Development of a methodology for the evaluation of safety systems for powered two-wheelers – final report

T L Smith, T Gibson and M McCarthy
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Development of a methodology for the evaluation of safety systems for powered two-wheelers

Final report

by T L Smith, T Gibson and M McCarthy (TRL)

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Evaluation of Motorcycle Safety Systems
Client: Department for Transport, TTS Division
(Adrian Burrows)

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<th>Position</th>
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Executive summary

The use of accident data to assess the effectiveness of a primary safety (accident avoidance) feature can be problematic. This is because when a primary safety feature is fully effective, there is no accident and no data for comparison or analysis. Furthermore, most available accident databases are focussed on accident outcome (secondary safety), and have insufficient data on the pre-crash phase and accident causation.

TRL were commissioned by the Department for Transport to develop a methodology to allow quick and consistent evaluations of powered two-wheeler (PTW) safety features in order to ensure that actions taken to improve PTW safety are implemented in the most appropriate and cost-effective manner. A wide range of techniques are available but they all have strengths and weaknesses and none will provide an ideal solution for every safety feature. It is therefore also important to ensure that the most appropriate technique is used and that the strengths, weaknesses and any assumptions used are transparent.

This is the final report for the Evaluation of Motorcycle Safety Systems project. The objective is to present the initial methodology developed for the assessment of PTW safety systems. The report also describes the implementation of this methodology to assess the benefits of three advanced braking systems. The three systems considered were:

- Antilock braking systems (ABS);
- Combined braking systems (CBS); and
- Brake assist systems (BAS).

The estimated annual benefit for Great Britain of ABS was between 239 and 2,389 casualties, with a best estimate of 1,432 casualties per year. The valuation associated with this best estimate was £273.2 Million. The estimated annual benefit for CBS was between 167 and 1,719 casualties, with a best estimate of 1,026; the estimated annual benefit BAS was between 382 and 3,915 casualties, with a best estimate of 2,339.

These estimated benefits were based on the overall effectiveness of the systems regardless of accident severity. Insufficient information was available to identify the benefits for each casualty severity and therefore it was not possible to estimate the associated casualty prevention valuation using the method applied to ABS. Estimates of £50.5 Million and £313.6 Million were generated using an alternative method for the assessment of CBS and BAS respectively, although these are likely to be underestimated. It was assumed that the BAS included ABS and CBS in order to allow the rider to meet optimum braking without wheel lock, thus the benefit cannot be added to that for ABS.

The benefit analysis was critically reviewed against the guidelines set out in the methodology in order to identify the quality of the evidence with respect to burden of proof required. The results are also reviewed against the methodology in order to identify knowledge gaps that are required to be addressed in order to achieve a higher burden of proof for the benefit estimates.

The report also describes the development of a desktop tool as part of the methodology. The spreadsheet-based tool allows the user to select groups of PTW casualties based on certain accident characteristics. The output from the tool includes casualty numbers by severity, the prevention value associated with the PTW casualties and PTW casualties as a proportion of all casualties. The annual data is presented alongside the three-year average. The tool can easily be updated as new annual data becomes available. One of the main improvements that could be investigated in the future is the inclusion of non-PTW casualties which are currently excluded from the output.
1 Introduction

In Great Britain, motorcycles and mopeds, referred to hereafter as Powered Two Wheelers (PTWs), account for approximately 1% of annual vehicle kilometres travelled, but contribute 19% of annual fatal and serious casualties (DfT, 2007). When the distances travelled by PTWs are taken into account, the rate of motorcyclists killed and seriously injured has declined over recent years. However, the rate of PTW users killed or seriously injured (KSI) is still approximately 31 times greater than for cars, and the increasing popularity of motorcycles and improved safety of other vehicles suggests that motorcyclists may continue to become a greater percentage of the KSI casualty total in the future. In 2005, the Government published a motorcycling strategy that set out to identify and address the many issues and challenges raised by motorcycling. Improved rider safety through vehicle design and the application of new technologies was one of the key areas identified.

Using existing accident data to assess the effectiveness of a primary safety (accident avoidance) feature can be very difficult. This is because when a primary safety feature is fully effective there is no accident and, therefore, no data for comparison. Furthermore, most available accident database are focussed on accident outcome (secondary safety), and have insufficient data on the pre-crash phase and accident causation. Thus, in order to ensure that actions taken to attempt to improve PTW safety are implemented in the most appropriate and cost-effective manner, there is a strong need for the development of a methodology to provide quick and consistent evaluations of motorcycle safety features. All existing techniques have some strengths and weaknesses so it is also important to ensure that the most appropriate technique is used and that the strengths, weaknesses and any assumptions used are transparent.

The objective of this report is to present the initial methodology developed for the assessment of PTW safety systems and then to apply the methodology to assess the benefits of advanced braking systems for PTWs based on existing literature and data. The benefit assessment made has been reviewed against the proposed methodology with respect to the burden of proof that can be achieved with the information available.
2 Phase 1 – development of a common methodology

The following section of the report describes the methodology that has been developed. The objectives of this methodology are:

- To identify the most suitable and cost effective method of providing the evidence of a safety benefit for a range of motorcycle safety systems.
- To include provision to estimate the potential for accident avoidance or injury mitigation using accident statistics (STATS19) or in-depth accident data by identifying causation factors and then assessing the likely impact advanced safety systems might have on relevant accidents.

In addition to these objectives, it will be possible to use the methodology to critically appraise research that has already been completed.

The methodology consists of three main steps, an overview of which is shown in Figure 1.

![Burden of Proof Required?]

- **Very Low**
  - **Step 1** Preliminary Filter

- **Low – Very High**
  - **Step 2** Target Population
  
- **Medium – Very High**
  - **Step 3** Define Effectiveness

**Figure 1. Overview of methodology.**

**Examples- Burden of proof**

**Very low** – policy makers are often confronted with a large number of proposals for a huge range of potential new safety measures. In this type of situation it is considered useful to have an initial filter to help identify which measures warrant further investigation. At this stage it is not necessary to have rigorous proof of the exact effects, merely a high level estimate.

**High – very high** – If a major new regulation is planned that is likely to cost substantial amounts of time or money and/or to encounter significant opposition, then it may be necessary to have very rigorous supporting analysis that accurately and incontrovertibly demonstrates the effects.
2.1 Step 1 – preliminary filter

Step 1 of the methodology is the definition of a preliminary filter that can be applied to accident data. The primary objective of this step is to define groups of accidents, against which an initial evaluation of the potential benefit of a countermeasure can be assessed. Additionally, a secondary objective is to allow the most frequent or most severe groups of PTW accidents to be identified.

Step 1 can be used for quick stand-alone comparisons for a range of potential countermeasures. It could also be used to quickly assess how relevant proposals from other countries are in the UK, or as a quick reference to assess the maximum benefit of a new safety system.

2.1.1 Inputs

The input to step 1 of the methodology is the system specification, i.e. what are the functional characteristics of the system under investigation.

2.1.2 Key considerations

When setting up the preliminary filter the following questions should be considered:

1. **What is an appropriate data set?** It is recommended that the data set is a national sample, or is known to be representative of the national sample (evidence of the representativeness should be presented). The data should cover a period of at least one year, ideally an average of a number of years and be as up to date as possible.

2. **How should the accidents be grouped in the filter?** The grouping of accidents can be influenced by the vehicle type to which the safety system is to be fitted, as well as the types of system under consideration. The following aspects should be considered and any limitations of the grouping should be noted.
   a. The grouping should allow comparison of accident types and be independent from the detailed functionality of the safety systems.
   b. The grouping should be appropriate to the systems being reviewed. It should allow differentiation between different systems where possible (e.g. a braking system could influence a small proportion of a large number of groups, whereas a cornering stability control system might influence only one or two groups).
   c. The groups should be mutually exclusive to avoid double counting where multiple groups are affected by a system.
   d. All casualties within the accidents should be included, i.e. PTW casualties, casualties in the opponent vehicle (1st impact) and any other casualties in the accident (including pedestrians).

3. **How will the groups be compared?** The accident groups can be compared using a number of different measures that reflect the frequency and/or severity of the casualties (e.g. number of casualties, number of fatalities, casualty prevention value etc.).
2.1.3 Outputs

The output from Step 1 of the methodology is an initial estimate of maximum potential benefit. This estimate will be based on the sum of the casualty groups that can potentially be affected by the system under consideration.

Examples

*Junction collision warning system* – select multiple vehicle accidents >>> at junctions.

*Forward collision warning system* – select multiple vehicle accidents >>> PTW impact location front.
2.2 Step 2 – defining target population

Step 2 of the methodology is intended to identify more accurately the accidents that could be affected by the system under consideration (defined as the target population). The target population is specific to the safety system and should be as accurate as possible including causation factors where required.

The term “target population” can be used in a variety of ways, for example:

- The number of casualties that could be prevented by a system that is 100% effective in each of the accident situations it is intended to influence e.g. works in all weather conditions, at all speeds and accounts for driver behaviours etc; or
- Casualties within a group of accidents that could potentially be influenced by the measure e.g. head-on collisions, rear-end shunts etc.

For the purpose of this methodology, the target population is defined as the number of casualties that could be prevented by a system that is 100% effective in each of the accident situations it is intended to influence. This number can also be expressed as a percentage of all accidents.

2.2.1 Inputs

The inputs to Step 2 of the methodology are:

- The detailed functional specification of the system;
- Appropriate accident data.

2.2.2 Key considerations

In order to define the target population, the following aspects require consideration:

1. In what situations is the system intended to assist the rider? In order to define the target population it is necessary to understand how the system operates and the situations where the system is intended to assist the rider. There should be a written description included in the write-up of the analysis.

2. What are the relevant types of accident and vehicle for the system being assessed? The definition of each accident type and relevant vehicles should follow these guidelines:

   a. The accident types that could be influenced by the safety system should be identified in as detailed manner as possible for the data source being used. The definition should include criteria that will allow the accidents relevant to the specific system to be identified. For example, head-on collisions can have a number of different causative factors (inattention of the PTW rider, inattention of the other driver, impairment of the rider/driver etc.). It is recommended that the accident type is defined by the impact configuration (where appropriate) as well as at least one causation factor such as rider/driver behaviour (where appropriate). There may be multiple types of accident that could be influenced.

   b. It is often appropriate to define the target population in relation to the vehicle type to which the system is to be fitted (e.g. HGV, passenger car, PTW etc). The composition of the vehicle fleet can be very different when comparing countries. Sometimes it may be appropriate to define the target population for a sub-set of one vehicle type. For example, when considering ABS for PTWs, the target population can be separated by engine capacity, PTW less than 50cc and PTW greater than 50cc.
3. **What information is available to estimate the target population?** The target population can be estimated based on different sources:
   a. Accident data will allow the most flexibility in defining the target population (within the constraints of the data sample being used). This is the preferred method for defining target population.
   b. Literature can also be used, however the definition of the target population is likely to vary between different studies and if no UK studies are available the answer could be misleading, particularly for PTW accidents where patterns of use vary considerably between different countries.

