVCIS project (Knight & Whitehead, 1999) routinely carries out predictive analyses on a wide range of safety measures, including both primary and secondary vehicle safety as well as other environmental or infrastructure measures. For each and every fatal accident coded onto a database from a police report, an extensive list of safety measures is considered. A set of coding instructions defines the assumed characteristics of the measure and the circumstances in which it should be considered. Depending on the measure, the judgement as to whether it is applicable can be largely subjective but can also be related to calculations and reconstruction of the accident data. In order to help make the analysis more consistent a probability scale is applied to each measure to reflect the confidence with which the analyst believes the measure could have been beneficial. Knight and Whitehead (1999) also state that the benefits predicted for individual safety measures cannot be summed to predict the benefit of a suite of changes because of the fact that one measure might prevent an accident where a severity reduction measure would also have been expected to be beneficial.

All of these analyses identify the potential for accident reduction rather than the actual change that would occur if the new measure were implemented. They generally assume that if the measure had been implemented then the behaviour of the drivers involved would not have been affected. If in reality drivers’ behaviour is modified then the actual reduction will differ from the potential reduction. Section 5 considers human factors research, and the literature suggests that the actual benefit is generally less than the potential benefit.

3.4 Retrospective analyses

Elvik and Vaa (2004) present detailed information on statistical methods and techniques for defining and assessing road safety problems of all types. They define a taxonomy of factors influencing road safety, which defines the number of casualties as the exposure multiplied by the probability of an accident occurring multiplied by the consequences of an accident occurring. Each factor in this taxonomy can be divided into sub categories. The authors defined exposure as the amount of travel on the road but noted that there could be different modes of travel (for example, pedestrian, car bus etc.) and a different mixture of modes in different places. The book also highlighted that there were a very
large variety of risk factors relating to the probability of an accident occurring and the consequences of the accident and that each of these could be divided into risk factors relating to infrastructure, vehicles and road users.

When attempting to quantify the effect of a primary safety measure the main item of interest is the effect that that measure has on the probability of accident occurrence. It can be seen very simply from the equation described by Elvik and Vaa (2004) that, in order to identify changes in the probability of accident occurrence, both the exposure and the consequences must be known.

Exposure to risk is generally taken to mean the amount of travel but it is not always that simple. Elvik and Vaa (2004) highlight that there are different measures of travel, ideally the amount of person travel would be used but more often it is the traffic volume (vehicle kilometres) that is available and pedestrians and cyclists tend not to be included because there are no reliable counts of their numbers. The relationship between traffic volume and the number of accidents can also vary by type of accident. For example, Elvik and Vaa (2004) cited Norwegian research suggesting that for a 1% increase in traffic volume, motorcycle accidents would increase by 0.75% whereas pedestrian accidents would increase by 1.1%. This relationship will also change in different areas where there are different traffic mixes and in different road environments. In addition to this, the relationship between traffic volume and accidents is not necessarily linear. Elvik and Vaa (2004) show an example of an analysis of pedal cycle casualties in 15 European countries that shows that the fatal casualty rate per million pedal cycle kilometres increases exponentially where the average number of kilometres cycled per inhabitant decreases. An analogy of this might be where driver ‘A’ drives double the annual distance of driver ‘B’ and is, therefore, exposed to greater risk of an accident. However, the risk of an accident for driver ‘B’ may not be twice that of driver ‘A’ because driver ‘B’ is a more experienced driver spending a greater amount of time on safer roads such as motorways. Mathematically, the dependent variable (e.g. probability of being injured in a year) is a function of various factors and the relationships may well be non-linear. With modern methods and computers, however, these conditions are easier to model and “test” groups can be established to validate any findings.

Despite all of these variations, Elvik and Vaa (2004) do conclude that there is little doubt that traffic volume is the single most important factor that influences the number of road accidents. However, they also highlight that accident rates per unit of traffic volume must be used appropriately if the results of a study are to be considered valid. This means that when making comparisons, the exposure of the two groups must be consistent and other major risk factors must be either identical in each group or controlled for with additional relationships.

In the UK, the Department for Transport (DfT, 2005) collect traffic and travel information to estimate national exposure levels. However, this information is aggregated by mode of transport such that the traffic volume and passenger traffic is only known at the level of “cars”, “buses” and “heavy goods vehicles” etc. When considering exposure in studies of the effect of safety features fitted to cars this information can be used to analyse any change in the frequency of accidents or severity of injuries as a result of a mandatory introduction of a new safety feature on all cars at one particular time. However, it is not sufficient to enable comparison of vehicles with inherently different fundamental safety performance or where different safety devices have been voluntarily fitted to some vehicles and not others. It is highly likely that different models of cars will experience different exposure to risk. It is likely that a small hatchback in the “micro” class will travel a shorter distance each year than an executive saloon and it is also likely that the characteristics of that exposure will differ in that they will be driven in a differing mix of road environments. In the UK, there is no published information on the traffic volume divided by specific make and model and it is believed that this is true in most, if not all, countries around the world.

In the absence of exposure data relating to the traffic volume for specific models, researchers aiming to quantify the effect of primary safety features by comparing models of car with different characteristics have had to use alternative measures of exposure. These alternative measures can be broadly categorised into two groups:

- Vehicle registration data
Induced exposure methods

The use of vehicle registration data is a direct substitute for traffic volume data in that it is used in the same way to generate accident rates per 1,000 vehicles registered. While this does allow some of the exposure to be taken into account because some models are much higher sellers than others, it does not account for the potential different use of vehicle. For example, the fact that many vehicles in the Ford Mondeo class may be driven by company drivers averaging 20,000 miles/year but that other cars, perhaps in the supermini class may only average 10,000 miles/year. Despite this limitation several researchers have used the technique with some degree of success, particularly in recent studies of the effectiveness of electronic stability controls (ESC) where it has been possible to limit the samples in a way that controls for the lack of exposure data to some extent.

Aga and Okada (2003) studied the effectiveness of ESC in Japan, based on comparison of accident rates per 10,000 vehicles registered for vehicles with and without the system fitted and found substantial differences in the accident rates. The analysis was based on three Toyota models that had introduced ESC during model “face-lifts”. By restricting the analysis in this way to three identical models with and without ESC it can be argued that the lack of a traffic volume measure has little impact because it is reasonable to assume that the models would have appealed to the same population of drivers and would, on average, have been driven approximately the same distances unless other changes to the vehicle had a substantial affect.

The results were that the accident rate for severe accidents was found to be substantially lower in ESC-equipped cars, although there was less difference when accidents of all severity were considered. However, the paper did not report whether the observed differences were found to be statistically significant or what the confidence intervals were on the observed changes so it was difficult to assess the quality of the analysis in statistical terms.

Farmer (2004) studied the effect of ESC in the US. Vehicles were identified where ESC had been introduced as standard in one particular model year but no other safety related design changes had taken place such that there was always a directly paired comparison between models with and without ESC. The models were grouped by the presence, or otherwise of ESC, and the number of vehicles registered for each group was defined to produce a number of registrations for ESC equipped and non-equipped cars. A rate of accidents per 100,000 vehicle registrations was defined for the non ESC group and then multiplied by the number of registrations for the ESC-equipped group to produce the number of accidents that would have been expected from the ESC-equipped group if there was no difference in risk between the two groups. The actual number of observed crashes for the ESC-equipped group was then divided by the expected number of crashes to produce a risk ratio, such that a value less than one implied a lower accident risk in ESC-equipped vehicles and a value greater than one implied an increased risk.

The results of the analysis by Farmer (2004) were discussed in terms of statistical significance and those that were not statistically significant were treated as indicative only. One of the main findings was that cars equipped with ESC had a single-vehicle crash risk that was 41% lower than non-ESC cars. This result was statistically significant and had a confidence interval of a 33% reduction to a 48% reduction. However, the study also noted that the sample size was not large enough to find statistically significant results if the accident types were divided into sub-categories of too much detail. For example, the study did not have enough statistical power to identify whether the presence of ESC reduced the incidence of side impacts with poles and it was not possible to compare different vehicles within the groups to investigate whether fundamental handling performance of the vehicles had any interaction with the ESC performance or whether any particular ESC type was better than another.

It can be seen that this method of compensating for the lack of detailed exposure data can have some success but it also introduces inherent limitations. For example, physical testing of ESC has suggested that the system interacts with the fundamental handling performance of the vehicle such that at the

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2 Observe, however, that accident liability is not directly proportional to annual mileage, so information about annual mileage is not sufficient to compensate fully for differences.
extremes it is possible that a very good handling car without ESC can be more responsive and stable than a very bad handling car with ESC. This suggests that a car with ESC should meet a suitable minimum performance standard in order to avoid using ESC as a cheap method of covering up bad handling performance rather than using it to enhance a car that was already good to begin with. The performance of a car in this respect could also be objectively quantified and published in order to provide incentives for manufacturers to exceed the minimum standard of performance. However, the currently available accident data only shows a benefit of ESC-equipped versus non-equipped cars. This makes it very difficult for policy makers to be sure that the cost of introducing such tests and assessments will be justified in terms of casualty reduction. Studying the methods used by Farmer (2004) and Aga and Okada (2003) shows that the analyses are based on paired comparison of cars. This means that the fundamental handling behaviour of both groups of vehicles is identical, thus specifically excluding any possibility of assessing the influence of fundamental handling in the grouped comparison. Although it would, in theory, be possible to make some estimate of effects by comparing the risk between different pairs of vehicles in the group, the studies so far have had insufficient sample size to achieve this and other variables would remain an influence in the analysis. The available accident data cannot, therefore, be used to either support or deny the existence of a relationship between accident occurrence and the handling performance of ESC-equipped cars.

