A study on the feasibility of measures relating to the protection of pedestrians and other vulnerable road users – Addendum to final report

by B J Hardy and G J L Lawrence

EC Contract No. ETD/FIF.20040644

PROJECT REPORT

TRL Limited

A STUDY ON THE FEASIBILITY OF MEASURES RELATING TO THE PROTECTION OF PEDESTRIANS AND OTHER VULNERABLE ROAD USERS – ADDENDUM TO FINAL REPORT

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by B J Hardy and G J L Lawrence (TRL Limited)

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1 Introduction and background

The European Parliament and Council have approved a Directive (2003/102/EC) to require certain standards of pedestrian protection to be integrated into cars. The Directive has a two-stage approach. The first stage requires a certain level of pedestrian protection and the second stage a higher level of protection. However, because it was thought that it might be difficult to meet the more demanding protection requirements of the second stage, the Directive required that a feasibility study be carried out before it comes into force. This feasibility study included estimates of the benefits of introducing pedestrian protection and suggestions to change the second stage of the Directive to improve both feasibility and the test methods. This study was carried out and reported by TRL Limited (Lawrence *et al.*, 2004).

Following completion of the TRL feasibility study there was a meeting of the EC's Pedestrian Protection Monitoring Committee (26th July 2004) where presentations were made of the TRL study and studies carried out for or by the car industry on feasibility. The benefits of the second stage of the Directive and the benefits of fitting brake assist to all vehicles were presented. ACEA's contractor for their benefit and brake assist system (BAS) effectiveness study was the Technical University of Dresden (TUD).

At the meeting the industry expressed concerns about the feasibility of meeting the original phase two requirements. It was clear that many if not all of these concerns had been addressed to some extent by TRL's proposals. However, it was not clear whether the changes proposed by TRL were sufficient to meet the industry's concerns.

It was also clear that the estimates of benefits made by TRL and industry were very different. The main point of disagreement was that industry produced a higher estimate of the benefits of brake assist. When these were combined with industry's estimate of a small increase in benefits when going from phase one to phase two, industry concluded that brake assist with phase one was more effective than phase two. It was clear that these conflicting estimates made it difficult to come to any decision on what the final form of the second stage should be.

Following discussion it was agreed that the following actions would help to inform the debate:

- ACEA or TUD to
    - consider the TRL feasibility proposals and indicate whether with these changes they considered phase two feasible or, if not, to decide what additional changes they would consider necessary.
        - to provide the outcome of these considerations to TRL.
    - to provide to TRL their more detailed report describing their method of estimating the benefits of pedestrian protection on the vehicle and the benefits of brake assist systems in reducing the severity of or avoiding pedestrian accidents, if it were fitted to all vehicles.
    - produce revised calculations of the benefits of pedestrian protection on the vehicle and the benefits of brake assist systems. (These revised calculations would be based on any suggestion from TRL to improve the calculations that were accepted as reasonable by ACEA or TUD.)
- TRL to:
    - study in detail the industry calculations of benefits of pedestrian protection on the vehicle and of brake assist systems and provide a list of suggestions to improve their calculations.
    - revise their estimates of the benefits of brake assist systems based on improved data provided by industry.
    - recalculate the benefits of a revised phase two, if industry proposed any further changes for feasibility.

Following the Monitoring Committee meeting it was agreed that the above actions would be carried out by TRL and ACEA or TUD. This addendum describes the additional work carried out by TRL and the information provided to TRL by ACEA and TUD.

2 Discussions with ACEA and their contractor

At the Monitoring Committee meeting the Technical University of Dresden (TUD) made a presentation on their estimates of the benefits of phases one and two and the benefits of brake assist, a study that they had carried out for ACEA. Following the meeting they (via ACEA) supplied TRL with an electronic copy of their more detailed report.

TRL studied the TUD report and produced a list of differences between the TRL and TUD studies, which was then sent to TUD and ACEA. This document is attached as Appendix A. This included suggestions for changes to the TUD study. The main comments and suggestions for TUD were:

- The first comment concerned TUD's basic approach of using conservative estimates of benefits. At the time TRL thought that it was TUD's intention to do this so that the main estimates of relative effectiveness were conservative, so that the conclusions were more robust. In this case it would have been necessary for the secondary safety benefit estimates to be optimistic rather than conservative / pessimistic. However, from subsequent discussion it was learnt that it had been their intention to be conservative / pessimistic for both primary and secondary benefits, as a matter of principle, not to produce a robust conclusion. This remains a difference between the TRL and TUD studies, as TRL thinks that the most accurate final estimates will be achieved by trying to use the most realistic estimates throughout, as it would be difficult to get equal degrees of conservatism on both sides when comparing benefits.
- TRL expressed concerns about the specific method of the BAS calculation, where logistic injury risk curves were used to convert the with-BAS calculated impact velocities into casualties saved. It was thought that these curves might not adequately reflect the complexity of the data and TUD were advised to consider the robustness of their approach.
- TRL considered that the assumption that 'saved' injuries would be reduced in severity by one AIS level was too pessimistic. TRL's preference was to assume that fatal injuries (AIS 5 or 6 in TUD's analysis) would become serious injuries and serious injuries 'saved' would become slight injuries.
- TRL considered that it was too pessimistic to assume no benefit in the lower protection zones.
- TUD had not limited the impact speed at which casualties could be 'saved'. TRL thought this was too optimistic, as a tested area with good secondary safety would 'bottom out' at high speeds, so few high-speed impact injuries would be prevented.
- TUD had not taken account of the difference of test speed between phase one and phase two. Limiting casualties saved by impact velocity provides a mechanism to take account of differing test speeds.
- TUD had not taken account of the different legform acceptance criteria between phase one and phase two.

TUD also supplied TRL with data from the 712 case dataset that they had used. This included injury and case fields. The fields supplied were adequate for TRL to use in their analysis, for both the BAS and secondary safety estimates. TRL's use of these data is described in Section 4. The accident data used for the BAS calculation is discussed further in Section 3.

TRL supplied ACEA / TUD with a copy of their database analysis program, which had been written and further modified for a series of benefit studies. Although TUD didn't use the program themselves it should have helped them to develop their own analysis software.

Over the course of this extension phase project, three meetings were held between TRL, TUD and ACEA. Additional communications were exchanged, mainly by email. At the first meeting, ACEA made available to TRL their revised (September 2004) proposal for phase two.