4. **How can these relevant accidents be identified in the accident data?**
   a. Does a national data sample have sufficient level of detail? Is causation data and pre-impact information available to identify the relevant accidents in the national data sample.
   b. If it is not possible to identify the relevant accidents using a national data sample, is there an in-depth study available that has appropriate detail and representativeness (at the level of detail required)? If so, the use of a more detailed accident database should be considered. However, it is necessary to identify the limitations of such an approach. One of the most important limitations will be related to the representativeness of the data sample. Any assumptions must be reported, for example if the representativeness is not known at the level of detail required (e.g. rider behaviour factors) but is known at a high level (types of casualties and vehicles involved), it may be assumed that the rider behaviour is representative but this must be stated in the report.
   c. What factors could influence the target population? The target population can be defined in a number of ways. This could lead to the inclusion or exclusion of accidents where certain factors were involved. For example, should impaired drivers (e.g. through alcohol or drugs) be included in the target population? In general, accidents should only be excluded from the target population on the basis of this type of factor if it is clear that there is no chance that the measure will affect them. This will help to allow consistency in study approaches using different data sets, for example, in different countries. However, in some circumstances it will be appropriate to limit the target population in this way and wherever this occurs the limitation should be stated and the calculation of effectiveness that will be applied in step 3 should be modified accordingly.
   d. Are there any limitations with the criteria that have been used to define the target population? Some data recorded in databases have inherent limitations. For example, the information required may frequently be unknown, or some may rely on subjective assessments.

5. **Have the correct accidents been identified?** It may be possible that the criteria used to select a specific group of accidents could unintentionally return some non-relevant accidents. The analysis should be accompanied with some indication of confidence in the query that has been used. If the data source has written descriptions of the accidents then these could be used. However if there are no written descriptions then an alternative method should be considered, for example cross-referencing to another database that does have written descriptions.
2.2.3 Outputs

The output from Step 2 is the target population for the specific system that is being assessed. The target population is a group of accidents that are relevant to the system under consideration. This is the maximum potential benefit for the system, i.e. if it were 100% effective; target population is equal to the expected benefit. In reality, most systems are not 100% effective at preventing the collisions/casualties for which they are designed and thus, step 3 is required to more accurately quantify the expected benefits.

Where possible, the target population should be expressed for each casualty severity as a proportion of all casualties of that severity. However, in some cases it is not possible to identify all casualties of a particular severity. For example, official statistics for the EU-27 provide the number of fatalities and the number of all accidents but not the number of serious and slight casualties. Therefore the target population should also be shown as a proportion of all accidents (of all severities) within the sample. This will assist direct comparisons across different countries. However, when using the target population as a proportion of all accidents, care should be taken when translating results from one country to the accident numbers from another country because of variations in the definitions used for the casualty severities. A table showing how that data should be presented is shown in the example below. Figures that may not be readily available are identified by an asterix.
Step 3 – system effectiveness

2.3 Step 3 – system effectiveness

Step 3 of the methodology is intended to refine the benefit estimate that was defined in Step 2, that is, to translate the analysis from the maximum possible benefit (target population) to a realistic likely benefit. The main objective of this step is to determine how effective the system will be for preventing the casualties/accidents that make up the target population. There are a number of different methods for determining/identifying the effectiveness of the system and this step is intended to help identify the most appropriate method for the quality of estimate/burden of proof required. It is possible to define the effectiveness of the system under consideration without defining the target population in Step 2.
2.3.1 Inputs
The inputs into step 3 of the methodology can depend on the approach taken, but can include:

- Accident data;
- Literature;
- System specification;
- Quality requirements;
- Test/trial results.

2.3.2 Key considerations
In order to determine the effectiveness of the system in the most appropriate manner, the following aspects require consideration:

1. **What burden of proof is required?** The burden of proof required should be classified on a scale from very low to very high. Step 3 is typically only required when the burden of proof is medium or higher. Figure 2 summarises how to determine the most appropriate method. Additional guidelines are provided below.

2. **What is most appropriate assessment method for the information available?** The selection of the method to be used will be based on the burden of proof required, the availability of the system being assessed, constraints on cost and time and the availability of accident data and literature. The main types of method that can be used for determining/estimating the effectiveness of the system are described below and summarised in Table 2-1.

   a. Predictive studies examine accidents where vehicles were not equipped with the specific feature under consideration and make calculations and/or judgements to assess whether the accident would have been avoided or mitigated if the safety feature had been present. There are a number of different methods that can be used when carrying out a predictive study. The most appropriate method will again be influenced by the burden of proof required and budgetary/time constraints:

      i. A parameter based study is the most straightforward, and it is likely to be appropriate for a medium burden of proof. This type of study is an extension of the target population exercise described in step 2 and involves interrogating an accident database to identify in more detail the casualties where a system is likely to be effective. If a forward collision warning system was assessed for PTWs the target population might be all front to rear shunt collisions where the PTW approached from the rear. The effectiveness calculation might further restrict the target population to exclude accidents where the PTW rider was impaired, accidents on a bend, or those that occurred in severe weather conditions where the system was known not to function well. The quality of this type of analysis will depend upon the detail, accuracy and representativeness of the data source used and any assumptions made to overcome limitations in the data.

      ii. Case by case analysis involves the detailed review, reconstruction and prediction of effects in a range of individual accidents. The predictions can be made in a number of ways:

         1. An assessment of the effectiveness of the safety system can be made for each accident case identified based on the information available and engineering judgments. Again the quality of this assessment can be influenced by the source of data. If the
cases have been reconstructed based on the sequence of events, the evidence left at the scene (e.g. tyre marks) and mathematical calculations (e.g. police accident reconstruction) there is more information available than what may be available from a limited number of database fields. The method can be made less subjective by providing guidelines that define when the system is expected to be effective. Weighting of the assessment with estimates of the probability of effectiveness (e.g. definitely, probably maybe) can also reduce the subjectivity of the assessment. This method is likely to be appropriate for a high burden of proof.

2. Mathematical modelling can be used on a case by case basis and is less subjective than the method described above. This method involves creating a computer model of an accident and simulating the outcome with the fitting of the safety system. Such an approach has the advantage of being fully objective but is more complex and time consuming and, because it is firmly rule based, can miss some more subtle factors that influence outcomes. This method is likely to be appropriate when a high burden of proof is required.

3. A limitation of both techniques above is that it is difficult to rigorously include driver behaviour factors associated with the new system in the assessment of its effectiveness. Particularly for primary safety systems, this means that it can be easy for critics to argue that the results are not valid because the system would induce a behavioural change that would reduce or eliminate the predicted benefits. Where the highest burden of proof is required this limitation can be overcome through the use of physical trials involving ordinary drivers as subjects. These can take the form of simulator trials, track trials or field operational trials. This method can allow for human factors issues to be combined with the accident data assessment, however the reliability of the data is dependant on assumptions made and the experimental methods used.

b. Retrospective studies treat the feature under investigation as a risk factor and use statistical methods to compare the relative risk of accidents in real world accident data where vehicles can be identified that both do and do not have the safety feature fitted. Where such an approach is possible, it has the most potential for providing a rigorous and defendable outcome because it seeks to objectively measure the actual effect on real vehicles in service with real drivers, thus accounting for many of the factors that can confound predictive studies. The size of the sample will have a strong affect on whether statistically significant conclusions can be drawn and the analytical design, particularly the control of confounding factors (e.g. systematic biases such as age of driver etc), will strongly affect the quality of the results.
Table 2-1. Summary of assessment methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Burden of proof</th>
<th>Relative cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predictive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameter based</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Subjective case-by-case</td>
<td>Medium – High</td>
<td>Medium</td>
</tr>
<tr>
<td>Case-by-case reconstruction</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Retrospective</td>
<td>Statistical</td>
<td>High – very high</td>
</tr>
</tbody>
</table>

3. **Is the system on the market?** Whether the system is on the market, or available for trials will influence the type of analysis that can be completed.
   a. No – If the system is not on the market, or at least not in significant numbers, then the estimation of effectiveness is restricted to a predictive study.
   b. Yes – If the system is on the market then either a retrospective study, a predictive study, or both can be carried out depending on the burden of proof required, analytical design factors and budgetary constraints for completing the analysis.

4. **What sources of information are available for determining the effectiveness?**
   a. Literature – This could include the findings from a range of studies that have already been carried out which could have determined the effectiveness of the system under consideration. The findings from other studies should be critically reviewed and any assumptions made should be identified in order to determine if the effectiveness quoted is appropriate for the target population. The use of multiple sources is recommended, identifying where there is agreement or differences between studies. It may be necessary to define a range of effectiveness if there is no consensus in the literature and the logic used to define the range should be reported. Where sufficient detail exists a formal meta-analysis can be undertaken. This essentially involves calculating a statistical weighted mean of the effects identified by the previous studies. However, this can require considerable time and effort and requires the data in the literature to be well reported in considerable detail.
   b. Specific research studies can be used as a substitute for accident data and can include field operational trials or questionnaire surveys to compare the accident involvement of equipped and unequipped vehicles and estimate the relative change in risk for equipped vehicles.
   c. Accident data can be used to allow either predictive or retrospective studies. The data sources used will be influenced by the burden of proof required, the type of analysis and also the function that the system is intended to achieve. For example a parameter based predictive analysis for assessing the benefits of improved helmets is likely to require a different source of data to a case-by-case predictive analysis of an advanced braking system. Retrospective analyses have different requirements again, and are typically based on national accident data.
   d. Vehicle equipment data can be used to identify whether the specific vehicles recorded in the accident data are fitted with a specific safety system. This type of information is an essential pre-requisite of retrospective analyses.
   e. Exposure data, or the use of an induced exposure technique, is required to allow the probability of an accident occurring to be determined when carrying out a retrospective analysis.
2.3.3 Outputs

The output from Step 3 is an estimate of system effectiveness that is relevant to the target population that was defined in Step 2. This can then be applied to the target population to estimate the casualty benefits for the safety system.

The estimated benefits should be clearly expressed as a percentage of the target population (so it can be seen how effective the system is at addressing the intended group of accidents) and as a percentage of all accidents. In particular, the latter measure is important for comparison with other studies and for context for the predicted casualty benefit.

The estimated casualty benefits can be combined with vehicle registration data, casualty valuation information and details of the costs of the system to produce a full cost benefit analysis. Defining procedures or guidelines for the generation of cost benefit analyses was beyond the scope of this project. However, it is possible to define a preliminary assessment on the basis of the calculation of a break-even cost for the system. This is calculated by multiplying the number of casualties by their casualty prevention value and dividing by the number of new registrations expected each year. This represents the maximum cost that can be associated with fitting the system to a single vehicle that could still produce a benefit-to-cost ratio to equal one. If the actual costs of the system are likely to be substantially below this break-even cost then it is likely that the system would prove to have a positive benefit to cost ratio if a full analysis was undertaken. If the cost is substantially greater it is likely to have a negative ratio. Where the actual costs are relatively close to the break-even cost, the simplifications inherent in this method mean that the outcome remains uncertain.
Figure 2. Identification of appropriate method for determining effectiveness.
3 Phase 2 – implementation of the methodology

Phase 2 of the project involves implementing the methodology described in section 2 to three types of advanced braking systems:

- Anti-lock braking systems (ABS). ABS works by preventing wheel lock during braking, helping to prevent vehicle instability and allowing the rider more confidence to use the full braking potential of the motorcycle, thus reducing typical stopping distances.

- Combined braking systems (CBS). CBS means that both front and rear brakes are applied by a single braking control instead of two independent controls. The braking force is therefore automatically distributed between the two wheels helping to ensure that the optimum braking force is applied at each wheel. This makes it easier for riders to apply maximum braking without instability but does not prevent wheels locking (and instability) if the brakes are applied too hard.