Many studies have used alternative methods in order to avoid the need for exposure data and these methods have been generically referred to as “induced exposure” methods. Page et al (2005) describe an analysis of the observed effects of brake assist systems (BAS) using induced exposure methods. The method was based on analysis of French national accident data and involved dividing the accidents into groups: those that were relevant to brake assist and those that were not. The involvement of vehicles that were and were not equipped with BAS in each group of accident types was then compared using an effectiveness measure, which in this case was defined as an odds ratio. The odds ratio was designed to be a measure of the relative risk of being involved in a BAS relevant accident for BAS equipped cars compared with non-BAS cars. The paper acknowledges that the results of the analysis can be very dependent on the choice of the effectiveness measure and that, in isolation, this was a crude measure that ignored other explanatory variables. In order to improve the effectiveness method these other explanatory variables, or confounding factors, must be accounted for. Page et al. (2005) describe accounting for the presence of ESC on vehicles by eliminating accidents that were relevant to ESC from the group of accidents defined as not relevant to BAS and using logistic regression to estimate an adjusted odds ratio considering confounding factors such as:

- Driver age and gender
- Vehicle age and Year of accident
- Pavement status (dry/wet)
- Location of accident

No details of the precise nature of the adjustments were provided in the paper.

The results of these analyses showed an indication of a reduced risk for BAS vehicles but the results were not statistically significant even when accidents of all severities were considered. The paper cited the fact that various restrictions in the data to account for confounding factors had reduced the sample size substantially. In particular, Page et al (2005) noted that it was very difficult in France to identify vehicles in the national accident database where sufficient information was available to robustly specify the safety equipment fitted. This had led them to restrict the analyses to just two models of car where the information was known from their links with the manufacturers, thus greatly restricting the available sample size.

Kreiss et al (2005) present a methodology that they state could be applied to the investigation of possible effectiveness of a general primary safety function. As an example, they applied the method to an investigation of the effects of ESC using German national data. It is worth noting that the report
stated that investigation of the effectiveness of ESC for specific makes and models of vehicles was specifically excluded.

The method proposed by Kreiss *et al* (2005) was also an induced exposure method. The first step involved defining accidents where the feature could definitely have been of influence and those where it definitely could not have been of influence. Any accidents where it was not certain that the feature could have been of influence were excluded from the analyses. For each accident one of the vehicles has to be specified as the assigned vehicle which the analyses will focus on and for this vehicle it has to be possible to identify whether the primary safety feature of interest is fitted. The paper acknowledges that even these first steps can be difficult because the large data sources required for appropriate sample sizes often do not contain sufficiently detailed or accurate information about the accident to be able to definitively conclude that the primary safety feature is relevant or not in all of the accident cases. The authors also acknowledge that information on whether a case vehicle is equipped with certain features is difficult. They state that the make, model and date of first registration can usually be extracted from the accident database but that input has to be sought from manufacturers to determine its equipment level. They state that this usually results in three equipment groups:

- Cars most likely equipped with the safety function
- Cars most likely not equipped with the safety function
- Cars for which the equipment is unknown

Again, cases where the information is unknown must be excluded from the analyses, thus further reducing sample size, and there is the potential for misclassification of the remaining cases. Kreiss *et al* (2005) state that such misclassification of accidents and features will lead to an underestimate of the true effects of the primary safety feature under consideration.

The Kreiss *et al* (2005) conclusion that misclassification leads to an under-estimate of effects is an important one when considering the ability to assess primary safety features in the UK. For example, it is generally considered that fields such as “skidding” in the STATS 19 database have a lot of potential misclassification within them. Therefore, if an analysis of braking performance, ABS or ESC was based on classifying accidents using the skidding field, then the estimate of benefits would be expected to be a large under-estimate. This means that there has to be a large “true” underlying effect of the feature being assessed in order to have any chance of registering statistically significant results. If policy decisions rely solely on this type of statistical analysis then the benefits accrued from a larger number of smaller safety improvements could be ignored such that only large step changes in safety were pursued.

Kreiss *et al*, (2005) also use an odds ratio as the measure of effectiveness of a feature and recommend studying the influence of confounding factors by dividing the analyses by factors such as year of registration, driver gender, road conditions etc in order to identify whether there is a different outcome due to one or more of the factors.

Becker *et al* (2004) describe a retrospective effectiveness measure E, defined as:

\[
E = \frac{\text{Share of accidents without system}}{\text{Share of accidents with system}}
\]

They use ESC as an example to illustrate the method. Using data from the GIDAS database they showed that 15% of passenger cars without ESC that contributed to the cause of an accident skidded but that only 8.3% of those with ESC skidded. They then calculated using the formulae above that the effectiveness was such that 44.7% of all accidents caused by a passenger car skidding could be prevented if all passenger cars were fitted with ESC. It should be noted that this specific example does not control for the possibility that the skidding accidents were changed into some other accident type rather than avoided altogether. To assess that possibility the analysis would need to be repeated on all other accident types and any percentage effects converted to absolute numeric effects to compare the net benefit.
In addition to this, Becker et al (2004) used German national statistics to assess the time series effect of ESC by studying the involvement of a specific VW car model in loss of control accidents during the time that ESC was introduced to that model. It was shown that “leaving the road” accidents reduced substantially as a proportion of all accidents involving that model. An analysis of all other car models in the database showed only a slight reduction. The methods used and results obtained were very similar to an analysis of Daimler Chrysler car models during the time period when they were first fitted with ESC (Unselt et al, 2004).

Most of the studies reviewed in this report have used an estimate of effect based on the odds ratio. Elvik & Vaa (2004) agree that this is the most common estimate of effect but list other commonly used estimators of effect as, simple odds, ratio of odds ratios, ratio of relative risk and the accident rate ratio. It should be noted that the choice of appropriate estimator should not be arbitrary, it is conditional on the form of relationship being modelled.

The concept of study quality or validity is also considered by Elvik & Vaa (2004). They cite a definition taken from Cook and Campbell (1979), stating that “Validity denotes the degree to which research approximates the truth” and the importance of the words “approximates the truth” are highlighted because researchers can never claim to know the truth for certain. Study quality can be influenced by a large number of characteristics of study design and conduct and these variables are discussed in detail. Reviews of previous studies are carried out to show the extent to which research can be misleading as a result of poor study quality and methods for assessing study quality are discussed. Elvik & Vaa (2004) state that ideally the assessment of study quality ought to be standardised and expressed in numerical terms but that no formal assessment of quality has yet been developed. Where assessments of study quality are used they are usually systematic but not numerical. Although research is currently being carried out to develop such a method it is not yet complete and has proved more difficult than originally anticipated.

Elvik & Vaa (2004) also describe a method of combining and summarising the results of a number of different analyses. They define the meta-analysis method as “a quantified synthesis of results of several studies that have evaluated the same road safety measure, stated in the form of a weighted mean estimate of effect”. This is a potentially powerful technique to more objectively compare the merits of different studies in order to come to a common estimate of effect and can include assessments of study quality in the weighted mean output.

However, all of the different effect estimators can give misleading results, even when such techniques as meta-analysis are used. Knight et al (2006) reviewed a meta-analysis of a large body of research relating to Daytime Running Lights (DRL) (Elvik et al, 2004). The individual research studies included in the meta-analysis typically used one of three estimators of effect:

- The accident rate ratio (ARR) – is the ratio of accidents per kilometre of driving for cars using DRL to accidents per kilometre of driving for cars not using DRL.
- The odds ratio (OR) – is calculated as the ratio of (multi-vehicle daytime accidents with DRL to all other with DRL accidents) divided by (the ratio of multi-vehicle daytime accidents before DRL to all other before DRL accidents).
- The ratio of odds ratios (ROR) – is calculated as the ratio of (multi-vehicle daytime with DRL accidents by single-vehicle daytime with DRL accidents) by (multi-vehicle night-time with DRL accidents by single-vehicle night-time with DRL accidents) all divided by the same double ratio but calculated for accidents before DRL was introduced.

These definitions are consistent with the definitions expressed in other research reviewed for other safety measures. A simulation of what each measure would conclude given a certain change in one or other of the accident groups of interest was carried out and it was found that each measure controlled for confounding factors in different ways. If only the group of accidents expected to be influenced by the measure (multi-vehicle daytime crashes in the case of DRL) was changed then all three measures give consistent results. However, where other changes take place it becomes more complex and each measure can give different conclusions. In order to be confident in an effect it would be desirable that differing analyses such as these were available and that all gave at least a consistent direction of
change even if the magnitude of the change was variable. Most of the research evaluating primary safety features that has been studied in this review has used only a single estimator of effect, which means that for each individual study there is less confidence. However, different studies have used different estimators and it would be interesting to carry out a meta-analysis to try to assess the influence of different measures as well as an overall estimate of effect.

One limitation of retrospective analyses of accident data is that it cannot be used to evaluate safety measures until after they have entered into service and start to have accidents. Rieger et al. (2005) showed that this can take a substantial amount of time. Analysis of the number of VW Golf cars (one of Germany’s top selling models) within the GIDAS database showed that it took about 5 years from the introduction of the model before there was a sufficient number of accident cases that involved that model to enable robust statistical analysis. The authors highlighted the delaying effect that this could have on the evaluation of new technology and the development of enhanced versions if this was the only data relied upon. Nevertheless, such retrospective assessments should be useful to check the accuracy of the earlier predictive analyses, in the hopes of building confidence in their predictions.

3.5 Specific research studies

The previous Sections have considered the uses of data that have already been collected, for example, vehicle registration data or STATS19 accident data. An alternative approach exists: to collect data as part of a specific research project. While more expensive than the analysis of data that already exist, this approach can overcome many of the problems identified above by collecting all details that the researchers judge to be appropriate.