In this process there were detailed discussions about both sides' benefit analyses. Provisional results were also presented. Another topic discussed was BAS and the accident data used to estimate the benefits of BAS; this part of the discussions is dealt with in this report in Section 3.

The discussions provided information for some of the detail of the revised TRL benefit study, although the main revisions were already planned in the list of differences supplied (Appendix A). TRL was concerned that the 6 m/s^2 BAS threshold used by TUD might not be appropriate for TRL's study, which was using the most realistic estimates where possible. ACEA were asked whether they could provide a more realistic threshold but they were unable to do so. Apparently the threshold would be set in terms of pedal force rather than deceleration.

The greater part of the discussions related to the revised TUD benefit calculation. They accepted the need to include adequate discrimination between the current phase two and the ACEA proposal (they did not make estimates for the TRL proposal). Their original analysis already discriminated by test area. Their revised analysis also discriminates by impact speed and acceptance criteria (using injury risk). They also included some benefit in the reduced protection zones. Though there are many differences of method and detail, their analysis now discriminates using the same basic mechanisms as does TRL's analysis. TRL now considers that TUD's analysis adequately discriminates between the test procedures.

TUD also accepted that it was reasonable to assume that fatalities would be saved to become seriously injured, and that the seriously injured would become slightly injured, and have assumed this in their analysis.

From the results presented by TUD it seems that their estimate for the effectiveness of the ACEA September 2004 proposal with BAS compared with the current phase two, for seriously injured casualties, is very close to TRL's estimate. However, for fatalities their estimate is more than twice as great; this is discussed below.

The main remaining differences between the TUD and TRL calculations for relative effectiveness are:

- TRL considers that the TUD sample of 35 'fatalities' (MAIS 5-6) is too small to make adequate estimates of benefits for fatalities. TRL therefore used additional fatality data from the IHRA database; this is discussed in Section 4.1.8. TRL accepts that the data used (Japanese cases and some German cases not in the dataset supplied by TUD) are not so relevant for Europe or as recent as the TUD data. Nevertheless, in TRL's opinion it is preferable to use these IHRA data in order to have a larger sample size. The combined fatality sample is still only 98 'fatalities' from 96 accidents, which is still less than ideal given that the expected differences in proportions saved will be only a few percent. This difference in samples accounts for the large difference between the two studies in the relative effectiveness of the ACEA proposal with BAS for fatalities.

- TRL preferred to calculate the casualties saved by BAS using a banded injury risk distribution (this is described in Section 4.1.2). TUD provided a copy of their logistic injury risk function calculation to TRL. TRL found that the software used didn't always find the best fit solution for the logistic curve. Also multiple cases at the same speed had less weight than if they had been at distinct speeds. TRL found that the banded injury risk distribution worked well and therefore continued to use it. However, TRL now considers that the basic method is quite robust, because it involves applying both the original impact speeds and the with-BAS calculated impact speeds to the injury risk distribution and takes the difference as casualties saved. This means that fairly similar results would be obtained whether the logistic function or the banded distribution is used.

- TUD use conservative estimates of benefits whereas TRL try to find the most realistic estimates. This was discussed above.

- TRL have serious concerns about the quality of the accident data used to estimate the BAS benefit in terms of impact speed reductions, see Section 3, and therefore prefer that estimates for BAS are regarded as ‘indicative’.
- TRL initially estimated the BAS benefits for BAS thresholds of 6.0 m/s² as used by TUD, and for 4.0 m/s² as the 6.0 m/s² threshold was thought to be conservative rather than a most realistic estimate. The results presented in this report are obtained from the mean of the benefits for the two threshold values. This was done at a late stage, as to give both sets of ‘indicative’ results might have implied that the true answer was within the range specified.
- TUD increase the ‘equivalent car speed’ (the car speed that is assumed to be equivalent to the chosen sub-system test speed) for the bonnet top to reflect a ‘k’ value (ratio of head impact speed to car impact speed) of 0.8. TRL assume a ‘k’ value of 1.0 (so the test speed is the same as the equivalent car speed). This is discussed in Section 4.1.9. Support can be found for either value in the research literature.
- TRL increase the ‘transition speed’ (the speed up to which the test procedures are assumed to provide protection) by 5 km/h above the ‘equivalent car speed’ to take account of the manufacturers’ allowance on crush depth, see Figure 2.1.

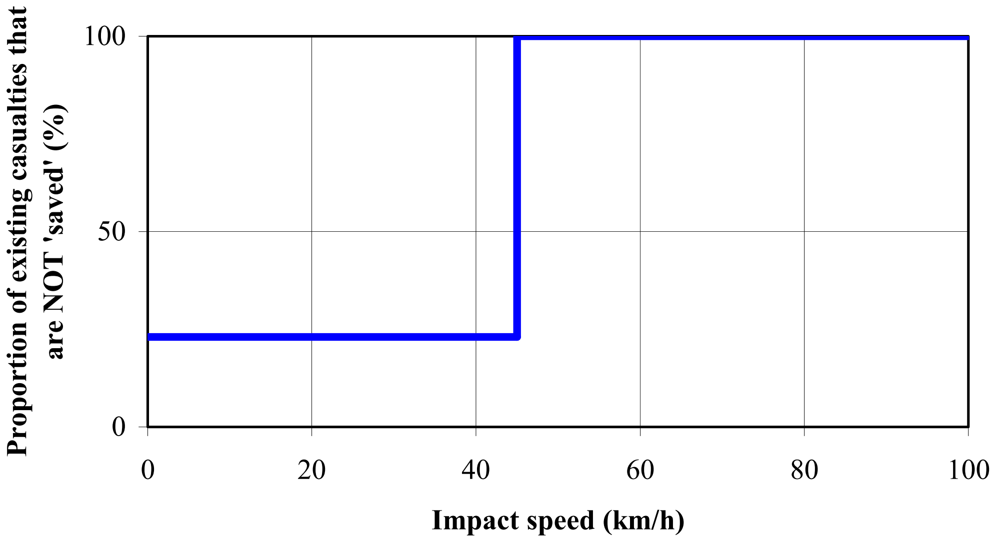

Figure 2.1. Injury risk against impact speed model used in benefit calculation for 40 km/h equivalent car speed

The injury risk up to the transition speed varies according to the part of the car contacted and the test proposal

After these meetings and discussions with ACEA, TRL provided to the European Commission (at the November 2004 Monitoring Committee meeting) early results of the TRL benefit calculations. Subsequently, in December 2004, ACEA made improvements to their offer (see Appendix B). TRL’s benefit estimates were then revised, to take account of the December offer, and are presented in Section 4.2.