- Brake assist systems (BAS). BAS incorporates the functions of ABS and CBS. In addition to this, BAS sense when the rider is attempting to apply full emergency braking. When this is the case the system will apply full emergency braking using the ABS to ensure wheels do not lock and CBS to ensure the optimum brake distribution, thus allowing the vehicle to stop in the shortest distance possible.

The implementation of the methodology was restricted to the use of information that was already available, i.e. mainly literature supplemented by limited analysis of existing accident data. No additional data has been collected specifically for this project.

The burden of proof that can be achieved through the use of existing data is variable, depending on what studies have already been carried out. The level of the burden of proof for the assessment has been identified using the methodology defined above.

3.1 Step 1 - preliminary filter

3.1.1 Design/development

A preliminary filter has been developed for PTW accidents in Great Britain. In relation to the key considerations outlined in section 2.1.2:

- A three year STATS19\(^1\) data set has been used;
- Casualty groups have been defined as shown in Figure 3;
- The number of PTW casualties are presented, divided by casualty severity;
- The output from the filter is presented in terms of numbers of casualties, proportion of all casualties and casualty prevention values, all of which are subdivided by casualty severity.

\(^1\) STATS19 is the system for collecting and processing road accident data recorded by police officers in Great Britain. (DfT, 2007).
Figure 3. Structure of preliminary filter.

Table 3-1 shows the options available for each of the input variables shown in Figure 3. Figure 4 shows a screen shot of the interface for the preliminary filter.
Table 3-1. Input options for preliminary filter.

<table>
<thead>
<tr>
<th>Input field</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTW type</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>( \leq 50\text{cc} )</td>
</tr>
<tr>
<td></td>
<td>( &gt;50\text{cc and } \leq 125\text{cc} )</td>
</tr>
<tr>
<td></td>
<td>( &gt;125\text{cc and } \leq 500\text{cc} )</td>
</tr>
<tr>
<td></td>
<td>( &gt;500\text{cc} )</td>
</tr>
<tr>
<td>Number of vehicles involved</td>
<td>All**</td>
</tr>
<tr>
<td></td>
<td>Single*</td>
</tr>
<tr>
<td></td>
<td>Multi-vehicle**</td>
</tr>
<tr>
<td>On a bend?</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Loss of control?</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Junction type</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Not at or within 20m of junction</td>
</tr>
<tr>
<td></td>
<td>Roundabout</td>
</tr>
<tr>
<td></td>
<td>Junction</td>
</tr>
<tr>
<td></td>
<td>Slip road</td>
</tr>
<tr>
<td></td>
<td>Other</td>
</tr>
<tr>
<td>Pre-impact manoeuvre</td>
<td>Waiting</td>
</tr>
<tr>
<td></td>
<td>Turning</td>
</tr>
<tr>
<td></td>
<td>Overtaking</td>
</tr>
<tr>
<td></td>
<td>Slowing/stopping</td>
</tr>
<tr>
<td></td>
<td>Going ahead</td>
</tr>
<tr>
<td></td>
<td>Changing lane</td>
</tr>
<tr>
<td></td>
<td>Other</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
</tr>
<tr>
<td>PTW /other vehicle 1st point of impact</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Did not impact</td>
</tr>
<tr>
<td></td>
<td>Front</td>
</tr>
<tr>
<td></td>
<td>Back</td>
</tr>
<tr>
<td></td>
<td>Offside</td>
</tr>
<tr>
<td></td>
<td>Nearside</td>
</tr>
<tr>
<td>Impact vehicle</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Pedal cycle</td>
</tr>
<tr>
<td></td>
<td>PTW</td>
</tr>
<tr>
<td></td>
<td>Car</td>
</tr>
<tr>
<td></td>
<td>Minibus</td>
</tr>
<tr>
<td></td>
<td>Bus/coach</td>
</tr>
<tr>
<td></td>
<td>Light goods vehicle</td>
</tr>
<tr>
<td></td>
<td>Heavy goods vehicle</td>
</tr>
<tr>
<td></td>
<td>Agricultural vehicle</td>
</tr>
<tr>
<td></td>
<td>Other motor vehicle</td>
</tr>
<tr>
<td></td>
<td>Other non-motor vehicle</td>
</tr>
<tr>
<td></td>
<td>Tram</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
</tr>
<tr>
<td>Impact object</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>On carriageway</td>
</tr>
<tr>
<td></td>
<td>Off carriageway</td>
</tr>
</tbody>
</table>

*Pre-impact manoeuvre, impact vehicle and 1st point of impact on other vehicle cannot be selected for single vehicle accidents.

** On a bend? or loss of control? cannot be selected when multi-vehicle or all accidents are selected.
3.1.2 Applying the preliminary filter

The preliminary filter is intended to be used to identify casualty groups that could potentially be affected by the technology under consideration. However, the advanced braking systems that are under consideration here can influence a broad range of casualty groups to a varying extent. It is, therefore, only possible to generate a coarse estimate of the target population for braking systems using this tool. However, analysis by the type of PTW involved could provide an insight into where to target the technology. The data in Table 3-2 was generated using the preliminary filter.
Table 3-2. PTW casualties by severity and engine capacity.

<table>
<thead>
<tr>
<th>Severity</th>
<th>≤50cc</th>
<th>&gt;50 and ≤125cc</th>
<th>&gt;125 and ≤500cc</th>
<th>&gt;500cc</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of casualties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatal</td>
<td>23</td>
<td>62</td>
<td>66</td>
<td>435</td>
<td>585</td>
</tr>
<tr>
<td>Serious</td>
<td>773</td>
<td>1397</td>
<td>683</td>
<td>3138</td>
<td>5991</td>
</tr>
<tr>
<td>Slight</td>
<td>3751</td>
<td>4914</td>
<td>1828</td>
<td>6801</td>
<td>17293</td>
</tr>
<tr>
<td>KSI</td>
<td>796</td>
<td>1458</td>
<td>749</td>
<td>3573</td>
<td>6576</td>
</tr>
<tr>
<td>Total</td>
<td>4547</td>
<td>6372</td>
<td>2571</td>
<td>10374</td>
<td>23870</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Casualty prevention value (£M)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>37.9</td>
<td>101.7</td>
<td>108.2</td>
<td>717.0</td>
<td>964.9</td>
</tr>
<tr>
<td>Serious</td>
<td>143.2</td>
<td>258.7</td>
<td>126.5</td>
<td>581.3</td>
<td>1109.7</td>
</tr>
<tr>
<td>Slight</td>
<td>56.3</td>
<td>70.2</td>
<td>26.1</td>
<td>97.1</td>
<td>246.9</td>
</tr>
<tr>
<td>KSI</td>
<td>181.1</td>
<td>360.3</td>
<td>234.7</td>
<td>1298.3</td>
<td>2074.5</td>
</tr>
<tr>
<td>Total</td>
<td>234.6</td>
<td>430.5</td>
<td>260.9</td>
<td>1395.4</td>
<td>2321.5</td>
</tr>
</tbody>
</table>

The results of this analysis indicate that a measure such as braking, which could potentially apply to all accident types, is likely to gain the greatest benefit when fitted to motorcycles with an engine capacity greater than 500cc. These larger motorcycles are involved in approximately 75% of all PTW fatal accidents.

Additionally, it is possible to logically assess the types of accident where advanced braking systems are more likely to have an influence, for example accidents at junctions where the PTW is travelling ahead and single vehicle loss of control on a bend, and then quantify the number of casualties occurring in these “more likely” accident types (Table 3-3). Such an assessment will be imperfect because not all of these casualties will be influenced by the technology and there will also be other casualty groups that have been excluded but may be influenced. However, it could give a closer indication than considering “all” accidents only.

Table 3-3. Examples of casualty groups where advanced braking systems are more likely to have an influence.

<table>
<thead>
<tr>
<th></th>
<th>Junction accidents - PTW going ahead</th>
<th>Single vehicle loss of control on bend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Casualties</td>
<td>Casualty prevention value (£M)</td>
</tr>
<tr>
<td>Fatal</td>
<td>108</td>
<td>180.2</td>
</tr>
<tr>
<td>Serious</td>
<td>1238</td>
<td>229.2</td>
</tr>
<tr>
<td>Slight</td>
<td>3218</td>
<td>45.9</td>
</tr>
<tr>
<td>KSI</td>
<td>1347</td>
<td>409.5</td>
</tr>
<tr>
<td>Total</td>
<td>4565</td>
<td>455.4</td>
</tr>
</tbody>
</table>

*Note: asterisked values are not a direct output from the preliminary filter but are calculated using only the data generated by the preliminary filter.
It is also possible to identify groups that are less likely to be influenced by the systems, for example where the PTW is waiting or turning (Table 3-4). However, some of the casualties within these groups could be affected.

**Table 3-4. Examples of casualty groups where advanced braking systems are less likely to have an influence.**

<table>
<thead>
<tr>
<th></th>
<th>Accidents where the PTW is turning</th>
<th>% of all PTW accidents by severity*</th>
<th>Accidents where the PTW is waiting</th>
<th>% of all PTW accidents by severity*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Casualties</td>
<td>Casualty prevention value (£M)</td>
<td>Casualties</td>
<td>Casualty prevention value (£M)</td>
</tr>
<tr>
<td>Fatal</td>
<td>12</td>
<td>20.3</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>Serious</td>
<td>290</td>
<td>53.7</td>
<td>77</td>
<td>14.2</td>
</tr>
<tr>
<td>Slight</td>
<td>1191</td>
<td>17.0</td>
<td>779</td>
<td>11.1</td>
</tr>
<tr>
<td>KSI</td>
<td>302</td>
<td>74.0</td>
<td>77</td>
<td>15.3</td>
</tr>
<tr>
<td>Total</td>
<td>1493</td>
<td>91.0</td>
<td>856</td>
<td>26.4</td>
</tr>
</tbody>
</table>

Ideally the target population for all three braking systems would be any accident where the vehicle braked. Unfortunately, this cannot be identified from the available data. Therefore, the only rigorously acceptable target population is all casualties. The preliminary filter has been used to compare the relative size of the different casualty groups. It can be seen that the greatest benefits would appear to lie with larger motorcycles, simply because of their greater involvement.

A more subjective approach can be used to try to get a more realistic target population. An upper estimate was based on excluding accidents where the PTW was waiting or turning (where it is logical to assume braking might be less relevant). A lower estimate was derived from considering only accidents with loss of control on a bend and junction accidents (where logically, braking is likely to occur frequently). The estimated target population using this approach is:

- 154 to 572 PTW fatalities;
- 1534 to 5624 serious PTW casualties; and
- 3538 to 15323 slight PTW casualties.

Further estimates of the benefits associated with the advanced braking systems are made in the following sections of this report.

The quality of the estimate generated using the preliminary filter is dependant on the technology being considered. As mentioned previously, braking systems can affect a proportion of a large number of casualty groups. However, the casualty groups that are likely to be influenced by junction collision warning systems or forward collision warning systems are more readily defined, as shown in the example below.
3.2 Step 2 - defining the target population

The target population is the group of accidents that are considered relevant to a technology that is being assessed. If a system is 100% effective, all accidents within the target population will be prevented or the severity of the injuries reduced.

3.2.1 Target population definition

The target population is defined by considering the accident types which could be influenced by the systems under consideration, ABS, CBS and BAS. The definition of the target population is often dependant on the purpose of the research and also by the data that is available. Fundamentally, all three of the systems under consideration are intended to influence the outcome from accidents within the same target population. The target population is accidents where the rider of the PTW braked prior to the collision.