A relevant example is a study of the effectiveness of ABS that was carried out by Broughton and Baughan (2000). US studies had been able to investigate ABS using data that already existed because ABS was fitted to several popular car models as standard from a specific date. The US researchers were able to compare the accident records of the newer (equipped) cars with the records of the older (unequipped) cars, and they could plausibly attribute any differences to the presence of ABS in the newer cars.

This approach was not feasible in Great Britain because no popular car models had been equipped with ABS as standard in this way. Instead, a large-scale questionnaire survey was carried out. The questionnaire asked about the range of factors that previous studies had shown might affect accident liability. It also asked whether the respondent’s car was fitted with ABS, and a range of supplementary questions relating to drivers’ behaviour, attitudes and knowledge. Statistical analysis of the data supplied was able to estimate the effectiveness of ABS – taking account of the other factors which influenced accident liability significantly such as age, sex and annual mileage. The analysis was able to show that effectiveness varied among drivers, and to test potential explanations based on drivers’ knowledge of ABS and general driving behaviour as recorded in supplementary questions.

Police reports into fatal accidents can provide another source of information for a specific research study. Projects such as HVCIS routinely code police fatal accident reports into accident databases for research purposes. However, the HVCIS project is a broad project considering accidents involving all types of large vehicle and all circumstances and does not necessarily include all information available from the reports. For example, Pearce et al (2001) studied the incidence of prosecution for driving offences in relation to a change in the Road Traffic Act. Information on conviction rates in relation to accidents was not available from standard databases containing information derived from Police reports so the original source reports were re-reviewed to identify the information.
4 Potential methods for improving current techniques

Investment in databases aimed at assessing primary safety has been much less than for those assessing secondary safety (Mackay, 2005). Before the introductions of EACS most in-depth investigations of car accidents were not able to provide answers on active safety questions because they were focussed on passive safety (Sferco et al, 2001). Sandin & Ljung (2005) agree, stating that active safety demands different data collection procedures for accident investigations compared to passive safety.

Many authors recognise the need for improving current accident data and analysis techniques. Aga and Okada (2003) highlight the need for improved information about the vehicle manoeuvres immediately prior to the collision and the safety features that vehicles are equipped with. ETSC (2001) highlight the need for the collection of exposure data. NHTSA acknowledge that although pre-crash data elements have been added to NHTSA’s on-going data collection systems, these systems are still lacking in the crash avoidance area (NHTSA, 2005).

In the following sections, potential improvements to data sources and analytical techniques are discussed in relation to the improvement of the ability to quantify the effectiveness of primary safety features.

4.1 Improvements to pre-crash data

The research shows that there are an increasing number of accident databases based on investigation at the scene of the accident. This type of analysis does increase the amount of pre-crash information that can be gleaned from an accident but in terms of describing the vehicle dynamics the method remains limited to the traditional reconstruction methods based on interpreting tyre and scratch marks left on the road surface. These methods do carry a significant margin of error, particularly depending on the level of investigation of actual friction conditions present, and in court are used cautiously to derive minimum travel speeds. In most research studies based on an at-the-scene approach, interviews with drivers are extensively used to supplement the physical evidence at the scene. It is well documented that such marks are not always left at the scene and the presence of systems such as ABS reduce the likelihood of marks being left. There are also limitations in what can be inferred from marks at the scene about the presence or effectiveness of advanced control systems. For example, early research (Lambourn et al, 2006) has suggested that little, if anything, can be inferred about the presence or effectiveness of electronic stability control systems from the tyre marks left at the scene of a collision.

It is, therefore, important that the reconstruction methods used in at-the-scene research studies are improved in order to gain as much information about the immediate pre-crash phases as possible. While there is still room for improvement in traditional reconstruction techniques, and particularly analysts understanding of their limitations, the scope for this improvement may be fundamentally limited. The largest scope for improvement in pre-crash data is likely to come from the use of Event Data Recorders (EDRs).

A wide variety of researchers (for example, German et al, 2001; Gabler et al, 2003; Chidester, 2001) have recognised the potential of EDR to offer direct safety benefits and indirect safety benefits in terms of the information that can be provided to the research community.

EDRs for road vehicles were first discussed in the USA in 1974 (NHTSA, 2001). The NHTSA EDR working group (NHTSA, 2001) stated that there were two main types of EDR; those fitted by OEMs, usually as part of the airbag module, and aftermarket systems. General Motors (GM) have led the way in the USA incorporating EDRs within their airbag controls for many years and they were the first manufacturer to provide the data for a publicly accessible tool to be developed such that anybody with the right equipment could download the data. This device is manufactured by Vetronix and, in 2001, was used by more than 30 law enforcement agencies in North America as well as the research community (NHTSA, 2001). However, later research refers to systems fitted to GM, Ford and Toyota vehicles (Niehoff et al, 2005) and a submission to GRSG from the expert from the United States
(GRSG, 2006) stated that 64% of all new 2005 model year cars were voluntarily equipped with an EDR device.

A wide variety of different EDR systems are in existence. NHTSA (2001) stated that the OEM systems from GM typically collected information on change in velocity (Delta-V) at 10ms time increments during the crash phase and also vehicle speed, seat belt status, brake status, engine RPM, and throttle % at 1 second intervals for 5 seconds before the point of EDR activation. The aftermarket systems were very varied but often recorded acceleration in two axes as well as yaw rate and the status of various vehicle systems. This information was often recorded with much higher sample rates, particularly for the pre-crash phase. Some systems even included video of the driver view. Lehmann & Reynolds (undated) state that one aftermarket EDR included extensive information such as accelerations and yaw rate samples for 30 seconds before and 15 seconds after an accident at a frequency 500 Hz, providing a much more complete accident data set at much higher resolution than the more simple OEM system.

Menig and Coverdill (undated) highlighted the fact that many commercial vehicles already extensively use a variety of forms of recording equipment and that some very sophisticated systems, such as the Eaton Vorad radar based collision warning system are installed as an OEM option on some vehicles. They state that 1.5% of new commercial vehicles employ recording systems comparable to aviation data recorders.

German et al (2001) carried out assessments of both the pre-crash and crash functions of GM EDR. They found that they could provide very useful data particularly in accidents where other information was not available, for example, single vehicle crashes with no witnesses and crashes where no tyre marks were left. They also found them very useful for understanding the role of advanced occupant protection systems in the crash. This was supported by Gabler et al (2003) who found that for 58% of cases where the delta-V in a crash was unknown from traditional reconstruction techniques, the GM EDR could provide the data. Chidester et al (2001) report that NHTSA consider the use of EDR to be a fundamental requirement when considering the performance of advanced occupant protection systems.

NHTSA (2001) found that there was generally good agreement between EDR acceleration records and instrumentation used during 21 US NCAP crash tests. Typically the EDR record was slightly lower than the instrumentation possibly because it wasn’t triggered until 2g deceleration was reached. However, Both German et al (2001) and Gabler et al (2003) highlighted that current (in 2001/2003) systems had some severe limitations that could be improved. Overall, they found that the data captured was very valuable and recommended that traffic safety researchers should make every effort both to exploit the data that was already available from EDRs and to support initiatives for improving and extending the data collected. Niehoff et al (2005) reported tests on OEM EDR fitted by GM, Toyota and Ford. They found that the recorded pre-crash speed information was typically very good, usually within 1 mile/h (1.6 km/h) of that recorded by test instrumentation with an average error of 1.1%. For crash phase Delta-V the average error was about 6% but there were outlying data points with some crashes almost exactly right and others with errors up to 22%. Problems were identified where only part of the crash pulse was recorded due to duration restrictions. They found that the full Delta-V time history could potentially be available in as few as a third of cases.

NHTSA (2001) stated that fitment of an EDR where the driver knows it is there has an inherent accident reduction affect. SWOV (1997) carried out a trial involving 840 vehicles where some of the vehicles were fitted with EDR. The study found that the group equipped with EDR showed a statistically significant reduction in accident involvement. The sample size was relatively small and, therefore, the statistical confidence limits were quite wide but the authors suggested that simply fitting the recording equipment could in itself result in a direct reduction in accidents of around 20%. This type of finding was also supported by Lehmann and Reynolds (undated). It should be noted that while this is good for safety overall, it may mean that safety research based on analysis of accidents within EDR equipped fleets may have a slight bias due to the more risk averse driving that leads to these accident reductions.
As early as 2000 NHTSA had recognised the value of recording data from EDR and had incorporated the collection of EDR data in its accident data collection databases (SCI, CIREN and NASS-CDS) (NHTSA, 2001). In 2001, only a few cases including these data had progressed as far as the public versions of the databases but more were expected in the near future. At that time, the availability of EDR data was flagged in the main database but the actual data was kept in a separate file because of the fact that all the different EDR systems included different data making it difficult to define a set of standard fields in the main database.

In response to this recognised benefit, regulatory activities have begun in the USA. NHTSA (2004) issued a notice of proposed rulemaking not to require EDRs but to require that those fitted carried a minimum standard array of data, specified a standard data format, increased crash survivability, and required manufacturers to publish information allowing public download tools to be developed.

The state of Virginia in the USA prepared draft legislation in 2005 (http://jcots.state.va.us/pdf/ProgressiveERDlegislation.pdf) considering privacy aspects of EDRs to ensure that the presence of an EDR was disclosed to purchasers and to limit access to the data to the owner or to those with a court order. However, an exception was made to allow accident researchers to download data, provided that the identity of the owner was not disclosed in relation to the data.