TRL has not seen TUD’s estimates of the benefits of ACEA’s December 2004 offer, made by TUD’s method as described above. ACEA’s revised offer was accompanied by estimates that were described as “using the method and dataset of the Commission contractor” (i.e. TRL). This doesn’t imply that TUD now accept TRL’s method. These estimates by TUD of the effectiveness of the ACEA December 2004 proposal are higher than those of TRL, but ACEA has informed TRL that they are similar in the without-BAS case. The with-BAS estimate by TUD included additional benefits estimated for BAS in non-frontal pedestrian accidents. This point is discussed further in Section 3.1.

3 TRL opinion of the benefits of BAS for pedestrians

When brake assist detects an emergency situation, from an above average brake pedal force or a fast brake pedal speed, or a combination of these, it can have two benefits. The first is that it can apply emergency braking faster than the driver, and the second is that it will apply full ABS braking in cases where the driver was only applying brake pedal pressure for less than the maximum possible braking.

TUD have stressed that their method of calculating brake assist has the advantage of being made on a case-by-case basis based on real accidents, by estimating what would have been the accident outcome had the vehicle been so equipped. However, the data that can be gathered from an accident study, by attending each accident scene shortly after the accident occurred, are limited. The key information required to determine when brake assist would have been of benefit is:

- the vehicle travelling speed just before the accident (or before the driver's first reaction)
- in cases where pre-impact braking occurred, the distance between first brake application and impact (first contact)
- in cases where pre-impact braking occurred, the average deceleration achieved
- the maximum braking deceleration that could potentially have been achieved.

The potential for BAS in each accident case depends on the difference between the assumed maximum braking deceleration that a BAS equipped car could achieve on that road surface and the estimated actual mean braking deceleration. Because the BAS potential depends on the difference of these two estimates it is very sensitive to the accuracy of both values.

The estimate of the maximum braking deceleration is determined by the road material and surface condition (e.g. wet, dry), and tables of maximum deceleration values. TRL does have some concern about how accurate these estimates are, particularly if the road surface is worn.

However, TRL's greater concern is with the estimates of the actual mean braking deceleration in each case. The first three factors listed above are used to calculate this. In reality it is impossible to determine any of these with any accuracy and this is only possible when detectable tyre marks have been left on the road surface. In this case the travel speed can be estimated by the total length of the tyre marks, the estimated braking deceleration and the estimated or measured road surface coefficient of friction. Likewise the impact speed can be estimated by taking the estimated travel speed and deducting an estimate of the pre-impact braking velocity change by using the pre-impact length of the tyre marks, the estimated braking deceleration and the estimated or measured road surface coefficient of friction.

TRL asked ACEA / TUD how they obtain estimates of actual braking decelerations for cases where brake assist would provide a benefit by providing a higher braking effort than the driver used (because in this case tyres might not leave marks). The TRL question was *"Does obtaining mean braking decelerations from tyre marks rely on there having been fairly large slip angles (approaching those at which ABS works) or can they be obtained at much lower slip angles?"* the reply was**:**

> **"**The mean decelerations which were used are average values over the distance from start of braking till the impact with the pedestrian. Interrupts and single side traces (which are appearing with lower decelerations) are considered too. Tyre marks can also be obtained with lower slip values and are considered. The characteristic of the road surface has a main influence of the appearance of slip marks."

This implies that TUD can detect low braking decelerations from marks left on the road. However, the TRL authors have consulted their expert in accident reconstruction (an experienced accident reconstruction expert previously employed in the police forensic science laboratory) and he has reported that for dry roads at near full braking a dull/cleaned tyre track can sometimes be seen on the road surface, but not often. When braking with a locked wheel, dark to black tyre marks are left. When ABS braking is taking place, tyre marks are rarely seen, but when they are found, they are usually faint and continuous rather than broken. However, for all cases where tyre marks can be detected the level of marking is very dependent on the type of road surface. On wet roads, tyre marks are rarely seen, although they can sometimes be found later when the road has dried out. Therefore, in his opinion, it is normally only possible to determine decelerations from tyre marks when a driver was braking at close to the optimum. If the TRL view on tyre marks is accepted then there will be no tyre mark evidence in the cases where brake assist would have made its main difference, when there was pre-impact braking at well below the maximum that could have been achieved. In this case it is not possible to estimate from the other available data what the benefits, if any, would have been.

Therefore it appears that there is some disagreement as to whether it is possible to detect cases where the driver would have benefited from brake assist because he did not use full braking pre-impact. If TRL's view is accepted the process used by TUD for this appears to have been based on incorrect assumptions.

One method that might be used to estimate the benefit of harder braking is to compare the length of pre-impact tyre marks with estimates of the speed and coefficient of friction. If TRL's opinion on tyre marks is accepted then this would be a spurious calculation, as braking would have had to be close to the maximum to have left marks. However, if tyre marks from low braking decelerations can be identified then this method can be used, provided the estimates of travelling speed, impact speed, pre-impact braking distance and road surface coefficient of friction were all accurate. TRL asked TUD how the coefficient of friction was estimated for each accident. This was particularly pertinent because the distribution in the TUD accident database was not of the form expected (some form of roughly normal distribution would be expected, with a large peak at zero from the no braking cases); see Figure 3.1 for the TUD distribution.

> The first TRL question on this point was: "*If the decelerations achieved were in many cases limited by the driver's applied pedal force then why did so many drivers achieve 7.5 m/s² (compared with 7.0, 8.0 m/s², etc)?*" (as shown in Figure 3.1).