3.2.2 Applying the target population

If TRL were conducting a new full-scale analysis of GB accidents, then the target population would be identified as defined in 3.2.1. Data from a detailed in-depth study which is representative of the national statistics (STATS19 data) would be used to identify the proportion of PTWs that braked prior to impact and this proportion would be applied to the casualty numbers recorded in STATS 19 to obtain a sound estimate of the target population nationally. However, the scope of this research project is restricted to analysis based on existing accident data and literature. So, although a definition for the target population is provided in the previous section, based on the methodology defined in this report, the analyses reported in existing literature may have structured their findings differently. The following section summarises the literature and data relating to target populations for the three technologies.

Examples

**Junction collision warning system** – select multiple vehicle accidents at junctions.
3 year average of 131 fatalities, 1784 serious casualties and 6022 slight casualties

**Forward collision warning system** – select multiple vehicle accidents PTW impact location front.
3 year average of 352 fatalities, 3076 serious casualties and 8391 slight casualties

However, it is important to note that the groups for junction collision and forward collision warnings are not mutually exclusive and cannot be combined without double-counting.
Table 3-5. Summary of target populations defined in literature.

<table>
<thead>
<tr>
<th>System</th>
<th>Target Population</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>All cases in which it can be conclusively proven that braking took place in the</td>
<td>Gwehenberger et al (2006) Allianz centre of technology</td>
</tr>
<tr>
<td></td>
<td>pre-crash phase (45% of all accidents)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All motorcycle accidents</td>
<td>McCarthy and Chinn (1998 &amp; 1999) TRL Ltd</td>
</tr>
<tr>
<td></td>
<td>All motorcycle accidents involving downfall* prior to first impact</td>
<td>Baum et al (2007) University of Cologne</td>
</tr>
<tr>
<td></td>
<td>All accidents in sample</td>
<td>Teoh (2008) Insurance Institute for Highway Safety USA.</td>
</tr>
<tr>
<td></td>
<td>All accidents in sample where at least one wheel has locked prior to impact or</td>
<td>McCarthy et al (2008) PISa</td>
</tr>
<tr>
<td></td>
<td>loss of control (34% of all fatal PTW accidents)</td>
<td></td>
</tr>
<tr>
<td>CBS</td>
<td>All accidents in sample that involved pre-event braking and loss of control before</td>
<td>McCarthy et al (2008) PISa</td>
</tr>
<tr>
<td></td>
<td>impact (1% of all fatal PTW accidents)</td>
<td></td>
</tr>
<tr>
<td>BAS</td>
<td>All accidents in sample with evidence of braking but the PTW has failed to stop</td>
<td>McCarthy et al (2008) PISa</td>
</tr>
<tr>
<td></td>
<td>prior to impact (3% of all fatal PTW accidents)</td>
<td></td>
</tr>
</tbody>
</table>

* downfall accidents are when the rider becomes detached from the PTW before the first impact.

The target population identified by Gwehenberger et al (2006) was derived by taking all the accidents in which it was possible to identify that pre-event braking took place. Of an original sample size of 200 cases it was found that 90 of these cases involved braking and were relevant to ABS (45%). The research also showed that 69% of ABS-relevant cases take place outside of city limits and that the proportion of collisions involving a vehicle turning into or crossing a main road is very high, 83%. Gwehenberger et al (2006) define the target population in a manner that is most comparable to the definition provided in section 3.2.1. This defines the target population as all accidents in which it can be proved that braking was a pre-crash event. This equates to approximately 45% of all motorcycle accidents in the database. However, the database used in the study was based on insurance claims in which the value was between €1500 and €2million, rather than police reported casualty severity and is for Germany rather than Great Britain. The database includes fatal, serious and slight injuries although the proportions are not representative of the national statistics of Germany, with a bias towards serious accidents.
The Kebschull and Zellner (2007) report does not specify a target population as such, but instead uses all the accident cases collected in two in-depth studies. The first was completed by Hurt in 1981 and uses American accident data. The second is the MAIDS study which took place across Europe with data collected from five teams in various European countries. Together they comprise approximately 1800 accidents. These were investigated using a computer model to determine whether an ABS system could have mitigated the outcome or prevented the accident. The MAIDS data is representative of the European PTW population as a whole, but is not representative of the vehicle population found in the UK, which includes more motorcycles than other parts of Europe. Approximately 87% of the UK PTW fleet is made up motorcycles (i.e. greater than 50cc) and those 87% of vehicles were involved in 81% of the injury accidents involving PTWs in 2007 (DfT, 2008). This is compared to the MAIDS statistics where approximately 57% of the injury accidents in MAIDS resulted from accidents involving motorcycles greater than 50cc.

The studies conducted by McCarthy and Chinn (1998 and 1999) use a target population of all accidents, although the estimate of effectiveness was based on a sample that only included BMW motorcycles. This could introduce systematic bias into the assessment if some characteristic (other than ABS) of BMW motorcycles, their riders or their use (exposure to risk) is significantly different from other makes and models. BMW introduced ABS into its vehicle fleet in 1990, so data was collected for vehicles manufactured before 1990 as a non-ABS sample and post 1990 as an ABS sample. Data was collected for several years between 1989 and 1996. This is a typical method used in retrospective studies, looking at a technology which has been used by certain vehicle manufacturers for several years and evaluating its performance in comparison to previous models without the technology fitted.

Baum et al (2007) defined a target population of all motorcycle accidents involving a downfall, they state that this was limited because their data set did not allow them to consider other scenarios e.g. all accidents in which braking occur. The authors believe that the overall casualty reduction estimates are lower as a result of the restricted target population.

Teoh (2008) has completed a retrospective study, comparing PTW accident rates for PTWs where two models are produced with the only difference between the two being the fitment of ABS. In addition to this requirement, in order for the accident data to be found, the model name of the ABS equipped vehicle must contain the word "ABS" to allow the accidents to be identified. This restricts the target population to eight different types of PTW and 16 models.

As identified earlier, the ideal target population is one which includes all PTW accidents and casualties where the PTW was braking before impact. With regard to this criterion, the most appropriate study would be Gweenberger et al (2006). However, this study uses German accident data and the accidents are not representative of national statistics. Although Germany has a similar PTW vehicle parc to GB, particularly compared with some other European countries, there are still some differences. Approximately 70% of the vehicle parc in Germany are motorcycles compared with 87% of the GB parc.

From this review, it is most appropriate to define the target population as all accidents involving a PTW. This is because there is no study that is representative of GB that identifies the proportion of accidents involving pre-impact braking. The use of all PTW accidents as a target population has been used in several of the studies.

### 3.3 Step 3 - system effectiveness

If a new analysis of the three systems under consideration was to be undertaken in accordance with the methodology defined in Section 2 with a high burden of proof then the programme of work could involve:
• Detailed definition of the performance characteristics of the three systems;
• Predictive analyses, based on case by case review and reconstruction of OTS and/or Fatal cases to assess the influence of each system with extrapolation of results to STATS 19 for an estimate of national benefits;
• Human factor experiments on the test track to assess rider response to the system and identify any behavioural risks;
• Identification of makes and model of PTW fitted with the systems (which is possible based on manufacturers literature but is labour intensive);
• Retrospective statistical analysis of the relative accident involvement of PTWs with and without the system.

However, the scope of this research is limited to a review of existing literature. The following sections summarise and discuss the findings from this review with respect to the effectiveness of each of the systems.

3.3.1  ABS

Information about the effectiveness of ABS identified in the literature is summarised in Table 3-6.

Kebschull and Zellner (2007) found a relatively low effectiveness compared with other studies. A large percentage of the 900 European accidents investigated contained accidents which involved either no braking or braking with no loss of control, which was assumed in their investigation to be sub-limit braking. A large proportion of the accidents that involved over braking also involved an emergency steering action. In general, PTW ABS does not allow the PTW to maintain stability while braking heavily in a curve/swerve. This was reflected in the ABS model used in this study, which was not capable of maintaining stability in a swerve when braking was severe enough to activate the ABS. This was a predictive study that used computer simulation to predict how the outcome of real accidents involving PTWs without ABS would have been changed if the vehicle had been fitted with ABS. This approach would result in evidence that has a high burden of proof according to the methodology defined earlier in this report. However, the assumption that ABS would have no influence in any accident where braking occurred without loss of control contradicts several other studies which suggests that ABS gives the rider more confidence and in turn, results in higher maximum achievable deceleration. Therefore, the method used in the analysis may tend to under-estimate the benefits.

Gwehenberger et al (2006) found that the proportion of probably/possibly avoided accidents accounts for approximately 17% to 38% of the 90 accident European target population. This was completed by using in-depth analysis of the cases assuming that ABS can stabilise the braking process, prevents the front wheel from over-braking or prevents a fall as a result of over-braking and can shorten the braking distance. They used test data gained from tests completed by motorbike magazines “Motorradfahrer” and “Tourenfahrer” to gain an estimate for the increase in braking deceleration when using a motorcycle fitted with ABS. The outcome of the accident if the vehicle was fitted with ABS was the estimated using three categories; probably avoidable, possibly avoidable and not avoidable. When based upon the whole sample of 200 serious accidents, the effectiveness was estimated as between 8% and 17%. Accidents not involving other persons were under-represented compared with national statistics. However, according to Kramlich and Sporner (2000). ABS has a similar avoidance potential for accidents not involving other people. This predictive study used subjective in-depth analysis on a case by case basis, so it is categorised as potentially providing a high burden of proof. However, the sample used for the in-depth analysis was relatively small and not representative of the national statistics. In particular, the report acknowledged a bias towards fatal and serious injury accidents. This has been caused by
the way that the data has been collected, using insurance data from claims above €15,000.

Table 3-6. Effectiveness of ABS identified from the literature.

<table>
<thead>
<tr>
<th>Effectiveness</th>
<th>Source</th>
<th>Region*</th>
<th>Study type</th>
<th>Sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>85% of all downfall accidents with downfall before initial impact</td>
<td>Baum <em>et al</em> (2007) based on a retrospective study.</td>
<td>Germany</td>
<td>Retrospective</td>
<td></td>
</tr>
<tr>
<td>Approximately 10% of motorbike accidents involving injury can be avoided or positively influenced</td>
<td>Sporner <em>et al</em> (2000,2002,2004) cited in Gwehenberger (2006) describe the dangers of braking with conventional braking systems and the avoidance potential through ABS in several studies based on the GDV accident database (insurance claims).</td>
<td>Germany</td>
<td>Predictive</td>
<td></td>
</tr>
<tr>
<td>Avoids 8%-17% of serious motorbike accidents</td>
<td>Gwehenberger <em>et al</em> (2006). Results of analysis of 200 serious accidents by Allianz Center of Technology. Extrapolated to Germany would result in around 100 deaths and more than 1,000 serious injuries avoided a year</td>
<td>Germany</td>
<td>Predictive – case by case subjective</td>
<td>200 accidents</td>
</tr>
<tr>
<td>Net injury benefit 1%-3% of all casualties</td>
<td>Kebschull and Zellner (2007) conducted a series of computer simulations based on data collected in the MAIDS (2004) and Hurt (1981) studies. Several configurations of ABS were simulated.</td>
<td>USA and Europe</td>
<td>Predictive case by case computer modelling</td>
<td>1800 accidents</td>
</tr>
<tr>
<td>Analysis of Austrian statistics showed that the benefit was comparable to the 55% stated by Sporner <em>et al</em> (2000)</td>
<td>Vavryn and Winkelbauer (2005)</td>
<td>Austria and Germany</td>
<td>Predictive</td>
<td></td>
</tr>
<tr>
<td>Increase in braking performance observed of novice and experienced test riders from 5.7ms^{-2} to 7.7ms^{-2} for novice riders and 6.6ms^{-2} to 7.8ms^{-2} for experienced riders</td>
<td>Vavryn and Winkelbauer (2005)</td>
<td>Austria</td>
<td>Human factors study</td>
<td>47 novice riders and 134 experienced riders</td>
</tr>
<tr>
<td>ABS reduces risk of riders being thrown from the bike. May lead to a reduction in forward collision and off-road crashes.</td>
<td>Bayly <em>et al</em>, 2006 (2006)</td>
<td>Australia</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Effectiveness | Source | Region | Study type | Sample size
---|---|---|---|---
3% reduction in fatal and serious casualties | McCarthy and Chinn (1999) | UK | Retrospective | 

The effectiveness of ABS is currently under investigation as part of the PISa project. However, the report contains a ranking of various safety systems including ABS, CBS and BAS. Each system was given a score based on the potential influence on the accident outcome, however was not expressed as a percentage of the target population. ABS was given a score of 2.39.