The USA presented details of a new regulation to GSRG (GSRG, 2006) relating to requirements for EDR. It does not make the fitment of EDR mandatory but, where fitted, for model years from 2011, manufacturers will be required to notify owners that an EDR is fitted to their vehicle and the system must contain a set of standard data elements. Where certain other data elements, contained on an optional list, are collected they must conform to standard requirements for format, sampling and duration. These standard parameters include acceleration, yaw rate and activation of safety systems such as ABS and ESC that would provide invaluable pre-crash data for the evaluation of primary and e-safety performance.

Much less evidence of EDR activity was found in Europe. However, in the UK, the Parliamentary Advisory Council for Transport Safety (PACTS, 2006) noted that a debate had been held in the House of Lords about an amendment to the Road Safety bill to allow vehicles to be fitted with EDR in the near future. It was noted that the Government had opened discussions about the possibility of carrying out trials of EDR and PACTS welcomed this interest.

4.2 Enhanced exposure data

In section 3.4 it was identified that the distance travelled was the single most influential exposure measure but that it was not available at a sufficiently detailed level to identify the exposure of different makes and models of vehicle, only to distinguish between vehicle types such as passenger car, truck or bus. The work identified that typically, the number of vehicles registered was used as a direct substitute or alternative analysis techniques often referred to as induced exposure methods were used.

In the UK many more vehicle related activities are becoming computerised. Two key examples are the road tax system and the annual roadworthiness examination (MOT Test). Both of these examples mean that databases of information relating to vehicles are now in existence and in both of these examples the make and model of the vehicle are recorded and the mileage of the vehicle is entered as an optional field. Although the field for mileage is optional it is present as a measure to help prevent fraud and car owners do, therefore, often opt to enter the information.

These new databases offer the potential to provide the basis for nationally representative estimates of exposure for individual makes and models of cars. There are difficulties that must be overcome because in both sets of data the information is not sampled at one moment in time – people get their cars taxed and MOT’d at varying times of the year and this could affect estimates for any particular calendar year. However, it should be possible to overcome, or limit the effects of, these problems using statistical techniques.
In addition to this, at least one major vehicle insurer is investigating improved data collection to help assess risk with an ultimate aim of assessing the potential of implementing pay-as-you-drive policies. TRL has met with an insurer and discussed the experiment with them. For this particular insurer a group of 5,000 customers took part in an initial pilot trial which meant that there were cars fitted with data recorders that used GPS to record vehicle position and speed every second that the vehicle engine was running. The data is combined with digital mapping technology to provide information on the exact roads that vehicles have travelled on as well as information about their speed and the speed limit in the area they were travelling in. The data was transmitted via GSM to a central database where it was available for analysis. Since the original pilot trial, it has been decided that the experiment should be expanded and it is anticipated that by the end of 2007 the company will have 100,000 vehicles equipped with the system in circulation.

The system has a relatively slow sample rate and the only additional accident data collected relies solely on the analysis of customer claim forms so it is difficult to see how a sufficiently detailed accident analysis could be conducted directly on the sample of vehicles to enable accurate estimates of the effects of primary safety performance. However, the data recorded mean that it would be possible to derive estimates of exposure that was not only broken down by vehicle make and model but also on the proportion of travel for each make and model that took place on different classes of roads and in different environments. Although the sample would inevitably be slightly biased and would not necessarily be entirely representative of the UK it is possible that it could be combined with the national estimates described above to produce national estimates.

This particular insurance company has indicated to TRL that they would be prepared to sell data from their trial to interested parties, provided it was anonymised such that the identity of their customers was not compromised and no adverse publicity could be attached to the company. In addition to this, they have indicated a willingness to consider allowing research organisations to use their infrastructure to carry out additional, more detailed trials, where customers agreed to volunteer for the additional trial. Potentially, this could include fitting more detailed EDRs and/or recording more information about accidents.

### 4.3 Vehicle performance data

Several of the accident research papers reviewed referred to the difficulty of identifying the presence of safety features on the specific vehicles involved in the accidents recorded on the databases studied. In many of these cases the sample size was dramatically reduced as a result, or accidents were classified with a great deal of uncertainty. In both these cases, this results in difficulty providing statistically significant results or in very wide confidence intervals being quoted. In order to improve the quality of analyses of primary safety performance it will, therefore, be essential to improve and standardise the availability of vehicle primary safety performance data.

One of the more rigorous analyses of the influence of ESC (Farmer, 2004) did find statistically significant results and had comparatively narrow confidence intervals in some cases. This study was carried out by the Insurance Institute for Highway Safety (IIHS) in the USA.

The accident databases used in the study record the Vehicle Identification Number (VIN) of each vehicle involved in the accident and published information exists enabling the VIN to be decoded. Some information on certain safety features can be extracted directly from the VIN but the main information derived from the VIN in this study was the make, model and model year of the vehicle. The IIHS have created and maintained an up-to-date database of the safety equipment fitted to passenger cars in the USA. This database was used to identify makes, models and years of cars that definitely did, definitely did not and may have had ESC fitted and this information was combined with the accident data to identify the relevant vehicles and accidents to study.

However, it is not possible to simply use this database in analyses of UK accidents. The makes and models of vehicle available vary from country to country. In addition to this, even where the same make and model of vehicle is available, the specification level of that model may vary from country to
country. No such comprehensive database of vehicle specification by VIN number is publicly available in the UK and in addition to this, the STATS 19 database does not record the VIN.

The STATS 19 database does record the vehicle registration number and this enables the database to be linked to DVLA vehicle registration database and from there it should be possible to obtain the VIN, and the make and model of the vehicle. However, the link between the two databases depends upon the accuracy with which the police record the VRM, so is not 100% reliable. It may be that the reliability of the data could be improved by recording the VIN directly in STATS 19, although the greater length of the VIN introduces greater risk of transcription error. Software to record STATS19 data using PDAs is being developed, and a GPS module should eliminate errors in recording accident location. It might be possible to incorporate a suitable device to record the VIN automatically and eliminate transcription errors. This would only be accepted by the police authorities if the value of the enhanced information could be demonstrated to them.

While it may be possible for the accident data to be linked to the VIN, the VIN is unlikely to contain sufficient characters to be able to code all of the desired information directly and it is likely that, as in the IIHS study, its main use would be to provide detailed make model information to cross reference with a separate database of vehicle specifications.

It is known that the Society of Motor Manufacturers and Traders (SMMT) in the UK do collect and keep information on the numbers of vehicles of different models and specifications of vehicles sold in the UK each year. The SMMT may, therefore, be in a good position to generate and maintain a suitable database. It is possible, although labour intensive, for organisations independent of vehicle manufacturers to compile databases. For example, Thatcham research has recently compiled a database of the makes and models of cars in the UK that are fitted with ESC, based on the marketing literature published by manufacturers. It is known that EuroNCAP are considering developing a similar database for the whole of Europe, although this may depend on more direct contribution from industry. It would be technically feasible to expand this type of database to cover a much wider range of vehicle safety features.

Although the development of such a database of vehicle specification would be a very powerful new development in the field of evaluating primary safety, it would remain limited to assessing whether the presence or otherwise of a safety feature influenced accident involvement. That is, it would be essentially binary in nature and would enable only assessments of reduction in accidents because of the presence or otherwise of a particular systems, for example, ESC fitted or not, BAS, fitted or not, DRL required or not. It would not help to enable any assessments of the performance of vehicles or safety features. For example, it would not enable an assessment of whether a car with better brakes and shorter stopping distance could reduce accidents or whether improved lights or field of view influenced accidents. It would not be possible to correlate an increased safety performance with a decreased accident or casualty rate, for example a correlation of the rollover stability of SUVs with involvement in single vehicle accidents.

In order to enable the performance of either fundamental vehicle design or advanced control systems to be evaluated in terms of accident data a database of detailed test results would be required. This is entirely possible to generate within specific research projects. For example, the UK PNCAP project (Knight et al, 2005) tested the primary safety performance of a range of nine test vehicles in a variety of primary safety areas. If a link to the VIN number in STATS 19 had been available it would have been possible to attempt an analysis correlating the differences in performance with differences in the frequency of specific accident types that would be expected to be affected. This type of technique has been carried out successfully in some cases. For example NHTSA carry out tests of rollover propensity on a wide range of vehicles each year and, hence, have a comprehensive database of rollover performance which they have correlated with real world accident risk (http://www.safercar.gov/Rollover/pages/faqs.htm#howisa).

One problem with linking physical test results to accident data within specific research projects is a lack of standardisation. In theory, it is possible that one project could define one test of, for example, a braking system and find no correlation with accidents while another project could define a different test of the same system and find a positive correlation. This could lead to confusion as to whether the
effects were genuine or not. However, creating a standardised test database for all vehicles in all areas would prove to be a very expensive and time consuming exercise that may be difficult to maintain. It may also be difficult to continually add new tests for new safety features.

It is possible that a limited standardised database of vehicle performance data could be generated by the type approval authorities. Although most type approval tests have a simple pass/fail criteria it should be possible to record actual performance in the tests at a much lower cost than it would take to generate an independent database tailored specifically to the needs of accident research. It is likely that such a type approval database could significantly improve the ability to assess the influence of primary safety performance but it would remain limited to those areas where performance is regulated and may be affected by repeatability issues between test sites that are not considered to be of sufficient importance to compromise the pass/fail approach that forms the main objective of type approval.