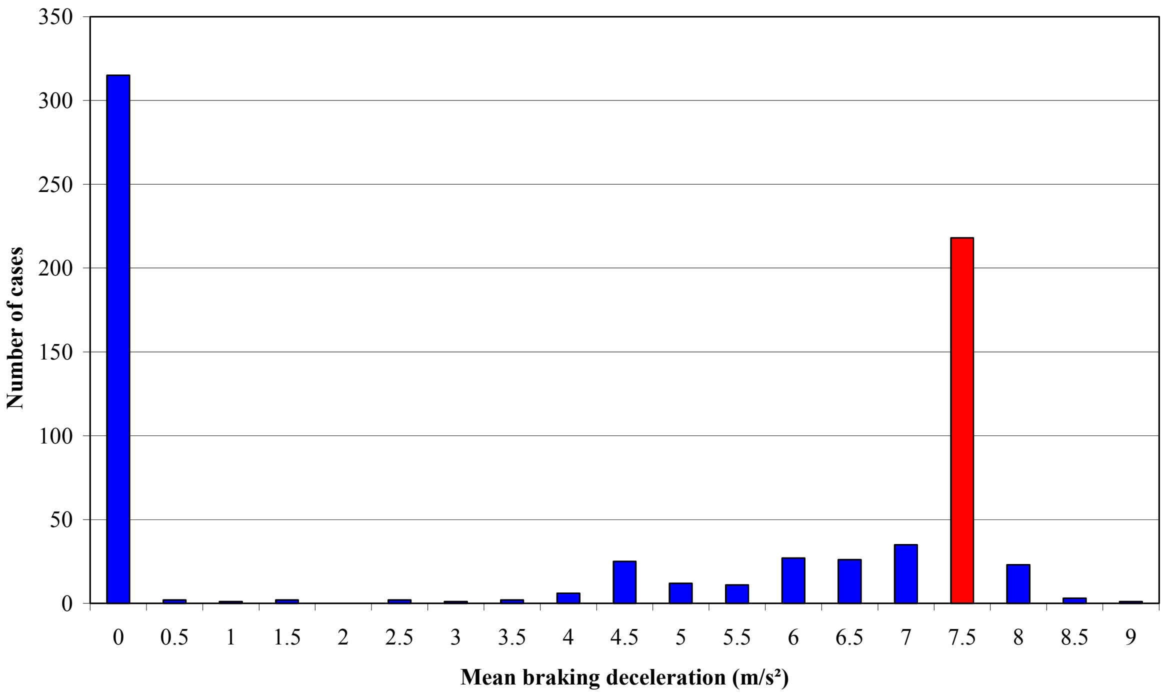

Figure 3.1. Number of cases in BAS database by mean braking deceleration

> ACEA / TUD's answer was: "The values in the database are average values and depend on the results in the investigation on the spot. They vary because e.g. the traces aren't homogeneous over the length. The BAS benefit consists of a constant high deceleration, a

better usage of the friction coefficient and of the compensation of insufficient driver pedal application."

The second TRL question was: "*Is there something about the reconstruction method that keeps giving this value, in which case how reliable are the braking deceleration values produced?*"

ACEA / TUD's answer was: "The values used in the accident reconstruction are based on experience of the expert. The braking decelerations in the recalculation are based on objective tests with BAS equipped cars (significantly reduced due to the conservative approach)."

A second, fuller answer to these questions was received later, after the appropriate TUD and MUH experts had been consulted:

> "Determination of the average braking deceleration bv:
>
> The initial traces are subdivided into sequences of different textures of road surface, e.g. change in character from concrete to asphalt surface or driving on tram tracks.
>
> Thereafter, the drawn traces are evaluated within these sequences. Basis of the evaluation are discontinuities or changes in intensity of the traces. Examples are offsets of traces, one-sided traces or full retardation without traces of rear tires.
>
> The roughness of the road surface is evaluated by means of visual impression on scene or pictures of the accident, comparing with praxis oriented measurements of the vehicle fleet. Thereby, a mean deceleration of 7.5 m/s^2 is assumed on dry and clean asphalt surfaces, for instance. On dry, but worn out and dirty asphalt a mean deceleration of 7.0 m/s^2 is assumed. Depending on the evaluation, the prior determined sequences are allocated to the probable decelerations and the values for cars equipped with ABS are partly higher. In praxis of a technical reconstruction, the gradation consists of steps of mostly 0.5 m/s^2.
>
> The range from 7.0 m/s^2 to 8.0 m/s^2 is also confirmed by braking tests carried out at the Medical School of Hanover.
>
> The average braking deceleration bv is calculated by covered distance and deceleration considering all sequences.
>
> Accidents involving pedestrians and passenger cars often happen under dry weather conditions on asphalt surfaces with maximum retardation of the vehicle. If only one sequence involving the sector of maximum retardation is examined, the values of the average braking deceleration scatter in a range around 7.5 m/s^2."

TRL also asked their accident investigation expert whether it is possible to accurately estimate friction in this way (i.e. by road surface type, observation and experience but not measurement). His opinion was that only a rough estimate could be obtained in dry conditions and only a very rough estimate could be made in wet conditions (UK police make actual measurements of coefficient of friction at the scene of serious or fatal accidents where it is thought relevant, by skidding a car to a halt).

Based on the above, if TRL's view is accepted then it is only possible to make accurate estimates of the benefits of brake assist in accidents where heavy pre-impact braking took place. In this case the only benefit would be that the transition from no braking to full braking would be achieved faster than the drivers leg can move, once the brake assist has detected the onset of emergency braking.

In general, TRL's view is that TUD's method often over estimates the benefits of BAS when obvious braking marks are left.

The responses reported above from TUD and the 'TRL expert' appear to justify TRL's concerns about the methods used by TUD to calculate the benefits of brake assist. It was therefore decided to see if some validation of the TUD method could be obtained by comparing the proportion of cars fitted with ABS in the whole sample and among those where pre-impact braking was detected. It appears reasonable to assume that these rates should be similar; however, because antilock brakes would leave less distinct tyre marks, this comparison would provide a check on the TUD method. Cars fitted with ABS form 17 percent of the sample but are in only 11 percent of the cases where pre-impact braking was detected. This check therefore appears to support the conclusion that the TUD method frequently fails to detect when pre-impact braking has occurred, whether or not ABS was fitted. Therefore TRL's view is that TUD often under estimates the benefits of BAS when faint braking marks or no marks are left.

Because of the above arguments TRL consider that the benefits of brake assist estimated by TUD can not be accepted as a scientifically justified estimates. However, it is clear that brake assist must in many cases offer significant benefits in reducing the injury severity or even avoiding vulnerable road user accidents. It seems to TRL that in some cases TUD are over-estimating the potential for improved braking with BAS, yet in other cases they are failing to detect braking and hence are assuming no benefit for BAS. Therefore, although the methods used by TUD may not be scientifically rigorous, it is possible that their estimates may be of about the correct order. Therefore they have been used in Section 4 to provide indicative estimates of the benefit of brake assist.