Sporner et al (2000), cited in Vavryn and Winklebauer (2006), undertook a study of 610 in-depth accident reports. Vavryn and Winklebauer (2006) stated that Sporner et al’s findings were that on average:

“Approximately 55% of the motorcycle accidents could be avoided or at least positively influenced by ABS”.


“approx. 10% of motorbike accidents involving bodily injuries can be avoided or at least positively influenced through ABS”.

There appears to be some discrepancy between these two interpretations of an estimate of effectiveness from a single source. The only immediately apparent difference in the citations is the effectiveness estimate and the fact that Gwehenberger et al reference their effectiveness as a proportion of PTW accidents involving bodily injury whereas Vavryn and Winklebauer’s citation does not mention injury severity so could refer to a specific severity level. However, it has not been possible to locate an English language version of the original paper to clarify the exact findings. The estimate of 10% is most likely to be applicable to the target population that has been defined for this study for the following reasons:

- The effectiveness of 55% was written as though it may be the effectiveness for a different target population.
- Sporner was one of the authors of the Gwehenberger et al (2006) paper and would be expected to ensure that his previous research was cited correctly.

The study by Sporner et al (2000) that has been cited by Gwehenberger et al (2006) and Vavryn and Winklebauer (2006) appears to meet a medium to high burden of proof, because it is a predictive study based on a reasonably large sample of in-depth cases. However, the summaries of the research do not state if the cases were analysed on an individual basis, or using a parameter based approach.

Vavryn and Winklebauer (2005) conducted a behavioural study regarding the braking performance of experienced and novice motorcycle riders. The study used a range of experienced and novice riders who undertook braking tests on their own bike or, in the case of the novice riders, the PTW on which they learned. The riders were then shown how to correctly use an ABS-equipped PTW and repeated the tests using a PTW fitted
with ABS. The experienced riders increased their average deceleration from 6.6ms\(^{-2}\) to 7.8ms\(^{-2}\) and the novice riders improved from an average deceleration of 5.7ms\(^{-2}\) to 7.7ms\(^{-2}\). The authors concluded that ABS allows riders of all experiences to obtain much greater decelerations when compared with the same group of riders on their own PTWs. Similar studies have been undertaken, for example by Kneebone (1992), in which a group of riders with varying experience are used to test motorcycles with and without ABS. These give similar results to those identified in Vavryn and Winkelbauer (2005).

This study is useful to confirm that it is reasonable to assume in an effectiveness study that ABS can be effective in accidents where pre-impact braking took place but there was no loss of control, an accident type which some other analyses have excluded. It also provides some evidence to support the retrospective statistical studies that show that the theoretical benefits are achieved, at least to some extent, in real use. If a new predictive study were to be undertaken, this research could be used to support an assumed increase in deceleration to be used in reconstructing collisions to assess whether the effect would have been sufficient to avoid the crash. However, the results are not appropriate to determine a direct measure of effectiveness that can be applied as a percentage to a target population. The fact that the tests could not (for health and safety reasons) be undertaken in a simulated emergency situation leaves a risk that drivers would respond differently in real emergencies. In addition, there was no study of the long term effects of the ABS and the training on rider response; it is possible that riders would revert to their previous behaviour over time or ride more aggressively if they had increased confidence in the brakes.

The Monash University report investigating Intelligent Transport Systems and Motorcycle Safety (Bayly et al, 2006) outlined the expected behaviour in comparison to accident types found in Australia. However, this report did not make any estimates of the actual effectiveness of ABS. The report is limited to defining the target population only and would, therefore, only provide a low burden of proof.

McCarthy and Chinn (1999) investigated the effectiveness of ABS by conducting a retrospective study using data collected from high level national statistics (i.e. Stats19). This was done by examining two sets of data from a vehicle manufacturer over period of eight years (1989 to 1996). The data including all accidents for a manufacturer split by the registration data, with one set prior to the introduction of ABS and one post. The main assumption in this piece of work is that, all vehicles produced after the introduction of ABS incorporated ABS. The report acknowledged that this was not always the case, which means that there was an element of misclassification of vehicles in the analysis, which in turn would lead to an underestimate of the effectiveness. In addition to this, the analysis of effectiveness was confined to only BMW motorcycles, which significantly limits the sample size available and could potentially introduce systematic bias (if some characteristic of BMW motorcycles, their riders or the use to which they are put is significantly different to the population of non-BMW vehicles). This analysis provides evidence that would meet a medium to high burden of proof.

McCarthy et al (2008) compared the potential influence of a wide range of active safety systems for PTWs. ABS was given a score of 2.39, and preventing wheel lock using ABS was ranked number 6 from a list of 43 functional requirements. The analysis was based on case reviews of 60 accidents recorded either in the OTS database or the COST327 database so has the potential to provide a high burden of proof. The sample consisted of accidents of all severities, but was relatively small and was not representative of GB national statistics, by type or severity of accident.

3.3.2 CBS

There was limited information about the effectiveness of CBS identified in the literature that was reviewed. The information that was identified is shown in Table 3-7.
Table 3-7. Effectiveness of CBS identified from the literature.

<table>
<thead>
<tr>
<th>Effectiveness</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>From the ranking of safety systems CBS had a score of 1.72, lower than ABS</td>
<td>McCarthy et al (2008) PISa OTS/COST327 cases</td>
</tr>
<tr>
<td>CBS can be effective in accidents in which heavy braking is required. However, this was not quantified.</td>
<td>Bayly et al, 2006 (2006), Australia</td>
</tr>
</tbody>
</table>

Vavryn and Winkelbauer (2005) state that several studies provide proof that a typical motorcycle rider is unable to brake appropriately using two different systems, particularly in emergency situations. However, none of the studies quantified the effectiveness of such a system. The study by Bayly et al (2006) also stated the types of accident that could be influenced, but did not provide any quantification.

McCarthy et al (2008) included CBS in their review of in-depth cases of PTW safety. Balancing front to rear braking force using CBS was scored 1.72 and was ranked number 7 in the list of functional requirements. However, the effectiveness of the system was not defined in a manner that could be applied to the target population defined earlier in this report.

### 3.3.3 Brake assist

There was very little information about the effectiveness of BAS for PTWs. Therefore, Table 3-8 includes some information about the effectiveness of BAS for passenger cars.

Table 3-8. Effectiveness of BAS identified from the literature.

<table>
<thead>
<tr>
<th>Effectiveness</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in the number of car occupant casualties by between 6.5 and 9%</td>
<td>Page et al (2005) reported the effectiveness of BAS for passenger cars.</td>
</tr>
<tr>
<td>A reduction in stopping distances should lead it to be effective in mitigating or avoiding forward collisions and collisions with objects in the roadway. No quantification of the effectiveness.</td>
<td>Bayly et al, (2006), Australia</td>
</tr>
<tr>
<td>BAS was assigned a score of 1.56 and was ranked lower than ABS and CBS.</td>
<td>McCarthy et al (2008) PISa OTS/COST327 case review</td>
</tr>
</tbody>
</table>

Page et al (2005) compared the expected and observed effectiveness of BAS in passenger cars. The study looked at occupant injuries and pedestrian injuries in terms of effectiveness estimates for BAS. This report provided evidence that has the potential to meet a very high burden of proof because it included both a predictive and a
retrospective study on BAS. However, the quality of the retrospective study is limited in terms of the sample size such that the results were not statistically significant. Page et al (2005) reported that BAS would be effective in reducing overall occupant injuries by between 6.5% and 9%.

The assessment of BAS as part of the PISa review of PTW safety systems resulted in an overall score of 1.56 and was ranked number 10 in the list of systems. As with ABS and CBS, the applicability of this data is limited for the purpose of estimating the benefits using the methodology outlined in this report.

### 3.4 Estimating the benefits

Table 3-9 shows the average annual number of PTW casualties for the period 2005 to 2007. This is the baseline data for the analysis that follows.

**Table 3-9. Number of PTW casualties, three year average 2005-2007, by PTW type.**

<table>
<thead>
<tr>
<th></th>
<th>Moped (≤50cc)</th>
<th>Motorcycle (&gt;50cc)</th>
<th>All PTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>23</td>
<td>562</td>
<td>585</td>
</tr>
<tr>
<td>Serious</td>
<td>773</td>
<td>5218</td>
<td>5991</td>
</tr>
<tr>
<td>Slight</td>
<td>3751</td>
<td>13543</td>
<td>17293</td>
</tr>
<tr>
<td>Total</td>
<td>4547</td>
<td>19323</td>
<td>23870</td>
</tr>
</tbody>
</table>

The following sections describe the estimated benefits associated with fitting each of the advanced braking systems to all PTWs in GB based on the target populations and information about system effectiveness described earlier. The benefit described is that which would have been realised if all relevant vehicles had been fitted with the safety system during the period covered by the baseline casualty data. The benefit of fitting the safety systems to motorcycles (>50cc) and mopeds (≤50cc) have been separated.

#### 3.4.1 ABS

Table 3-10 shows the estimated benefit of fitting ABS. The target population and effectiveness are shown in the table to allow readers to understand how the benefits have been derived. A best estimate of the effectiveness is shown in the table, accompanied by minimum and maximum effectiveness values.

The effectiveness of ABS used to identify the proportion of fatal casualties that can be prevented, was based upon the information found from a review of the PISa Fatal Accident Database. The development and analysis of the database was reported in McCarthy et al (2008). However, the target population used was not consistent with the other research identified and therefore the data was re-analysed as described in Appendix A. From this additional review of fatal accidents, an effectiveness of between 8.8% and 35.7% was estimated, with a best estimate of effectiveness of 18%.

For serious casualties, the effectiveness used is based upon the estimates outlined in Gwehenberger et al (2006) and McCarthy and Chinn (1999). Although Gwehenberger et al (2006) include accidents of all severities, the sample is most representative in relation to serious casualties and states an effectiveness range of between 8% and 17%. McCarthy and Chinn (1999) state an effectiveness for fatal and serious casualties, however the estimate is likely to be dominated by the effectiveness for serious casualties.
because the sample included only a relatively small number of fatalities. Therefore 3% was selected as a lower boundary for the effectiveness for serious casualties.