5 The role of human factors research

The main emphasis of this project has been on the use of accident data for evaluating primary safety performance. However, in all areas affecting the causes of accidents and the ability of vehicle design to help to avoid them there is a very strong interaction between the vehicle design and human behaviour. When considering traditional secondary safety measures the human also plays an important role. However, this is more associated with the characteristics of humans, how those characteristics vary in real driving and how well test methods and tools (such as anthropometric dummies) represent those characteristics. So, while the variation in human size, driving position, and physical tolerance to injury can substantially affect how crash test results relate to real casualty reduction in real crashes, the thoughts, actions and decision making of the humans involved has only limited influence because the crash phase lasts only fractions of a second. Primary safety vehicle design can have strong interaction with the thoughts, actions and decision making of human drivers and this can be even more variable than their physical characteristics.

One of the most common concerns when new safety measures are introduced is that drivers’ behaviour will change so that the expected benefit will not actually occur and could either be reduced, eliminated or even turned into a dis-benefit. These behavioural problems can be very broadly placed in two categories.

- Drivers adapt their behaviour in a way that adversely affects safety – loosely known as risk homeostasis or risk compensation, although the concept as originally defined has been discredited

- Drivers fail to adapt their behaviour sufficiently to take advantage of the capability offered by the new safety measure

Risk compensation theory is summarised by Elvik & Vaa (2004). They state that every road safety measure is intended to affect accidents by affecting one or more of the many risk factors that contribute to the cause of an accident or the severity of an injury. However, in addition to this, the safety measure may also have unintentional effects on one or more of the other risk factors affecting accidents or injuries. If these other risk factors are adversely affected then this can partially or fully outweigh the favourable affect on the risk factors that the measure was designed to affect. They state that it is these compensatory affects on risk factors that the measure was not designed to influence that are referred to as risk compensation.

Risk compensation could potentially influence the effectiveness of any safety measure, not just vehicle primary safety, although it is often easier to visualise the concept when applied to primary safety features. For example, improving the range and brightness of a vehicle’s headlamps will enable the distance at which a hazard can be detected to be increased. Thus, if no other risk factors are influenced by the change then the number of accidents at night will be reduced. Elvik & Vaa (2004) refer to this as the engineering effect of the measure. However, if the driver feels more confident in the driving task because he/she can see further then they may drive at higher speed, thus taking up at
least some of the added safety margin that the measure has provided. Elvik & Vaa (2004) refer to this as the behavioural effect and state that the net effect of the safety measure is determined by the direction and strength of both the engineering effect and the behavioural effect.

Elvik and Vaa also summarise research into the factors that influence the likelihood of behavioural adaptation, which include:

- **Visibility of the method** – measures which are more visible to road users, such that they are aware of them and believe that they reduce risk, are more likely to lead to behavioural change than those that are less visible. Elvik & Vaa (2004) offer the example that road markings are assumed to be more liable to behavioural adaptation than collapsible steering columns.

- **Whether the measure acts to reduce the frequency of accidents or the severity of injuries** – Elvik & Vaa (2004) state that measures that reduce the frequency of accidents are more liable to risk compensation than measures that reduce the severity of injury.

- **Whether road users have previously compensated for the risk factors that the measure is intended to influence or not** – areas where road users are accustomed to adapting their behaviour are more likely to be liable to risk compensation when new measures in that area are introduced.

- **The size of the engineering effect** – the greater the perceived influence of a safety measure the greater the probability that there will be behavioural adaptation.

- **The benefits of changing behaviour** – a measure will only lead to behavioural adaptation if there is some perceived advantage to the road user in doing so.

There are many new devices being fitted to cars that aim to make driving more convenient and safer by offering the driver more information. For example, satellite navigation aims to be more convenient by making it less likely that drivers will get lost, which was expected to improve safety by reducing the likelihood of drivers making sudden unexpected manoeuvres or reading maps or directions when moving. However, research has also shown that the system itself can prove to be a distraction, particularly if drivers attempt to programme new or amended destinations while actually driving.

There are also examples of measures that are intended to improve safety that result in the driver becoming over reliant on the measure. Adaptive cruise control (ACC) is intended to improve safety by keeping the car at a constant distance from the one in front in long distance driving. This was intended to improve safety by maintaining more appropriate headways and reducing close following, thus allowing greater reaction times in the event of emergency situations. However, human factors research has shown that drivers using the system often reduce their alertness to the environment such that they take longer to react when an emergency situation arises, thus at least partially negating some of the expected benefit.

Some primary safety improvements give the driver a greater opportunity to avoid accidents but rely on the ability of the driver to use those improvements. For example, ABS gives drivers the ability to steer to some extent during emergency brake applications, which should reduce accidents because many occur in situations where if steering had been possible the accident could have been avoided. Predictive accident analyses, therefore, suggest that there should be a substantial casualty reduction effect. However, retrospective analyses of accident data (Kahane, 1994) have suggested that while some accident types were reduced others were actually increased such that there was only a small net effect on accidents. Behavioural research (Perron et al, 2001) has shown that relatively few drivers use steering as an avoidance action and research by Broughton & Baughan (2000) has shown that many drivers did not properly understand the function of ABS and how to use it properly. These drivers had a higher risk of involvement in an accident. This suggests that the expected benefits of ABS did not fully materialise because of the inability of many drivers to correctly use the capability that the system gave them when they were placed in emergency panic situations. Similar arguments can be applied when considering increased field of view through the use of improved mirrors. Behrensdorff and Hansen (1994) found that the actual improvement found after the introduction of
new mirrors on heavy vehicles was only 50% of the expected benefit and it was likely that this was due to the number of drivers who were not using or adjusting their mirrors correctly.

It is possible to assess whether a safety measure has suffered from behavioural change by carrying out rigorous retrospective accident analyses. However, for all of the reasons discussed and highlighted in section 3.4 this can be very difficult for many primary safety measures. In addition to this, retrospective analysis cannot be used to assess new vehicle safety measures where there are not yet significant numbers of relevant vehicles on the road. When new safety proposals are made they are often based on accident causations studies and predictive analyses, as described in section 3.2 and 3.3. However, this type of study is not capable of accurately assessing whether a measure will be liable to behavioural change and this is often found to be a substantial obstacle to further development or implementation of the measure. In this situation, specific human factors experiments can have a very significant role to play.

Where a predictive accident study suggests there is a substantial benefit to a particular safety measure there is likely to be an argument that that predicted benefit will not be achieved due to a behavioural adaptation issue. For example, predictive studies have suggested that introducing electronically controlled braking systems on trucks would reduce fatalities because of the reduced stopping distance that the system can achieve (Knight and Whitehead, 1999). However, there is evidence to show that drivers typically do not use the full level of braking available to them and this is used as a counter argument to suggest that the measure would not be a benefit in reality. In this situation, carrying out a suitable human factors experiment to study the braking responses of a representative sample of ordinary drivers in emergency situations would assess whether drivers behaviour was fundamentally limited such that improved brakes made no difference or whether their inability to use the brakes was proportional such that an improved maximum did mean that the typical braking response was also improved. In the absence of a rigorous retrospective study of accidents (either due to a lack of equipped vehicles on the road or because of a lack of adequate data) predictive accident analyses coupled with human factors experiments supporting the assumptions made in the accident analysis is likely to represent the best evidence of effectiveness available to policy makers.

The development of ESC systems represents a good example of this method working. Accident causation studies highlighted that loss of control was a significant contributory factor in accidents, particularly fatal accidents. ESC was developed to limit loss of control and early predictive accident studies suggested that it would have a very high benefit. In support of these predicted benefits, Papelis et al (2003) carried out experiments in a driving simulator with ordinary drivers. This study used events such as a vehicle pulling out from a side road in front of the case vehicle in order to provoke drivers into reactions with the potential to cause loss of control. The results suggested a very large reduction in the proportion of drivers that actually lost control of the simulated vehicle when it simulated the vehicle behaviour associated with ESC fitment. Now, some years later, when there are sufficient numbers of ESC vehicles on the road, retrospective analyses of accidents appears to have confirmed these benefits, although the specific size of effects measured can very substantially.

In addition to the role of human factors research in specific assessments of the scope of behavioural adaptation to specific safety measures, different forms of human factors research can contribute greatly to more general knowledge in the field of primary safety evaluation. NHTSA (NHTSA, 2005) highlight the ability that their National Automotive Driving Simulator (NADS) brings in being able to study in detail the factors that lead to crashes. They also highlight the unique resource that the 100-car study provides in terms of studying “naturalistic” driving in order to define driver behaviour and performance capabilities, to document pre-crash causation factors and to determine “exposure” across a broad range of circumstances and drivers.

The 100 car naturalistic driving study was a very comprehensive study by the Virginia Tech Transportation Institute (VTI) where 100 cars were instrumented and returned to their owners to be used in ordinary driving. The study collected 42,000 hours of data from a year of ordinary driving. The instrumentation included footage from four video cameras, radar sensors all around the vehicles, lane tracking systems, GPS, accelerometers, glare sensors and radio frequency detectors as well as being connected to the vehicle CAN-bus in order to collect information from the vehicles own...
on-board electronics. The quantity of data collected during this study is enormous and has a huge potential to provide beneficial information contributing to the understanding of the causes of crashes, the responses of real drivers in real accident and near miss situations and in determining new measures of exposure to risk.

6 Discussion

6.1 Analysis using current sources of accident data

The review has shown that a wide range of data is available that can be used to assess the influence of primary safety and that in some cases this has proved successful.

In the UK, STATS 19, OTS and police fatal accident files all contain information on the events leading up to an accident and could be used in combination to produce good quality accident causation studies and could also be used as the basis of predictive studies of the potential benefits of various features. At present, police fatal accident reports are only routinely used to develop databases of heavy vehicle accidents. These databases have proved very valuable in a wide variety of heavy vehicle research that has considered both primary and secondary safety and could be used in a similar way to assess car accident causation and to carry out predictive scooping of primary and e-safety benefits. Causation and predictive studies based on these sources of data are capable of fulfilling short term needs to quantify the potential benefits of the wide range of primary and e-safety systems currently being fitted to new vehicles. This would be a valuable exercise in ranking the importance of the various countermeasures in terms of casualty reduction.