3.1 Benefits of BAS in non-frontal car accidents

At the third meeting between TRL and ACEA / TUD in November 2004, an additional benefit of BAS in non-frontal impacts was mentioned by TUD. As well as the 712 pedestrian to car frontal impacts in the GIDAS sample there were 114 pedestrian to car non-frontal cases. However, it was stated that the potential of BAS in these cases was difficult to assess without an additional study. This additional benefit was therefore not included in TRL's calculations for the ACEA September 2004 proposal.

When ACEA made a revised offer to the EC in December 2004 this additional benefit was mentioned, and the estimates of effectiveness relative to the current phase two that were provided with the offer included a contribution from BAS in non-frontal accidents. Subsequently, TRL was supplied by ACEA with a document that contained an additional calculation of the benefits of BAS in non-frontal accidents.

Essentially, this document makes an initial assumption that the proportions of casualties hit by car fronts that would be saved by BAS alone would also hold for casualties hit by other areas of the car. These proportions were stated as being five percent for fatalities and for seriously injured casualties. Benefits for BAS in non-frontal car accidents were then calculated forward from these proportions.

The document also included details of a case that was claimed to be a non-frontal accident where BAS would be of benefit. However this case involved impact with the front of the bumper, which caused serious injury. This is discussed further in one of the bullet points below. Later, TUD provided details of an example accident that was clearly non-frontal, in which BAS would have provided a reduced impact speed and therefore a reduced risk of injury.

When recalculating the benefits after ACEA's December 2004 proposal, it was decided by TRL that although there would undoubtedly be some benefits from BAS in non-frontal accidents, the magnitude of these benefits was in considerable doubt, therefore the non-frontal benefits would not be included in the estimates produced. However, these additional benefits would be mentioned in the text.

Although the benefit estimates by TRL that are given in the tables in Section 4.2 do not include the non-frontal benefits of BAS, TRL has made various rough estimates of the benefits that include the non-frontal contribution. These confirmed that the estimates by TUD were about right, *provided* that their assumption for the proportions saved by BAS in non-frontal cases is taken. These rough estimates are discussed further in Section 4.2.

The following comments are made about the assumption used by TUD:

- TUD quote the rate of benefit (i.e. casualties saved) of BAS in frontal impacts as being five percent for both fatalities and seriously injured casualties. However, this is approximately the rate for the frontal accident BAS benefit as a proportion of all impact directions and vehicle types. The benefit rates for car frontal accidents alone are about seven percent for fatalities and eight percent for seriously injured casualties. In this respect TUD appear to have under-estimated the non-frontal benefit.
- TUD have provided no data to show what proportion of non-frontal pedestrian to car accidents involve emergency braking. This should be possible with 114 non-frontal car cases. TRL would expect a lower proportion of accidents to involve emergency braking. The driver would in many cases not be expecting to hit the pedestrian in sideswipe type accidents as the potential conflict will be less obvious and less immediate. This accident type probably accounts for the great majority of non-frontal accidents. Some side-on impacts will arise from loss of control by the driver but these will be greatly reduced in the future by ABS. In rear impacts the drivers often would not be aware that the pedestrian was behind the car, in which case BAS would be of no benefit.
- TUD have said that impact speeds tend to be lower in non-frontal accidents. They claim that this will allow a higher proportion of non-frontal accidents to be prevented by BAS. It would have been preferable had they demonstrated this by accident analysis.
- Some cases labelled 'non-frontal' in the GIDAS dataset are frontal in the sense that the pedestrian is hit by the front of the car, including the example case mentioned above. These are essentially frontal impacts where secondary safety would provide a large measure of protection, and therefore where the *additional* benefit of BAS would be restricted to reducing the remaining risk of injury and potentially avoiding the accident and thereby preventing even a slight injury. The problem here seems to be that in the GIDAS data 'frontal' is defined by the direction of impact rather than by the area of the vehicle that first hits the pedestrian. This issue had also been mentioned in TRL's comparison of the original studies, see Appendix A. This will therefore reduce the proportions of casualties saved by BAS in impacts that are described as 'non-frontal'.
- National data for Great Britain have the same proportion of car non-frontal casualties of all car casualties as the GIDAS dataset for fatalities (15 percent) but more for serious (33 percent against 12 percent) and slight (40 percent against 15 percent). Using these GB proportions would therefore greatly increase the estimated non-frontal benefits of BAS.
- If the proportions saved by BAS in frontal impacts are over stated or under stated (as discussed in Section 3) then the non-frontal estimates, being based on them, will be biased likewise.

To summarise then, there is considerable doubt about the correct proportions saved by BAS in non-frontal cases, but there are factors to be considered that would suggest higher proportions, particularly for seriously injured casualties and for the all severities financial benefit, as well as factors that suggest that the proportions should be lower. Taking all these factors together, the proportions used by TUD in their estimates (five percent of non-frontal casualties saved by BAS for fatalities and for seriously injured casualties, and eight percent of impacts avoided for all severities together) seem to be reasonable.

4 Improved benefit and effectiveness of BAS analysis

The cost benefit study reported in the main feasibility study (Lawrence *et al*., 2004) was designed to make a number of relevant estimates, such as the proportions of casualties that might be saved, the number of casualties that might be saved, the financial benefit from saving casualties as well as the relative effectiveness of the TRL proposal (with and without BAS) against the current phase two. The study also improved on previous TRL studies by including allowances for pedal cyclists and non-reported cases. Although TRL had been given some data from TUD's BAS accident study, it had not been possible at the time for TRL to be given the full database. Because of the wider focus of the cost benefit study for TRL's feasibility report and the limited data available on BAS, TRL's estimate of the effectiveness of BAS in closing the gap between the TRL proposal and the current phase two was a fairly crude estimate. Crucially, the benefit of BAS was obtained by increasing the speed up to which the test procedures were assumed to provide protection. This meant that only the benefit from BAS for saving injuries that had been caused by the tested area of the car were quantified, thereby ignoring the benefit of reduced injuries from other parts of the car and from ground contacts. Although this limitation was pointed out in the text of the report, the point is easily overlooked when readers are looking at the relative effectiveness percentages. The relative effectiveness estimates (compared with the current phase two) made in the main study were 79 percent for the TRL proposal without BAS and 85 percent for it with BAS. The latter (with BAS) figure can be split into 85 percent for fatalities and 86 percent for seriously injured casualties.