Sporner (2000, cited in Gwehenberger et al, 2006) stated that ABS is effective in 10% of PTW accidents of all severity levels. However, Kebschull and Zellner carried out a comprehensive study resulting in an overall effectiveness of between 1% and 3%. Both of the studies have limitations as described earlier and therefore a weighted average from these two studies has been used for the best estimate. Based on the mid range value from Kebschell and Zellner of 2% and a quality rating of 3 for each study, the best estimate is 6%. This was generated by multiplying the effectiveness by the score (2% x 3 and 10% x 3), summing (6 + 30) and dividing by the sum of the score (36/6). The extreme values from the two studies have been used to generate the overall range of effectiveness.

Appendix B describes an analysis of the effectiveness for slight casualties which was based on the work carried out in the PISa project (McCarthy et al, 2008). However, the estimated effectiveness of 17% is not consistent with the effectiveness for fatal, serious and all casualties, i.e. and effectiveness of 18% for fatal, 10% for serious and 17% for slight, would not result in an effectiveness for all casualties of 6%. Therefore, an estimate of effectiveness for slight casualties was based on the existing literature, which is based on larger sample sizes and more robust methodologies. Using the 6% value for all accidents and the best estimates of 18% for fatalities and 10% for serious casualties, a best estimate effectiveness of 4.2% was calculated for slight casualties. The upper and lower effectiveness values are calculated using the same method.

Table 3-10. Estimated benefit of fitting ABS, number of PTW casualties prevented.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Target population (All PTW casualties)</th>
<th>Effectiveness (%)</th>
<th>Fitted to Moped ≤50cc**</th>
<th>Fitted to Motorcycle &gt;50cc**</th>
<th>Fitted to All PTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>585</td>
<td>18 (9-36)</td>
<td>4 (2-8)</td>
<td>101 (49-201)</td>
<td>105 (52-209)</td>
</tr>
<tr>
<td>Serious</td>
<td>5991</td>
<td>10* (3-17)</td>
<td>77 (23-131)</td>
<td>522 (157-887)</td>
<td>599 (180-1018)</td>
</tr>
<tr>
<td>Slight</td>
<td>17293</td>
<td>4 (0-7)</td>
<td>150 (0-251)</td>
<td>542 (0-907)</td>
<td>692 (0-1159)</td>
</tr>
<tr>
<td>Total</td>
<td>23870</td>
<td>6 (1-10)</td>
<td>273 (45-455)</td>
<td>1159 (193-1932)</td>
<td>1432 (239-2387)</td>
</tr>
</tbody>
</table>

*This is the mid-point of the range because insufficient information was available to derive a best estimate.

**Note that none of the literature studied considered the effectiveness of ABS separately for mopeds and motorcycles. This breakdown of predicted benefits is based on the assumption that the effectiveness of ABS is equal for both vehicle types.

The estimated casualty benefit of fitting ABS to all PTWs is between 239 and 2,387 casualties per year. The best estimate of the casualty saving potential of ABS is 1,432 casualties per year. The proportion of casualties that are riding motorcycles (>50cc) is highest for fatalities, 96%. As the severity of the casualty reduces, so does the proportion of casualties associated with motorcycles rather than mopeds, with 78% of slight casualties riding motorcycles rather than mopeds. The proportion of casualties that could be prevented that are fatally or seriously injured is higher for motorcycles than for mopeds, 54% of motorcyclists are killed or seriously injured compared to 30% of moped riders.

Table 3-11 shows the benefits expressed in terms of the valuation associated with preventing the PTW casualties. A three-year average casualty valuation was used, with
annual values taken for Road Casualties Great Britain (DfT, 2006, 2007 and 2008). The three year average valuations are:

- Fatality - £1,522,100;
- Serious casualty - £173,030;
- Slight casualty - £13,187.

Table 3-11. Estimated benefit of fitting ABS, valuation associated with prevention of PTW casualties.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Target population (All PTW casualties)</th>
<th>Effectiveness (%)</th>
<th>Fitted to Moped ≤50cc** (£M)</th>
<th>Fitted to Motorcycle &gt;50cc** (£M)</th>
<th>Fitted to All PTW (£M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>585 (9-36)</td>
<td>18</td>
<td>6.3 (3.1-12.5)</td>
<td>154.1 (75.3-305.6)</td>
<td>160.4 (78.4-318.0)</td>
</tr>
<tr>
<td>Serious</td>
<td>5991 (3-17)</td>
<td>10* (0-7)</td>
<td>13.4 (4.0-22.7)</td>
<td>90.3 (27.1-153.5)</td>
<td>103.7 (31.1-176.2)</td>
</tr>
<tr>
<td>Slight</td>
<td>17,293 (0-7)</td>
<td>4</td>
<td>2.0 (1.5-2.5)</td>
<td>7.1 (5.4-8.9)</td>
<td>9.1 (6.8-11.4)</td>
</tr>
<tr>
<td>Total***</td>
<td></td>
<td></td>
<td>21.7 (7.1-38.5)</td>
<td>251.5 (102.4-467.3)</td>
<td>273.2 (109.5-505.6)</td>
</tr>
</tbody>
</table>

*This is the mid-point of the range (rounded to nearest integer) and not a best estimate.

** Note that none of the literature studied considered the effectiveness of ABS separately for mopeds and motorcycles. This breakdown of predicted benefits is based on the assumption that the effectiveness of ABS is equal for both vehicle types.

*** This is the sum of the valuations for fatal, serious and slight casualties.

The analysis shows that the valuation associated with preventing casualties by fitting ABS to all PTWs is between £109.5 Million and £505.6 Million, with a best estimate of £273.2 Million. The value associated with the killed and seriously injured PTW riders/passengers accounts for 97% of the overall value. However, this second approach is only valid when the following two conditions are met:

- The proportion of casualties that are injured to each level of severity (fatal, serious, slight) is the same for the casualties considered in the analysis (PTW casualties in this case) as it is for all fatalities.
- The measure being assessed is equally effective at preventing casualties of all severity levels.

It is clear that a much higher proportion of PTW casualties are fatally or seriously injured when compared with casualties from all vehicles. There is also some evidence to suggest from the various studies that ABS is more effective at preventing fatal and serious casualties than slight. This means that calculating the financial benefits of the casualties prevented based only on the proportion of all PTW casualties prevented and the published average financial prevention value for casualties of all severities is likely to substantially under-estimate the ‘true’ value.

3.4.2 CBS

Table 3-12 and Table 3-13 show the benefit estimates for CBS. The benefit is defined both in terms of the number of casualties that could be prevented and the valuation associated with the casualties.
The effectiveness estimate used for CBS with respect to fatal casualties was based upon analysis of the PISa Fatal Accident Database (Appendix A). The effectiveness of CBS was estimated to be between 6.3% and 25.4%, with a best estimate of 7.7%.

The effectiveness of CBS for slight casualties was generated from reviewing the OTS cases that were reviewed in the PISa project reported by McCarthy et al (2008). The analysis is described in Appendix B. The analysis generated an effectiveness of between 2.1% and 21.0%, with a best estimate of 14.0%.

In contrast to the analysis for ABS, there was no information identified that reported the effectiveness for serious casualties, or the overall effectiveness of CBS measured against all PTW casualties. Therefore the approach used for ABS could not be applied to CBS. The ranking of functional requirements reported by McCarthy et al (2008) indicated that the effectiveness of CBS should be lower than for ABS. The ratio of the score for CBS: ABS can be used to scale the effectiveness of ABS in order to estimate the overall effectiveness of CBS. This method provided an estimate of 4.3% with a range of 0.7% to 7.2%. This then allowed the effectiveness of CBS for serious casualties to be estimated, as -24.0%. This negative effectiveness is generated because the effectiveness values for fatal and slight are too large to result in the overall effectiveness of 4%. Either the overall effectiveness is an under-estimate, the effectiveness for fatal and slight are an over-estimate or there is a combination of both.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Target population (All PTW casualties)</th>
<th>Effectiveness (%)</th>
<th>Moped ≤50cc</th>
<th>Motorcycle &gt;50cc</th>
<th>All PTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>585</td>
<td>8 (6-26)</td>
<td>2 (1-6)</td>
<td>44 (36-145)</td>
<td>46 (37-150)</td>
</tr>
<tr>
<td>Serious</td>
<td>5991</td>
<td>-24 (2-21)</td>
<td>-186 (79-788)</td>
<td>-1252 (284-2844)</td>
<td>-1438 (363-3632)</td>
</tr>
<tr>
<td>Slight</td>
<td>17293</td>
<td>14 (1-7)</td>
<td>525 (32-327)</td>
<td>1896 (135-1391)</td>
<td>2421 (167-1719)</td>
</tr>
<tr>
<td>Total</td>
<td>23870</td>
<td>4 (1-7)</td>
<td>196 (32-327)</td>
<td>831 (135-1391)</td>
<td>1026 (167-1719)</td>
</tr>
</tbody>
</table>

* Note that none of the literature studied considered the effectiveness of ABS separately for mopeds and motorcycles. This breakdown of predicted benefits is based on the assumption that the effectiveness of ABS is equal for both vehicle types.

It can be seen from the table that there is insufficient information available to create a robust estimate of the benefit of CBS for all casualty severities. The estimated effectiveness for serious casualties is negative, which would imply an increase in the number of serious casualties. When considering systems that mitigate injuries, this can sometimes be expected if the number of casualties that are reduced from fatal to serious are greater than the number that are reduced from serious to slight. However CBS is being assessed as an accident avoidance system and therefore the number of casualties at all severities would be expected to be reduced.

When compared with the effectiveness of ABS shown in Table 3-10, the CBS effectiveness that has been used for slight casualties appears to be higher than might be expected. Although this was generated from a case-by-case review of accidents resulting in slight injuries, the small sample and distribution of accident types could feasibly have resulted in an over-estimate of the effectiveness, which in turn has resulted in the negative effectiveness for serious casualties. However, with the information available, it is not possible to make any further refinement of this analysis.
The analysis has shown that between 167 and 1,719 casualties could be prevented by fitting CBS to all PTWs, with a best estimate of 1,026 per year. Approximately 4% of the casualties that could be prevented are fatalities.

Table 3-13 shows the valuation associated with the casualties that could be prevented by CBS. The valuation of the serious casualties and the total valuation have not been included in the table.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Target population (All PTW casualties)</th>
<th>Effectiveness (%)</th>
<th>Moped ≤50cc* (£M)</th>
<th>Motorcycle &gt;50cc* (£M)</th>
<th>All PTW (£M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>585</td>
<td>8 (6-25)</td>
<td>2.7 (2.2-9.0)</td>
<td>66.8 (54.8-220.0)</td>
<td>69.5 (57.0-229.0)</td>
</tr>
<tr>
<td>Serious</td>
<td>5991</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Slight</td>
<td>17293</td>
<td>14 (2-21)</td>
<td>6.9 (1.0-10.4)</td>
<td>25.0 (3.6-37.5)</td>
<td>31.9 (4.6-47.9)</td>
</tr>
<tr>
<td>Total**</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Note that none of the literature studied considered the effectiveness of ABS separately for mopeds and motorcycles. This breakdown of predicted benefits is based on the assumption that the effectiveness of ABS is equal for both vehicle types.

** This is the sum of the valuations for fatal, serious and slight casualties.

The analysis has only been able to determine the valuation associated with fatalities and slight casualties that can be prevented. However, it is likely that the slight casualty benefit is over-estimated.