In addition to the causation studies, it would be possible to carry out retrospective analyses of the benefits of existing safety systems such as Brake Assist and Electronic Stability Controls (ESC) using STATS 19 data combined with information specifically gathered from industry on the fitment of the systems. In the case of ESC, it may be possible to use the data gathered already by Thatcham to identify the fitment of ESC. This has the potential to provide a more robust assessment of the real benefit of these systems including any effects of behavioural adaptation. However, such analyses have not been extensively carried out based on STATS 19 data in the past so the exercise would inevitably somewhat experimental in nature and would also provide an opportunity to develop and refine the statistical techniques necessary for this type of analysis and help to identify where further improvements in accident data collection may be beneficial.

Although these analyses are currently possible and would provide very beneficial information, it must be remembered that all of the analyses will be limited by the various factors discussed in section 3. The predictive studies will give a scope of potential benefits but will not be able to answer any questions related to behavioural adaptation that may result from the measures. Given the current lack of detailed exposure data, the retrospective analyses may not be capable of providing statistically significant results or may only provide estimates with very wide confidence intervals.

6.2 Study quality

It became apparent from the review of literature that the quality of the various studies carried out to investigate the effectiveness of primary safety features can be quite variable. Much of this variation is because of the inherent limitations discussed within the data sources available and because of differing scope of analyses. For example, some authors have carried out relatively simplistic and small scale analyses and some have carried out comprehensive statistical analyses of multiple data sources. However, in some cases the research was considerably flawed, using incorrect assumptions or ignoring important parameters such that the results had little scientific value. While scientific researchers may be able to review analyses and assess the quality, at least subjectively, and account for this variation when drawing their conclusions, other stakeholders in the output of such research may not have the necessary expertise.
Policy makers are one of the main stakeholders in research aiming to quantify the benefits of primary and e-safety systems. Although the scientific research into systems and the resulting cost benefit analyses are only one of many factors that policy makers may have to consider when making decisions, they can form an important part of the decision making process. The development of primary safety features, particularly those active systems employing complex electronic controls, is moving very rapidly and more quickly than traditional regulations have evolved. Policy makers can, therefore, find themselves responding to many pressures to act either to permit new systems that regulations currently prohibit or to mandate new measures that are believed to be beneficial. Frequently, the evidence of effectiveness of various measures that is presented to policy makers will vary and offer differing conclusions. There is a need for policy makers to be able to quickly and easily review this information and assess the scientific confidence in the results in order to decide the best way forward in a consistent and fair manner.

There are examples where research of variable quality has been used in the formulation of policy in quite different ways. The EC negotiated a commitment with industry to fit Brake Assist Systems (BAS) to new cars as standard in order to enable a reduction in the requirements of phase 2 of the pedestrian Directive, based on the view that the casualty reduction effect of both measures would be similar but that BAS was cheaper and easier for the industry to achieve. In this case only one study was presented in order to demonstrate the benefits of BAS and this was a predictive study that was considered by many researchers to be flawed. In contrast, EuroNCAP decided that it could only pursue actions on primary safety in the area of Electronic Stability Controls (ESC) and speed limiting devices because these were the only areas where sufficient accident evidence predicting a casualty benefit existed. There have been many comprehensive studies of Daytime Running Lights carried out in many countries using a range of techniques and with statistically significant results. However, there is still considerable debate about the accuracy of the predictions made and about whether their use should become mandatory. Much of the debate on these issues can come about because of either a lack of clear evidence or a lack of understanding where research is conflicting or of variable quality.

While it may be very beneficial to educate the stakeholders in research outputs to have a greater understanding of the limitations of scientific predictions of accident reductions and to be very good judges of the quality of the various analyses with which they are presented, the main onus must fall on the research community to provide high quality research. Research is typically carried out in a commercial environment and this will inevitable mean that the scope of research projects and, therefore, the quality of output in terms of comprehensive assessment of all possible variables, will differ substantially. This does not mean that there is no value in carrying out small scale analyses of limited scope because all such studies help to contribute to a body of evidence concerning a particular measure. However, it does mean that all studies should as a minimum:

- Accurately specify the scope of the work and what areas of the overall evidence chain are considered
- Ensure that all assumptions used are clear and visible
- Highlight all limitations of the data sources and analytical techniques
- Avoid spurious accuracy and reflect any uncertainty in the analysis in the predictions of benefits, for example
  - Do not use decimal places unless confident in the accuracy of results
  - Present a range of predicted benefits within which the true answer is confidently expected to lie
- Include sufficient technical data in reports, at least as an appendix, to allow reviewers to re-analyse data

It is relatively straightforward to define an idealised lifecycle of a safety feature in terms of the evidence of effectiveness that it is possible to generate at each stage, and TRL have presented a potential model below.
Figure 1. Potential lifecycle model of a safety feature in terms of the assessments possible at each stage

Such a lifecycle can help to show whether there is evidence to support a policy on a safety measure in each of the areas indicated and, as described above, it is important for research to show where it lies within such a framework and how it combines with other research to contribute to the overall level of evidence available. However, it is still necessary for policy makers to decide whether evidence is required in each area and how convincing the evidence in each area needs to be before action can be taken. This may vary for different measures. For example, a system that requires a change in regulation before it can be permitted can never have any evidence in the box for retrospective accident analyses and cannot, therefore, have been refined based on real life experience. If there are no concerns about behavioural adaptation of a particular system, it may be considered acceptable with relatively simple analyses showing the accident type and cause that the measure is expected to benefit, physical tests to show that the solution works and simple predictive analyses to quantify the scope of potential benefits. If behavioural adaptation is considered a potential influence then sufficient behavioural studies may be needed to quantify any degradation of the expected benefit and to try to identify whether any unanticipated dis-benefits could occur. However, this is the most that can be done to assess whether a measure can be permitted on the road, although of course the measure could be permitted for a short period for the purpose of road trials to supplement the available evidence.

For measures that do not require changes to the regulations to be permitted on the road, manufacturers are likely to go through the same process as above to ensure that they sell a good product and do not open themselves up to liability issues. However, other policy makers will only have to consider action if the measure is considered to be sufficiently beneficial to warrant further incentives to increase the number of vehicles that have the safety measure, to improve the performance of the measure or to mandate the measure such that all vehicles are equipped with it.

In each of the above areas the need to assess the quality of the research remains. This task can be made much easier for policy makers if all research is consistently of a high quality and if the research is presented in a clear and visible manner as outlined briefly earlier in this section. In section 3, it was found that some researchers have discussed the concept of developing a standardised and objective method of rating the quality of accident research. Although those researchers acknowledge that it is a difficult task such a system could prove to be a very valuable tool for both the research community and policy makers to help assess the quality of research.
6.3 Improvements to currently available data

It is clear from the research that a number of improvements to accident data are feasible and that these do have the potential to increase the ability to reliably evaluate the benefits of primary safety features. At a fundamental level, current accident databases that consider the events leading up to an accident as well as or instead of the mechanisms causing the injury in impact, rely to some extent on accurate accident reconstruction. Standard practices in relation to accident reconstruction do exist but many of the principles were based on research carried out many years ago with older vehicles. Many updates or investigations of the effect of changes to vehicle design have been carried out but tend to be small scale studies. In addition to this many new tools to help reconstruct accidents have been developed, in particular computer programmes reconstructing the vehicle dynamics and the road environment. There is a need to ensure that the traditional reconstruction techniques used remain applicable for new vehicles and that the best use is made of new tools and that their limitations are well understood. In particular there is a need for uniform application of techniques and a need for uniform understanding of their limitations among those involved in accident reconstruction and the compilation of accident database but also among those analysing those databases.

Modern electronics, computing and telecommunication has meant that many more aspects of the transport system are becoming computerised. This means that much more information about the transport system is becoming known and accessible. In particular, the computerisation of the MoT and Vehicle Licensing systems offers the potential to generate realistic estimates of national exposure data (vehicle kilometres travelled) that can be attributed to individual makes and models of vehicle. It may also be possible to use data from specific activities undertaken in the private sector, particularly pay-as-you-go insurance trials, to develop estimates of vehicle travel and exposure by different makes and model of car on different roads and in different environments. This information would open up major new analytical possibilities for retrospective studies assessing primary safety and many other safety issues.

In addition to this, modern electronics mean that Event Data Recorders (EDR) are becoming much more prevalent and capable. These have been widely evaluated, particularly in the USA, and are universally acknowledged to have the potential to greatly contribute to improved research on road and vehicle safety in general. In terms of primary safety it is the potential to offer detailed pre-crash information that is of particular value and EDRs look capable of providing crucial and accurate data on speed, acceleration and motion as well as the status of safety systems in the immediate lead up to a crash. In the USA this area of opportunity has been developed to the extent that the majority of new cars are fitted with some kind of EDR as standard, tools are available publicly to enable data to be downloaded from several vehicles, accident databases have been modified to include the data from EDRs, privacy issues have largely been dealt with and a regulation has been introduced to standardise the parameters recorded. If this activity was replicated in the UK it would greatly improve the ability to carry out accurate and reliable predictive and retrospective analyses of accident data.