In the lead-up to the Monitoring Committee meeting in July 2004 it became clear that much of the focus of the debate would be on the relative effectiveness of different proposals with BAS against the current phase two requirements. A presentation by TUD of their BAS study (Hannawald and Kauer, 2004a) was made available on the EC website just before the meeting. TRL therefore decided to improve their estimate of BAS benefits by including the benefits obtained by saving injuries caused by the non-tested areas of cars and by the ground. Within the time and data available only a crude estimate was possible, and only for the 'equivalent car speed' method. This led to revised estimates of the relative effectiveness of the TRL proposal with BAS of 104 percent for fatalities and 96 percent for seriously injured casualties, which were verbally reported at the July 2004 Monitoring Committee meeting . The corresponding value for combined fatal and serious benefits is 98 percent.

The TUD estimates (Hannawald and Kauer, 2004a) were for a lower level of protection, phase one with BAS, yet their estimates of the effectiveness relative to the current phase two were much higher, 133 percent for fatalities and 115 percent for seriously injured casualties. After the July 2004 Monitoring Committee meeting it was agreed that TRL and ACEA / TUD would cooperate, as described in Section 1, in order to clarify the basis for their estimates of relative effectiveness. The intention was to seek to improve the estimates but not to seek compromise or a common result. The full report of the TUD study (Hannawald and Kauer, 2004b) was then made available to TRL. TRL studied this report and compared the methodology and data sources with their own. From this, TRL produced a list of the differences, which was sent to ACEA and TUD. This is included here, as sent, as Appendix A. This included proposals for changes to both the TRL and TUD studies. This was one of the starting points for the discussions with ACEA and TUD that were reported in Section 2.

In the document reproduced in Appendix A a number of changes were identified to improve the TRL estimates. Some of these required access to the GIDAS database, by this time the necessary data had been supplied to TRL. The main changes identified were:

- The GIDAS accident database is of relatively recent accidents and is more relevant to Europe. TRL should therefore use the GIDAS database provided the sample size, etc. is adequate.
- To carry out the BAS benefit part of the analysis in a similar manner to the case-by-case method used by TUD.

In subsequent discussions with ACEA / TUD, see Section 2, TRL decided to drop the speed-shift method from their analysis. Apart from this, the only changes to the TRL analysis methodology resulting from the meetings were matters of detail rather than principle.

At the first meeting between TRL and ACEA / TUD (in September 2004), ACEA provided a copy of a revised ACEA proposal for a revised phase two of the Directive. The TRL benefit study was therefore extended to include this option as well as the TRL proposal and the current phase two. However, ACEA revised their offer in December 2004; the secondary safety aspects of this offer are included here in Appendix B. The TRL benefit study was then modified to estimate benefits for this latest (December 2004) ACEA offer.

The test details in Appendix B can be examined and compared with those of phases one and two of the EU Directive 2003/102/EC and the associated EC Decision 2004/90/EC, and also with the TRL proposal in the main study report (Lawrence *et al*., 2004). From considerations of test velocity and acceptance criteria it can be seen that the ACEA December 2004 proposal provides a slightly higher level of secondary safety (i.e. excluding benefits from BAS) than phase one but a lower level than either the current phase two or the TRL proposal. The December 2004 proposal provides greater benefits than the September 2004 proposal.

4.1 Changes to the analysis and their consequences

A number of changes were made to the analysis methodology previously reported (Lawrence *et al*., 2004). These are reported here not in order of their importance but in an order and a way that allows the effect of each step to be most easily estimated. It should, however, be pointed out that had these changes been applied in a different order then the effects estimated for each step would be different. Also, the end point of each stage of the comparison does not necessarily correspond exactly with the starting point for the next stage, so the cumulative changes will be necessarily equate to the total change in the analysis result.

4.1.1 Dropping of speed shift calculation method

TRL decided to drop the speed-shift method for three reasons:

- The method does not consider impact speeds on an injury-by-injury basis or even case-by-case. It had already been found to be relatively inflexible in the main study. This extension study required a discrimination to be made between the different headform test speeds of the ACEA proposal and the current phase two, while the bumper test speeds were the same in both cases.
- The method is very sensitive to the choice of the speed at which cars are assumed to just meet the phase two requirements. Previous TRL studies using this method have used the same speed that was selected by MIRA for their study (Davies and Clemo, 1997). However, ACEA advised TRL that they considered that this speed was out-of-date for current cars.
- Given the limited time available, dropping this method allowed effort to be directed to other issues.

By considering only the ‘equivalent car speed’ method the relative effectiveness of the TRL proposal with BAS increases from 85 percent to 89 percent; this is proportionally a 5 percent increase. The effect is greater for fatalities, increasing from 85 percent to 90 percent, than for seriously injured casualties, which increased from 86 to 88 percent.

4.1.2 Case-by-case calculation of BAS benefit

In Section 3 the reliability of the BAS data was discussed. Despite these concerns the data were used ‘as if correct’ in the calculation. The results concerning BAS should therefore be regarded as ‘indicative’.

From discussions with TUD, TRL ascertained how the impact speed with BAS fitment calculation was performed by TUD, as a case-by-case calculation. The results obtained were quite close to those reported by TUD, but it was not possible to get exactly the same number of impacts prevented (57 cases obtained instead of TUD’s 56). One accident was found to have a much lower assumed deceleration with BAS than the estimated actual deceleration, because the road surface condition was unknown. This case was therefore discarded, leaving 711 cases.

The essence of the TUD method of obtaining the benefit of BAS can be split into three stages:

1. On a case-by-case basis, estimate what the impact speed would have been had BAS been fitted. Where there was no braking or where the braking was less than the assumed BAS threshold this would be the same as the estimated actual impact velocity. Where the BAS activation threshold was exceeded this would normally be a lower velocity or impact may be avoided.
2. Produce a distribution of injury risk by velocity from the accident data. This is done for fatalities, and for fatalities plus seriously injured casualties, so that at any speed the risk of serious injury is the difference between the two injury risks. As well as the risk for the original accident data, these distributions are obtained for the expected injury risk distribution after the introduction of each set of test proposals. This allows for the interaction between the BAS benefit and the secondary safety benefit, as the overall benefit will be less than the sum of both individually.
3. Apply the set of impact velocities with BAS fitted to the injury distributions and sum over all cases, to give the number of casualties. The reduction in the number of casualties, compared with the original number or with the number for the secondary safety alone, is then the additional BAS benefit.