In this situation, the total effectiveness can be used to estimate the total benefit, which is between £12.6 Million and £88.3 Million with a best estimate of £50.5 Million.

3.4.3 BAS

Table 3-14 shows the benefit estimates for BAS in terms of the number of casualties that could be prevented by fitting BAS.

The estimate of BAS effectiveness for fatal accidents was determined by using the PISa Fatal Accident Database, the development and analysis of which was reported by McCarthy et al., 2008. This analysis (Appendix A) was necessary because the reported analysis used a target population that is different to that which has been defined earlier in this report. Analysis of the data generated an effectiveness estimate for BAS in the range from 8.8% to 35.2%, with a best estimate of 19.4%.

The effectiveness for slight casualties was calculated by using a selection of On the Spot (OTS) cases identified from the PISa project (McCarthy et al, 2008), this analysis found range of effectiveness of 3.9% to 39% with a best estimate of 14.0% Appendix B.

The effectiveness for the total number of casualties for BAS was estimated using a similar approach to that used to determine the overall effectiveness of CBS, i.e. scaling the value of ABS by comparing the scores for ABS and BAS from the ranking exercise carried out by McCarthy et al (2008). The best estimate of the effectiveness of BAS was 3.8%, with a range of 0.64 to 6.4. This is the effectiveness of BAS on its own, whereas the BAS under consideration for this analysis includes ABS and therefore the effectiveness of ABS should be added, resulting in a best estimate of 9.8%. The effectiveness of CBS is not included because there is overlap between the benefits of ABS and CBS and, therefore, the benefits are not additive.
Page et al (2005) estimated that BAS is effective in preventing or mitigating between 6.5% and 9% of all car occupant injuries for vehicles already equipped with ABS. This is slightly higher than the 3.8% estimated above, however it may be appropriate when considering the differences between PTWs and passenger cars.

The effectiveness for serious casualties was calculated in the same way as it was for ABS by using the effectiveness for fatal, slight and all casualties.

Table 3-14. Estimated benefit of fitting BAS, number of PTW casualties prevented.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Target population (All PTW casualties)</th>
<th>Effectiveness (%)</th>
<th>Moped ≤50cc</th>
<th>Motorcycle &gt;50cc</th>
<th>All PTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>585</td>
<td>19 (9-35)</td>
<td>4 (2-8)</td>
<td>109 (49-198)</td>
<td>114 (52-206)</td>
</tr>
<tr>
<td>Serious</td>
<td>5991</td>
<td>-3</td>
<td>-19</td>
<td>-130</td>
<td>-150</td>
</tr>
<tr>
<td>Slight</td>
<td>17293</td>
<td>14 (4-39)</td>
<td>525 (146-1463)</td>
<td>1896 (528-5282)</td>
<td>2421 (674-6744)</td>
</tr>
<tr>
<td>Total</td>
<td>23870</td>
<td>10 (2-16)</td>
<td>446 (73-746)</td>
<td>1894 (309-3169)</td>
<td>2339 (382-3915)</td>
</tr>
</tbody>
</table>

* Note that none of the literature studied considered the effectiveness of ABS separately for mopeds and motorcycles. This breakdown of predicted benefits is based on the assumption that the effectiveness of ABS is equal for both vehicle types.

The outcome from this analysis is similar to that for CBS in that there appears to be insufficient information available to create a robust estimate of the benefit of CBS for all casualty severities. Again, the estimated effectiveness for serious casualties is negative (although to a lesser extent than for CBS).

When compared with the effectiveness of ABS shown in Table 3-10, the BAS effectiveness that has been used for slight casualties appears to be higher than might be expected. The estimate was generated in the same way as the one used for CBS (which was also lower than expected) and is therefore governed by the same limitations. However, with the information available, it is not possible to make any further refinement of this analysis.

The analysis has shown that between 382 and 3,915 casualties could be prevented by fitting BAS to all PTWs, with a best estimate of 2,339 per year. Approximately 5% of the casualties that could be prevented are fatalities.

Table 3-15 show the valuation associated with the casualties that could be prevented by fitting BAS. As with the analysis of CBS, the valuation of the serious casualties and the total valuation are excluded.
Table 3-15. Estimated benefit of fitting BAS, valuation associated with prevention of PTW casualties.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Target population (All PTW casualties)</th>
<th>Effectiveness (%)</th>
<th>Moped ≤50cc* (£M)</th>
<th>Motorcycle &gt;50cc* (£M)</th>
<th>All PTW (£M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>585</td>
<td>19 (9-35)</td>
<td>6.8 (3.0-12.2)</td>
<td>165.8 (74.6-301.4)</td>
<td>172.5 (78.3-313.6)</td>
</tr>
<tr>
<td>Serious</td>
<td>5991</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Slight</td>
<td>17293</td>
<td>14 (4-39)</td>
<td>6.9 (1.9-19.3)</td>
<td>25.0 (7.0-69.5)</td>
<td>31.9 (8.9-88.9)</td>
</tr>
<tr>
<td>Total**</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Note that none of the literature studied considered the effectiveness of ABS separately for mopeds and motorcycles. This breakdown of predicted benefits is based on the assumption that the effectiveness of ABS is equal for both vehicle types.

** This is the sum of the valuations for fatal, serious and slight casualties

The analysis shows that the valuation associated with preventing fatalities by fitting BAS to all PTWs is between £78.3Million and £313.6Million, with a best estimate of £172.5Million. The valuation associated with the overall casualty benefit (using the average value for all severities) is between £8.8Million and £90.8Million with a best estimate of £54.2Million.
4 Discussion

4.1 Reviewing the benefit assessment

In addition to the two main objectives of the methodology which has been developed, it is possible to also use the methodology to critically review research that has been carried out. The analysis reported here has been limited to the use of existing literature and accident data. Therefore the quality of the benefit assessment is directly related to the quality of the information available, which varies between the types of advanced braking systems that have been assessed. The benefit assessment for ABS has been based on information from a wide variety of sources, whereas there was limited information available for the benefit assessment for CBS and BAS.

4.1.1 ABS

The literature relating to ABS included:

- Case-by-case mathematical modelling (Kebschull and Zellner, 2007);
- Retrospective studies (Teoh, 2008 and McCarthy and Chinn, 1999);
- Case-by-case subjective analysis (Gwehenberger et al, 2006 and McCarthy et al 2008);
- Human factors study (Vavryn and Winklebauer, 2005).

These studies cover the wide spectrum of assessment methods that can be used as described in the methodological framework and some of the studies used methods that have the potential to produce evidence to meet a high burden of proof (Vavryn and Winklebauer, 2005, Kebschull and Zellner, 2007, McCarthy and Chinn, 1999 and Teoh, 2008). However, the overall benefit estimate for GB presented in this report is considered to provide evidence to meet only a medium burden of proof for the following reasons:

- The selection of cases by Kebschull and Zellner were restricted to those that were available in the in-depth studies, none of which were from GB. Additionally, the study assumed that there was no benefit from reduced stopping distance in accidents where there was no loss of control.
- The retrospective study by Teoh did not fully account for rider behaviour and was only statistically significant at the 90% confidence limit. There are also differences between the motorcycle populations and riders (compared with GB), including the use of helmets.
- Baum et al only considered downfall accidents. This is only one of the types of accident that can be influenced by ABS.
- The majority of the studies were not based on data for GB, therefore some assumptions have been made in order to translate the effectiveness to make an estimate of the benefits for GB.
- Many of the studies presented the effectiveness as a percentage of accidents of all severities. However, when valued financially, the benefit estimate can be substantially affected by the distribution of the benefit by casualty severity. Some information about the effectiveness was available to enable the effectiveness at each severity level to be estimated.
4.1.2 CBS
There was no literature identified that quantified the effectiveness of CBS in a way that could be used in the methodology. Therefore, analysis of data sources that were identified in the literature were re-visited. These data sources were the fatal accident database developed under the PISa project and a selection of 28 in-depth OTS cases studies for slight accidents, also collated under the PISa project. The effectiveness for fatal and slight casualties was derived from a case-by-case subjective analysis so the method has the potential to offer a high burden of proof where systems are not yet on the market. However, for systems such as ABS where the systems are on the market and, therefore, a retrospective study is possible, the predictive study would be considered to offer the potential for a medium burden of proof. In addition to this, both samples were small, particularly for the slight casualties, and the OTS cases were selected to represent the types of accident that happen throughout Europe, not Great Britain.

There was no literature that identified the effectiveness of CBS for serious casualties or the overall effectiveness in a manner that could be applied to the target population. However, it was possible to compare the overall score from the PISa review with that of ABS, to estimate the overall effectiveness relative to the effectiveness of ABS, which in turn allowed the effectiveness for serious casualties to be determined. However, the effectiveness for serious casualties that was estimated was negative, and therefore some inappropriate assumptions appear to have been made in determining it. A safety system that is beneficial for fatalities and slight casualties but a disadvantage for serious casualties is not very plausible. It is most likely that the small sample of slight accidents has generated an over-estimate of the effectiveness for slight casualties. Although in theory, this approach is valid, it is dependant of the information that is available.

This approach is not specifically included in the methodology and therefore it is difficult to review the overall benefit assessment within the framework of the methodology. If larger, more representative data sources had been available for all severities, then the estimated benefit would meet a high burden of proof. However, the small samples and lack of data for serious casualties result in an estimate that will at best meet a low burden of proof.

4.1.3 BAS
As with CBS, there was limited information available about the effectiveness of BAS for PTWs. Therefore a similar approach to that used for CBS was taken, supplemented by information about the effectiveness of BAS for passenger cars. The assumptions made for the assessment of BAS are similar to those used for CBS and the results of the analysis show similar limitations. Therefore the estimated benefit also meets a low burden of proof.

4.2 Knowledge gaps
If estimated benefits for the advanced braking systems are required to meet a higher burden of proof than has been identified in this report, then the knowledge gaps identified in the following sections need to be addressed.

4.2.1 ABS
There was a wide range of literature available to assess the benefits of ABS. However, specific GB studies that consider numerical modelling of individual cases or retrospective analyses would help to increase confidence levels for a higher burden of proof. In particular it would be useful to verify whether the system is indeed more effective in higher severity accidents because the distribution of effect by casualty severity will
strongly influence any cost benefit assessment and the estimate of the effect for fatalities was based on a single predictive study using a relatively small sample size.

4.2.2 CBS and BAS
There was very little information identified that had estimated the effectiveness of CBS and BAS. To improve the estimated benefits of these systems, studies are required that are designed appropriately to ensure that the burden of proof is met. For example, if evidence to meet a medium burden of proof if required, a parameter based accident analysis should be performed using an appropriate data set. Whereas for a very high burden of proof, the accident analysis should be expanded to a case by case analysis, potentially supplemented by field operational trials, simulator trials etc. If sufficient vehicles were to be equipped with the systems a retrospective study should be considered.

4.3 Future development of the methodology

4.3.1 Desktop tool
A desktop tool has been developed to allow the user to easily identify specific groups of casualties that could be addressed by specific safety systems. The tool was developed in Microsoft Excel, to allow accessibility, without a specific knowledge of specialist software or databases and within limited resources. However, this has required the development of some complex Macros, which have resulted in relatively long run times for each query. Further development of this tool to improve these run time could be considered in future, if it proves to be a valuable resource.

The current version of the tool only includes the PTW casualties. The inclusion of non-PTW casualties from the same accident sample was investigated. However, technical difficulties meant that this proved not to be feasible within the available resources, whilst maintaining the robustness of the data and keeping the run times to a minimum. This, could be investigated further if considered appropriate.