The improvement expected from such a programme of EDR activity would only arise in the longer term as existing databases such as OTS or even STATS 19 began to collect data in sufficient numbers. It may also be possible to gain some of the potential improvements in the shorter term. It is known that a number of vehicle fleets fit some kind of EDR to vehicles as a voluntary after-market addition. There is at least one insurance company who fits this type of monitoring equipment as part of a large trial and have offered the possibility of using their infrastructure to carry out additional trials. Studies based upon such fleets of vehicles could potentially offer many of the benefits of wider EDR adoption but would be limited by sample size, sample bias, variation in the quality and type of information collected and the need for cooperation with, and dependency on, commitment from third parties whose main activities are different from, and may conflict with, the research priorities.

It is also possible to carry out derivatives of this type of EDR study where vehicles are instrumented in order to record normal driving behaviour. This type of naturalistic driving study has been demonstrated in the USA and offers enormous potential for increasing the understanding of human behaviour in relation to accidents generally and primary safety features specifically. Driving simulators have been used for many years to investigate driver behaviour in relation to road safety.
issues such as the use of alcohol, fatigue, traffic calming measures. More recently they have been used to investigate the influence of vehicle primary safety features on driver behaviour but this type of work often has different needs and may require programming different vehicle characteristics into the system as well as more accurate simulation of the dynamic forces experienced by the driver.

In order to support all of the existing and potential improved data it is necessary to have a detailed understanding of the primary safety performance of all the different cars actually on the road. At present, this can only be achieved by specific investigation of features for particular projects with manufacturers or by carrying out independent test programmes. This can be difficult, time consuming and/or expensive. In the USA, the VIN is routinely recorded in accident databases and is used to identify some vehicle features directly. Additional information is obtained by using the VIN to identify specific make, model, and year of the vehicle and then cross-referencing this with a database of vehicle safety features that are fitted. Development of an equivalent database for UK vehicles would greatly increase the ability to assess the binary effect of fitting certain safety features (for example, ESC fitted/not fitted). However, this still would not enable the performance of safety features to be evaluated. For example, such a database would not allow an assessment of the accident effect of A-pillar thickness or braking performance. Some information to support this type of activity could potentially be obtained by using numerical results (rather than simple pass/fail results) from type approval tests. However, many features of performance that it may be beneficial to evaluate in terms of casualty reductions would still require data from a specific test programme.

6.4 Proposals for future research

6.4.1 Research to meet short term objectives

A wide range of primary and e-safety improvements are currently being introduced voluntarily or being proposed as candidates for new or amended regulation. Although many of these may be supported by individual estimates of benefits there has been no comprehensive review and ranking of the importance of such proposals. In addition to this, a wide range of differing data sources and analytical techniques have been used and the quality of the studies may be variable. There is, therefore, no clear and widely accepted view of how these should be dealt with and in what priority order.

It is proposed that, in the relatively short term, a comprehensive study of current accident data could be carried out with two main objectives:

- To increase the understanding of current data sources and to further identify the strengths, weaknesses, quality and reliability of differing analytical techniques
- To evaluate the potential casualty savings arising from a range of currently proposed primary and e-safety features in the most reliable and robust way currently possible, accepting the inherent limitations of current data sources.

It is proposed that this research should aim to use a wide range of data sources and analytical techniques. It should begin a comprehensive review of literature to identify what evidence of effectiveness of all of the different features already exists and what gaps remain in terms of both unanswered questions and the quality of the analyses already carried out. It should be noted that some of the gaps in knowledge may lie in the fields of physical and/or human factors testing of the features in order to determine the physical changes and behavioural adaptation that might be expected.

The next stage could be to carry out an analysis of accident patterns and contributory causes based on both STATS 19 and OTS data. The range of current and proposed primary and e-safety measures could then be categorised in terms of the accidents they would be expected to influence in order to define the field of application (scope of maximum possible benefits) for each of them. The accident types and causes could also be compared to the proposed measures to identify whether all of the most
important accident types are considered by the range of safety measures offered or whether there are areas where new safety measures need to be devised.

The safety measures considered to have the most potential can then be selected and subjected to more rigorous analyses. The number of selected systems would depend entirely on the scope, timing and budget of the research. This would begin with a predictive study of the benefits of each selected system. The OTS database is likely to be the most appropriate database on which to carry out this analysis. It has more technical detail on the pre-crash phase of the accident than any other UK database and has much technical strength in relation to this type of work. It is likely that differing techniques may be required to assess the benefits of each primary or e-safety feature considered and wherever possible, multiple techniques should be used to try to determine the level of uncertainty in the predictions and to see which techniques correlate most closely with those made in other research and with the findings of any retrospective analyses carried out.

One of the main limitations of the OTS database at this point in time is sample size. Although the database now contains information on approximately 3,100 accidents, there are some fields important for primary safety such as speed that are not completed for every case due to technical limitations in the available data. When the sample is divided into specific accident types and different accident severities and only cases where very detailed information is known then the remaining groups of data can be relatively small. An option at this point would be to increase the sample size by creating a database specifically aimed at assessing passenger car primary safety potential based on specific coding of police fatal accident files. Many thousands of police fatal accident reports are available to TRL for coding and they often contain detailed accident reconstruction data that can be used to assess the potential of a variety of countermeasures. This data source is routinely used to generate the HVCIS fatal database in order to assess the potential of a variety of primary, secondary and e-safety countermeasures for heavy vehicles and has successfully been used in a wide variety of heavy vehicle research.

The fourth stage of work would be to identify vehicles with different primary safety performance and e-safety features and carry out retrospective analyses using STATS 19 data. Each of the safety features in scope should be assessed using appropriate statistical techniques.

It is likely that in order to rigorously determine the effectiveness of a range of primary safety features that physical performance tests and or human factors experiments on certain systems will be required to support the accident analysis. However, it is not possible to determine what these may be until at least the first phase of work has been carried out. Given the expense of such test and experimental programmes it is likely that any primary safety evaluation research programme would need to be very flexible in terms of technical content and budget.

6.4.2 Development of new data sources and analytical techniques

6.4.2.1 Vehicle performance and specification data

The research clearly showed that it is essential to have information on the performance and specification of vehicles in order to carry out rigorous retrospective analyses and that it can be beneficial for predictive analyses. It is possible to identify information specifically for a particular project but many analyses had been limited by shortcomings in this area and it allows the possibility of a lack of consistency across different studies.

The development of a database of UK vehicle specifications should be feasible and its development would facilitate much improved capability in terms of analysis of existing UK accident databases. It is likely that such a database would represent a continuous development exercise because the specification of vehicles is regularly changing with various model face-lifts and because new systems are regularly developed and added to the range. The work could be defined in three stages:
Detailed identification of data needs, accessibility, links with other databases and availability of data sources.

Initial development of the database

Maintenance of the database

This work would require extensive cooperation with the UK automotive industry and their representatives, such as the SMMT. In fact, the SMMT may already hold a large part of the data required to populate the database and may be in a very good position to develop and maintain the database. However, it is important that the database is accessible to the wider research community and the Government and considers the needs of those sectors as well as industry.

It should be possible to link the STATS 19 database to such a database of vehicle specification via the vehicle licensing database, but errors in transcribing the VRM would lead to some false links.

The limitation of the above database is that it is likely only to record fitment of various systems, such as ABS, Brake assist, ESC, advanced front lighting etc and that for many vehicles this may be optional equipment such that it remains unknown whether a specific vehicle was equipped. This information does not help to assess the more fundamental primary safety performance of a vehicle. For example, the data would not be capable of assessing whether a high specification ESC system fitted to a car with good fundamental handling characteristics was involved in fewer crashes than a car with poor fundamental handling characteristics fitted with a low cost ESC system. Developing a database of vehicle performance would be considerably more difficult than a database of vehicle specification but it would be valuable to carry out a detailed feasibility study to determine what information could be compiled from existing sources such as the Type Approval scheme and to assess whether the development of such a data source was cost and quality-efficient compared with carrying out specific test programmes in connection with specific accident analyses in order to answer particular research questions.

6.4.2.2 Improved exposure data

Currently, the only exposure data typically available for use in studies of the safety effect of primary and e-safety features is vehicle registration data providing numbers of different car models registered and overall distance travelled by cars as a group. The former is only an approximation of true exposure and does not take into account different distances travelled by different models of cars or different roads on which they may be used. The latter cannot be used to distinguish between different models of cars and so can only be used in before and after evaluations of safety measures where all vehicles were affected at the same time, for example the introduction of mandatory seat belt use or the introduction of a requirement to use vehicle headlights during the day.

Increasing the level of detailed exposure data available will greatly increase the analytical options in retrospective studies of accident data and has the potential to provide more reliable and accurate estimates of benefits. The computerisation of the road tax and MoT systems offers the potential to produce estimates of annual distance driven by cars and other vehicles, disaggregated by vehicle make and model. The main difficulty with achieving this is the fact that individual vehicles are taxed and MoT’d at various times of the year rather than being a fixed census at one time. Research is required to identify the most appropriate way of analysing the available data to provide a reliable estimate of the exposure in any particular calendar year.

There are now some sources of data in existence within vehicle fleets that use data recorders equipped with GPS that is capable of identifying the distance travelled on different classes of road and in different environments. This has the potential to increase the accuracy and relevance of exposure data even further. The difficulties with this data might include:

- Gaining access to the data
• Scaling up the sample data to national estimates, taking into account the following possible problems
  o Biased sample of vehicle models
  o Biased age, sex or experience of driver sample
  o Possibility that drivers in the sample drive differently due to knowledge of the monitoring system
  o Geographical bias in fleet location/travel routes

A feasibility study in this area will provide valuable information on how these difficulties can be overcome and what additional analyses the data enables. Such a study should involve identifying at least one, but preferably more, sources of data that can be made available, identifying the extent of information in the source that can be used to quantify potential biases and experimenting with different methods of scaling the information to the national level in order to quantify the level of uncertainty in the estimates. It will also be invaluable, once appropriate national estimates have been made, to carry out analysis of at least one safety measure using different analytical techniques that both do and do not consider the more detailed exposure data in order to understand the effect that the additional data has on the conclusions drawn from the analysis.