TRL was content to use the TUD method for the first stage, and also for the third stage apart from the way impact avoided cases were dealt with. However, for the second stage TUD matched the injury distributions to a logistic curve. This is a two parameter 'S'-shaped curve and TRL thought that it might not reflect the complexity of the injury risk against velocity distribution; this could potentially affect the interaction between the secondary and BAS benefits, possibly over-estimating the combined benefits. In addition, TUD was constraining the logistic solution to ensure that the correct number of casualties were obtained if the without-BAS impact speeds were used in the calculation. TRL found that the software used could obtain 'solutions' to the logistic curve that were not the best fit solutions.

For these reasons TRL decided to use a banded injury risk distribution. The severity and impact speed data were banded into 10 km/h wide bands, of 1-10, 11-20, 21-30 km/h, etc. to obtain the injury risk for each band. (Both the GIDAS and IHRA databases contain only integer values for impact speed.) These distributions are shown in Figure 4.1, for current cars (no secondary safety by design), for the current phase two (shown as 'EEVC' in the figure) and for the TRL and ACEA December 2004 proposals. (These are for the final accident data used and so just illustrate the principle of the injury risk distribution, at this stage of the step-by-step discussion.) In each case the data point is taken at the average impact speed of the data points within the band, rather than at the band centre.

When the injury risks were obtained for each casualty they were obtained by interpolating between data points by impact speed. In the case of casualties impacted at speeds below the lowest speed data point the injury risk was obtained by extrapolation from the first two data points. In cases where the impact would have been avoided with BAS the injury risk was taken to be zero. It can be seen that the injury risk can vary wildly at high speeds where there are very few casualties in the accident databases. This can of course lead to large errors in the injury risk calculated for individual casualties; however, because there are so few casualties at these speeds the contribution they make to the total injury risk is very small, especially as most of these errors will tend to be cancelled by errors in the opposite direction for other casualties.

As a check on the validity of this banded injury risk distribution method the numbers of casualties obtained for the without-BAS case were found by using the method. This gave casualty numbers that were quite close to the original numbers, especially for seriously injured casualties. These were then factored to obtain exactly the original numbers and the same factors were used for the corresponding with-BAS case.

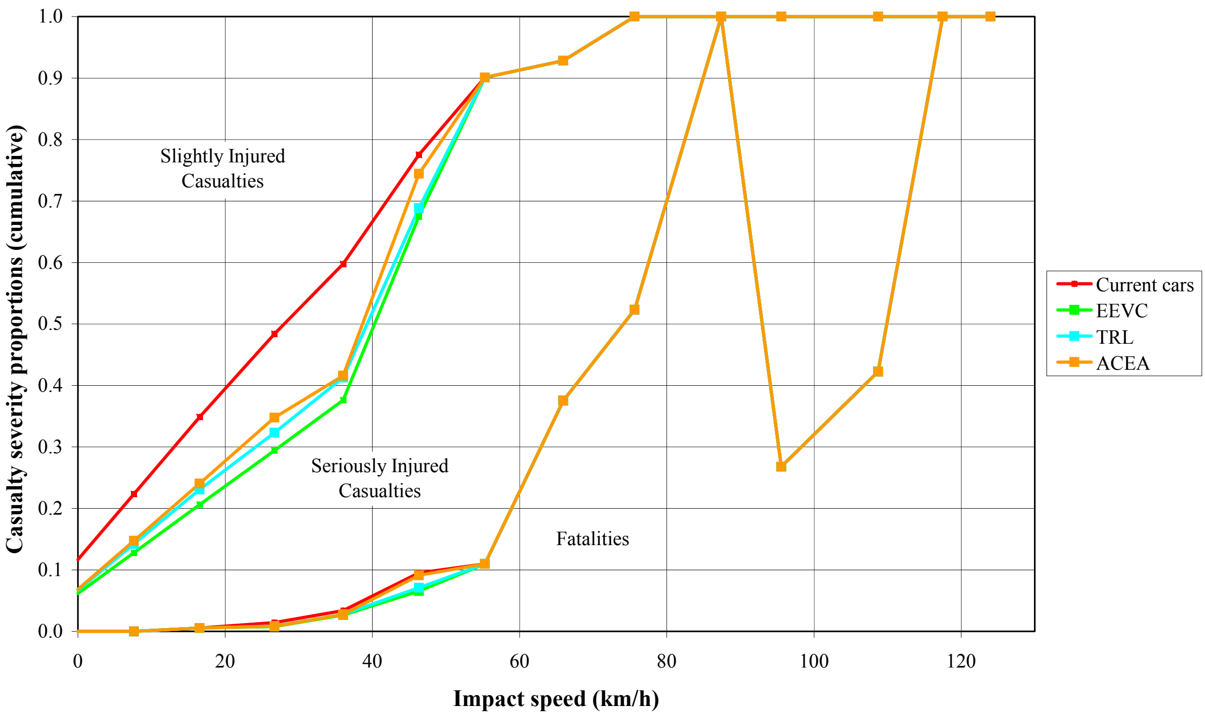

Figure 4.1. Injury severity risk by impact speed using banded data

Though this method may be less elegant than the constrained logistic method of TUD, TRL still prefers it for the reasons given above. However, TRL now thinks that this general method of using an injury risk distribution to estimate the additional benefits of BAS is quite robust, so that fairly similar results would be obtained whether the logistic function or the banded distribution is used.

The results obtained gave a higher benefit for BAS than a comparable estimate quoted by TUD; both were calculated for BAS without secondary safety, using the GIDAS dataset, a 6 m/s² BAS threshold and the GIDAS car frontal casualties of all pedestrian casualties proportion. Estimated benefits of a reduction in numbers of casualties of 5.8 percent of all pedestrian fatalities and 5.7 percent of all pedestrian seriously injured casualties were obtained, compared with the TUD estimates of 5.2 percent for both severities. The difference in benefits could be because here the injury risk was taken as being zero when the impact was avoided with BAS, rather than it being due to the use of the banded distribution method.

In TRL's main feasibility study (Lawrence *et al.*, 2004) the BAS benefits obtained were of a reduction in numbers of casualties of only around one percent of all pedestrian fatalities and seriously injured casualties (0.8 and 0.9 percent respectively) with the TRL proposal. The most comparable but readily available comparison with the new method is with the TRL proposal, 6 m/s² BAS threshold and GIDAS car frontal casualties of all pedestrian casualties proportion, but using the final dataset of GIDAS with extra IHRA fatalities. This gives a reduction in the numbers of casualties of 4.7 percent of all pedestrian fatalities and 3.8 percent of seriously injured casualties. If the accident data used to obtain the with-BAS reduced impact speeds are taken as being correct then these new TRL results show that the benefit of BAS was substantially under-estimated in the earlier study, by approximately a factor of six for fatalities and four for seriously injured casualties. The case-by-case data were not available for the earlier study.