In future, the desktop tool could also be developed to allow all types of vehicle to be included. If so, it would become much more relevant to consider casualties from outside the vehicle of interest because for other vehicle types such casualties are much more frequent and in some cases are more important than the occupants of the vehicles.

4.3.2 Reviewing literature
The methodology that has been developed has been used to critically review literature. Although the literature could be categorised by the type of study used in order to identify the burden of proof that can be met, the methodology did not allow other factors such as sample size and representativeness to be objectively included in the assessment. A paper describing a case-by-case modelling exercise or a statistical retrospective analysis has the potential to provide a high burden of proof. However, if the accident data used does not represent the GB accident situation, the assumptions used are questionable or the sample size is small, then the application of the information to estimate GB benefits may be of limited quality.

The methodology could potentially be extended to include guidelines to more objectively consider the burden of proof that the research has met with respect to regional representation, analytical quality, or sample size. However, any rating of the quality of the study will inevitably involve some degree of subjective judgement on the part of the reviewer and has the potential to be controversial.
Using the methodology to review existing literature would be considerably easier and more effective if the studies being reviewed had been undertaken according to the methodology. For example, the methodology recommends clearly identifying the complete sample, the target population and the casualties actually prevented or mitigated, each of them divided by casualty severity. However, the literature reviewed often expressed the findings in different ways that made the results difficult to compare. There could, therefore, be benefits to promoting a consistent analysis format such as this methodology more widely in the research community.

4.3.3 Costs

The methodology has focussed on estimating the benefits of the safety systems. The analysis has shown that there can be a large range in the casualty benefits that are estimated. When casualty valuations, which vary in different countries and are typically structured by injury severity level, are added this can result in an even wider range of financial benefits, particularly if the available casualty reduction estimates are not structured in the same way as the casualty valuations (as was the case for some of the ABS studies reviewed).

Typically, the cost information that is available can also vary widely. For example, comparing Kebschull and Zellner (2007) and Baum et al (2007) shows:

- ABS cost of €920, (Kebschull and Zellner, 2007); and
- ABS cost of €150, (Baum et al, 2007).

If the full range of financial benefits of ABS identified in the literature were to be combined with the full range of costs, identified by the literature, in a formal cost benefit analysis then the range of benefit to cost ratios calculated would be very large. This would accurately reflect the technical uncertainty inherent in a GB assessment of benefits, based on a limited range of existing literature, but may be of limited usefulness to policy makers. In such situations, small independent investigations and appropriate assumptions can narrow the range but for a higher burden of proof it may be more cost-effective to consider a new comprehensive study in accordance with the defined methodology that was specifically targeted to the needs of the time.

The methodology described in this report could also be expanded to allow the most appropriate costing method to be identified and also to allow the appropriateness of other peoples estimates to be reviewed in a similar way to that demonstrated in this report.
5 Conclusions

1. A methodology has been developed for the evaluation of PTW safety systems, taking into account the wide range of techniques available, and how these can be applied in the most effective manner to evaluate the benefits of motorcycle safety features.

2. The methodology has been implemented to evaluate the potential benefits of advanced braking systems (ABS, CBS and BAS) using existing literature and accident data.

3. A desktop tool has been developed to allow specific groups of PTW casualties to be identified. This can easily be updated as new annual data is available. Further development of this tool could be considered in future to improve its usability or to extend its application across other types of vehicle.

4. The benefit assessments estimated in this report have been critically reviewed to determine the level of the burden of proof that they meet. Although some of the literature provided evidence that was considered to meet a high burden of proof, the overall benefit estimate generated for ABS was considered to meet a medium burden of proof. The benefit estimates for CBS and BAS were considered to meet a low burden of proof because there was a minimal amount of evidence relating to the effectiveness of the systems.

5. The estimate benefit of ABS was between 239 and 2,389 casualties per year with a best estimate of 1,432 casualties per year. The valuation associated with this best estimate was £273.2 Million.

6. The estimated benefit for CBS was between 167 and 1,719 casualties per year, with a best estimate of 1,026. It was not possible to provide a valuation of these benefits using the same method as for ABS. However an alternative estimate of £50.5 Million was generated, although this is likely to be largely under-estimated.

7. The estimated benefit BAS was between 382 and 3,915 casualties per year, with a best estimate of 2,339. It was not possible to provide a valuation of these benefits using the same method as for ABS, however an alternative estimate of £313.6 Million was generated, although this is likely to be under-estimated. It was assumed that the BAS included ABS and CBS in order to allow the rider to meet optimum braking without wheel lock, thus the benefit cannot be added to that for ABS.

8. Many of the research studies identified were not based on GB accident data, vehicle fleet and riders. Therefore, if a higher burden of proof for ABS was required, equivalent studies based on GB data would be needed.

9. Any studies that identify the effectiveness of CBS and BAS (specifically for PTWs) would enable evidence to be generated that would meet a higher burden of proof than that generated in this report.
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Page, Foret-Bruno and Cuny 2005, Are expected and observed effectiveness of emergency brake assist in preventing road injury accidents consistent. PSA and Ceesar. ESV paper number 05-0268.


Vavryn and Winkelbauer 2005, Braking Performance of Experienced and Novice Motorcycle Riders- Results of Field Study. Austrian Safety Board, Austria.
Appendix A  Review of accidents resulting in fatal PTW casualties

McCarthy et al (2008) reported on the development and analysis of an in-depth database of fatal accidents which involve powered two wheelers. This database contained data on 70 accidents which resulted in 73 casualties, 70 of which were fatal injuries to the rider or passenger of the PTW. In two of the 70 accidents, the pillion passenger survived with slight or serious injuries. In one accident, a car occupant was also fatally injured.

A filter was applied to the data in order to identify the accidents in which braking has occurred before impact or loss of control. This filtering process resulted in a group of 39 accidents, each resulting in one PTW fatality. Each accident was then reviewed with respect to each of the three safety systems, ABS, CBS and BAS, with ratings given as to the likely effectiveness of the system in the specific accident. To estimate the effectiveness of the systems, these ratings were converted into a probability of having a positive effect on the accident outcome. The scale used was:

- No effect = 0;
- May have been effective = 0.25;
- Probably would have been effective = 0.75;
- Definitely would have been effective = 1.

Applying the probabilities to the scores and summing provides an equivalent number of casualties that could be prevented by implementing the safety system. The outcome from the analysis is shown in Table A- 1.

<table>
<thead>
<tr>
<th>Safety System</th>
<th>Number of cases (N= 39)</th>
<th>Best estimate of equivalent casualties prevented</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No effect</td>
<td>Maybe effective</td>
</tr>
<tr>
<td>ABS</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>CBS</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>BAS</td>
<td>14</td>
<td>12</td>
</tr>
</tbody>
</table>

Additionally, a range of effectiveness can be estimated by assigning the minimum and maximum probabilities to all relevant accidents (13+10+2=25), i.e. for ABS, 25x0.25 and 25x1.0 create a range of equivalent fatal casualties of 6.25 to 25. The number of equivalent casualties prevented can be used to estimate an effectiveness of the system, based on the target population of all PTW fatalities (N=70). The estimated effectiveness values for the three safety systems are:

- ABS 9% to 36% with best estimate of 18%;
- CBS 6% to 26% with best estimate of 8%; and
- BAS 9% to 36% with best estimate of 19%.

The effectiveness estimated from the sample of accidents can be applied to the national statistics to estimate the benefits of the specified safety systems. The accuracy of the estimated benefit is reliant on the in-depth sample being representative of the national statistics. The development of the database was intended to be representative of the GB fatal accident population, based on 150 accidents. However, the database only contains
70 accidents, although the sample remains closely representative of the GB accident situation.
Appendix B  Review of accidents resulting in slight PTW casualties

McCarthy et al (2008) reported an analysis of in-depth motorcycle accidents from the Great Britain On-the-spot (OTS) and the database created for the European COST327 project. The analysis considered accidents of all severities, but were not distributed by severity in a way that is representative of Great Britain. In order to determine an effectiveness for the three safety systems (ABS, CBS and BAS) for slight PTW casualties, the analysis was reviewed, considering only the slight casualties, and those that were sourced from the OTS database. This ensured that all the cases were from GB (some COST327 cases were from Germany) and resolved the issue of the representativeness of the severity distribution.

The filtering exercise described above resulted in a sample of 28 cases resulting in slight PTW casualties. Each accident was reviewed as part of the PISa project as the applicability of each of the three systems using a scale from 0 to 5, where 0 is not applicable and 5 is very applicable. To estimate the effectiveness of the systems, these ratings were converted into a probability of having a positive effect on the accident outcome:

- 0 = 0 i.e. no effect;
- 1 = 0.1 i.e. one in ten casualties prevented;
- 2 = 0.25 i.e. one in four casualties prevented;
- 3 = 0.5 i.e. one in two casualties prevented;
- 4 = 0.75 i.e. three in four casualties prevented; and
- 5 = 1.0 i.e. every casualty prevented.

Applying the probabilities to the scores and summing provides an equivalent number of casualties that could be prevented by implementing the safety system. The outcome from the analysis is shown in Table B - 1.

<table>
<thead>
<tr>
<th>Safety System</th>
<th>Frequency of score</th>
<th>Best estimate of equivalent casualties prevented</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ABS</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>CBS</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>BAS</td>
<td>17</td>
<td>3</td>
</tr>
</tbody>
</table>

Additionally, a range of effectiveness can be estimated by assigning the minimum and maximum probabilities to all relevant accidents, i.e. for ABS, 6x0.1 and 6x1.0 create a range of equivalent casualties of 0.6 to 6.0. The number of equivalent casualties prevented can be used to estimate an effectiveness of the system, based on the overall sample (N=28). The estimated effectiveness values for the three safety systems are:

- ABS 2% to 21% with best estimate of 17%;
- CBS 2% to 21% with best estimate of 14%; and
- BAS 4% to 39% with best estimate of 14%.
The effectiveness estimated from the sample of accidents can be applied to the national statistics to estimate the benefits of the specified safety systems. The accuracy of the estimated benefit is reliant on the in-depth sample being representative of the national statistics. In this case, there is no analysis of slight casualties that can be used to compare the distribution of accidents against and the sample is very small, 28 cases when there was an average of over 17,000 PTW casualties per year for the period 2005-2007 inclusive. The assumption that the sample is representative can have a significant bearing on the quality of any benefit estimates that are generated using this information.
Development of a methodology for the evaluation of safety systems for powered two-wheelers – final report

The use of accident data to assess the effectiveness of a primary safety (accident avoidance) feature can be problematic. This is because when a primary safety feature is fully effective, there is no accident and no data for comparison or analysis. Furthermore, most available accident databases are focussed on accident outcome (secondary safety), and have insufficient data on the pre-crash phase and accident causation. A wide range of techniques are available but they all have strengths and weaknesses and none will provide an ideal solution for every safety feature. It is therefore also important to ensure that the most appropriate technique is used and that the strengths, weaknesses and any assumptions used are transparent.

This report presents a methodology developed for the assessment of powered two-wheeler (PTW) safety systems. The implementation of this methodology is demonstrated by assessing the benefits of three advanced braking systems. The development of a desktop tool is also included. The output from the desktop tool includes casualty numbers by severity, the prevention value associated with the PTW casualties and PTW casualties as a proportion of all casualties. The annual data is presented alongside the three-year average.

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