6.4.2.3 Improved pre-crash data

Currently, the pre-crash data recorded in most accident databases is based on combinations of witness evidence and traditional accident reconstruction measures based on marks found at the scene. These reconstruction techniques were developed many years ago and technology and materials have changed substantially since then. The reconstruction methods used do have limitations that are generally acknowledged and when used by police tend to be used in a cautious way such that all of the expected uncertainty in the result would make the conclusion worse for the driver (i.e. predict a higher pre-crash travel speed). It is possible that changes to tyre design, road design and the introduction of electronic control systems such as ABS, BAS, and ESC may have an effect on the limitations and tolerances used in accident reconstruction. It is also possible that additional information may be obtained from evidence at the scene about the operation of such systems. Research in this area therefore has the potential to improve the abilities of accident reconstruction experts to reach accurate conclusions about the sequence of events leading to the collision. This would have the twin benefits of improving the pre-crash data in accident databases and improving the efficiency and quality of the justice system in respect of road accidents.

Although research may improve the quality of accident reconstruction from evidence at the scene, the methods will remain fundamentally limited because in many accidents there is little physical evidence left at the scene. For example, an ABS car may only leave faint tyre marks in dry conditions and none in wet conditions. The research reviewed in this report showed that it was widely acknowledged that the use of electronic event data recorders (EDR), similar to aircraft flight recorders, had a much greater potential to increase the quantity and quality of pre-crash data available to both researchers and law enforcers.

In the USA, some form of EDR has been fitted as standard to a number of vehicles for many years, usually as part of the airbag control unit. NHTSA have recognised the potential of these systems and acted to encourage their fitment such that now they are fitted to approximately 64% of new vehicle models, standard tools are available to download data, validation of the accuracy of recordings has been carried out, accident databases have been modified to include the data and a regulation has been introduced to standardise the information recorded. In years to come, when the market penetration is sufficient that large numbers of accidents are collected where EDR data is available, this will give researchers in the US a very powerful new accident analysis capability.
Similar benefits could be expected in the UK if the research and policy actions carried out in the USA were replicated over here. There may be distinct reasons why the fitment and use of EDR may be easier in the USA than in Europe, for example, differing laws on privacy and data protection. An initial feasibility study would help to clarify these issues and create a road map of how to achieve the same goals in the UK. It should be noted that it may take 5 to 10 years from the position in the UK now to achieve the aim of having a substantial database of accidents where data from factory fit EDRs is available.

6.4.2.4 Fleet based accident and exposure study

Fleets of vehicles are already in existence where, for their own reasons, fleet managers have seen benefits to equipping vehicles with some form of recording and monitoring systems. If access could be gained to the data produced by these fleets then it would be possible to get some of the benefits of improved pre-crash and exposure data in a shorter time frame. The work would present greater analytical difficulties because of smaller sample sizes and possible biases in the data but it should be possible to overcome these in order to analyse the data to produce detailed exposure estimates for the fleet of vehicles that can be used in combination with detailed data from accidents and near misses that are experienced. This would allow aspects of driver behaviour to be studied in normal driving, dangerous situations and accidents, as well as permitting the generation of accident rates for different vehicles with different safety performance in different accident types.

An initial feasibility study may be necessary to identify fleets of vehicles with suitable data available that were prepared to allow access for research purposes and to define research methods and possibly to agree incentive deals whereby the owner of the data gains some benefit by participation in the research.

6.4.2.5 Tailored accident and exposure study

The research described in the preceding section described a study that relied on whatever infrastructure existing fleets of vehicles had in place. Research that was more specifically targeted to the needs of the project could be carried out by actually equipping a fleet of vehicles with recording equipment specifically tailored to the research requirements. This would be expected to produce higher quality data and results than the preceding section described but would also be expected to cost substantially more.

The 100 car study in the USA fell into this category of research and was an example where a very comprehensive set of instrumentation was fitted to a relatively small sample of vehicles. Thus, very very detailed information was gathered on a large quantity of normal driving, a smaller quantity of near miss incidents and a relatively small number of accidents. Replicating this study in the UK would yield extremely useful information and expanding the study to a much larger sample would be expected to start providing firm conclusions on the benefits of different safety systems. One particular advantage of such a trial would be the ability to assess real behavioural adaptation effects of safety systems. Trials could be designed such that a range of vehicles with different specifications and performance characteristics were used such that direct comparisons of otherwise identical cars with and without specific safety systems was possible, demonstrating whether or not the driving behaviours changed as a result and, if so, by how much.

The type of work discussed could represent a very large and expensive research project. Where budgetary constraints are a consideration different approaches could be taken for the same basic research principle. A larger number of vehicles could be equipped with systems that record less information. For example, off the shelf event data recorders and/or journey data recorders could be used instead of the more expensive research equipment used in the USA study. In addition to this, it may be possible to collaborate with other organisations in this area. At least one company is carrying out trials for pay-as-you-drive insurance with a large sample of drivers that have volunteered to have
GPS equipment installed on their car that transmits data via GSM back to a central data archive. This company have indicated that they may be prepared to sell this infrastructure capability to research organisations to use for additional trials provided that the drivers involved volunteer specifically for the additional trial equipment. This type of research may form a good compromise between the benefits achieved and the costs of the work.

6.4.3 Development of research tools

The research showed that the quality of the various studies attempting to assess the benefits of primary safety in terms of accident reduction was quite variable and that the level of quality demanded to justify different safety measures in different areas also varied substantially, often leading to extensive disagreement. The development of a set of simplified and standardised quality assessment tools would offer both researchers and policy makers a quicker and more consistent way of assessing the quality of the wide variety of analyses that often need to be reviewed to assess the benefits of a system, and then judging how much weight to give to each analysis in formulating conclusions and recommendations for research and policy actions.

The development of such a quality assessment tool is expected to be quite difficult. It can be seen from the research reviewed in this report that there is a very wide range of parameters that need to be considered and controlled in analyses and that these parameters can vary for assessments of different safety systems. There is, therefore, a conflicting need for a tool to be detailed enough to ensure that a study rated as high quality really is high quality and for the tool to be high-level and/or flexible enough to be able to be applied to different types of analysis of different safety measures. Research to develop such a tool is likely to involve an iterative process of theoretical design, consultation with stakeholders and testing of the system against a wide range of existing analysis reports.

7 Conclusions and recommendations

1. The literature reviewed was in general agreement that the relative importance of primary safety research was increasing and that this type of research had different needs for accident data that were not currently fully considered in existing databases.

2. Most of the literature identified that there were a range of difficulties and limitations in the analyses carried out. However, appropriate analytical techniques were able to overcome many of these difficulties and there were many high quality robust analyses of primary safety features in existence.

3. It was found that the quality of analyses in the field was quite variable. Some of this variation was directly attributable to limitations in the data sources but a number of studies were found that contained questionable assumptions or failed to account for potentially important confounding factors.

4. There are a number of inherent limitations in currently available data that make the evaluation of primary safety features difficult. It is important that these limitations are acknowledged and accepted by all involved in the work and where the burden of proof required is high then it may be necessary to compile a body of evidence comprising predictive accident analysis, physical tests, evaluations of the effect on driver behaviour and retrospective statistical analysis in order to gain confidence in the conclusions.

5. A range of possible research to fill gaps in knowledge has been proposed:
   a. Predictive and retrospective analyses of the current range of proposed primary and e-safety systems using current data and the best of the available analytic techniques. This should have twin aims of providing an objective quantification of the benefits and relative importance of the range of safety features to the highest standard
currently possible, accepting the limitations of the available data, and enabling comparison and development of increased understanding of the data and analytical techniques that can be used. This research could include:

i. Predictive analyses of a range of new and existing measures using different techniques.

ii. Human factors experiments aimed at validating the assumptions about driver behaviour in relation to new technologies made in earlier predictions and seeking to identify any unintended consequences in terms of distraction or behavioural adaptation.

iii. Retrospective analyses of statistical data regarding new safety measures already on the market and comparison with the accident predictions and human factors experiments to establish whether the approaches agree on the benefits and what lessons can be learned, what new techniques or information may be required to improve predictions.

a. Investigation of the potential role of EDRs in the UK, based on the progress in the USA

b. Assessment and development of improved vehicle and exposure information

c. Naturalistic driving studies

i) Analysis of accidents and exposure within fleets of vehicles currently equipped with after-market EDRs

ii) Tailored accident and exposure studies based on specifically instrumenting fleets to a controlled design

d. The development of research tools such as quality assessment guidelines.

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Mackay (undated). Keynote lecture: The evolution of accident research


Techniques for assessing the effectiveness of vehicle primary safety features using accident data

Although there is still scope for substantial and worthwhile additional improvements in secondary safety, many researchers have suggested that there are limits to what can be achieved with secondary safety alone and have suggested that, in future, more cost-beneficial gains in safety will be achieved through primary safety measures and the integration of primary and secondary safety features into an intelligent safety system package. One of the main tools used to prioritise safety interventions, given a wide range of potential applications, is cost benefit analysis, using accident data to quantify the casualty reduction benefit. However, traditional sources of accident data can be very limited in terms of their ability to accurately quantify the effects of primary safety features.

The aim of this report was to establish current best practice in terms of using accident data to evaluate primary safety features of vehicles and to recommend ways to improve these analyses using different or new sources of data and/or new improved analytical techniques such that more robust cost-benefit analyses can be achieved. The work was completed in 2006.

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