The principle reason for this difference is that benefits were not included in the estimate for injuries saved by BAS outside the tested area, including those caused by ground contact. (This limitation of the benefit estimate was stated in that report.) Allowing for these benefits makes the estimated BAS benefit roughly three times greater.

The original analysis used an average speed change for BAS of 2 km/h. This was rechecked now that TRL has the case-by-case data and the average speed change is 2.8 km/h. Had this value (or 3 km/h) been used by TRL the estimated BAS benefit would have been roughly 50 percent greater again. The cause of the remaining difference isn't so obvious, but is probably due to the greater realism and hence accuracy of the TUD case-by-case method of obtaining the casualties saved from the modified impacts speeds, using an injury risk distribution (i.e. stage 3 above).

As reported in Section 2, TRL decided that the BAS threshold deceleration (the deceleration necessary to trigger a BAS) of 6.0 m/s^2 was probably too high for a most realistic estimate, but given the uncertainty on this issue TRL decided to take the mean of estimates obtained using thresholds of 6.0 and 4.0 m/s^2. This increases the benefit for BAS by varying amounts for the different proposals. For the ACEA December 2004 proposal this increases the BAS contribution by 12 percent for fatalities and 18 percent for seriously injured casualties.

4.1.3 Use of MAIS 5-6 instead of actual fatalities

In the original study (Lawrence *et al*., 2004) the IHRA database used had the fatalities identified, so that the estimates for fatalities were based on actual fatalities. However, TUD were not able to supply data with the fatalities identified. Instead they had taken MAIS 5-6 casualties to be 'fatalities' in their analysis. Using the GIDAS data supplied therefore meant that the same or a similar assumption had to be made. The consequences of assuming that MAIS 5-6 casualties were fatalities were therefore tested on the IHRA database. In terms of the numbers of 'fatalities' in the analysis the effect was very small, a reduction of 1 percent in fatalities. However, if MAIS 5-6 casualties are considered to be fatalities then logically a casualty should only be considered to be 'saved' if all AIS 5-6 injuries are 'saved'. For MAIS 5 casualties this made no difference but for MAIS 6 casualties the previous assumption had been that preventing all AIS 6 injuries was adequate to prevent the casualty. By only counting MAIS 5-6 casualties as 'saved' if all AIS 5-6 injuries were 'saved' the proportions of 'fatalities' 'saved' were reduced by 16 to 31 percent, depending on the proposal being considered. TRL would have continued to use the original assumption, that a fatality would be 'saved' if all of the highest severity injuries (AIS = MAIS) were 'saved', had the data been available in the GIDAS dataset. However, this is just an assumption and it could be that the revised assumption is more correct or equally correct.

4.1.4 Consideration of injury severities of casualties saved

In the original study (Lawrence *et al*., 2004) the benefit of saving only some of the injuries for some seriously injured casualties was allowed for by counting them as 20 percent 'saved' (i.e. each as a fifth of a casualty 'saved'). Taken in isolation this still seems a reasonable procedure, as although they will be still be seriously injured casualties, there will be a benefit to them, which could be taken as a financial benefit.

However, having estimated casualties 'saved' (fully 'saved' plus any allowance for partially 'saved) the benefit analysis obtains a financial benefit by multiplying casualties 'saved' by the casualty cost. This casualty cost for serious casualties represents the benefit of saving the *average* serious casualty. The serious casualty definition covers a wide range from relatively minor fractures at one extreme to permanent disablement requiring constant care at the other extreme. If, therefore, the casualties 'saved' tend to be those at the lower severity end of the range then applying casualty costs will over-estimate the financial benefit.

This possibility was tested by obtaining the proportions of MAIS 2, 3 and 4 casualties that were 'saved' in the analysis. These were 38, 39 and 12 percent respectively (of casualties hit by car fronts, for 'saved' by the current phase two option, using the IHRA dataset). It can be seen that the proportions 'saved' for MAIS 2 and MAIS 3 are very similar, but are much lower for MAIS 4. There are likely to be a number of reasons why a smaller proportion of MAIS 4 casualties are saved, such as higher impact speeds and casualties having a higher number of serious injuries.

These results show that serious casualties 'saved' will include a smaller proportion of the higher severity and hence higher cost serious casualties. However, it would be difficult to estimate a fair casualty cost for the casualties actually 'saved'. Therefore, instead, the benefit previously claimed for partially 'saved' serious casualties has been dropped as a rough compensation for the fully 'saved' serious casualties including too few high severity cases.

Similar considerations apply to the serious casualties 'saved' by BAS. They also will tend to be the lower severity serious casualties and there will also be additional benefits from casualties that are still seriously injured but whose injuries have been reduced. Dropping the partially 'saved' allowance for casualties 'saved' by secondary safety therefore puts the BAS and secondary safety calculations on a comparable basis in this respect.

4.1.5 Use of GIDAS data

TUD made the GIDAS dataset available to TRL, and TRL accepted that it was preferable to use it, because the data tended to be more recent than the IHRA data and it was also more relevant to the current study because it contained only European data, whereas the IHRA dataset previously used also contained American and Japanese data. However, even before using it TRL expressed concern about the sample size, see Appendix A.

When the GIDAS dataset is substituted for the IHRA dataset the proportion of 'fatalities' 'saved' is reduced by 83 percent for the current phase two and 66 percent for the ACEA proposal. For seriously injured casualties the reductions are 10 percent and 3 percent respectively. (These percentages for the ACEA proposal are for the September 2004 proposal; corresponding percentages for the December 2004 proposal are not available but would probably be similar.) Clearly this is a very large reduction in the proportion of 'fatalities' saved. The useable IHRA fatality sample is not particularly large for the purpose but the GIDAS fatality sample is only 30 percent of the size, with only 34 useable casualties. Of these only one 'fatality' is potentially 'saved', and this saving is reduced further still by the injury risk part of the calculation.

Using GIDAS data also nearly closes up the differences in 'fatalities' saved between the different proposals. Since the only potentially 'saved' 'fatality' is 'saved' by all test proposals the only differences are those caused by injury risk due to the different acceptance criteria. Differences of test speed and tested area have no *apparent* effect on fatalities when using the GIDAS dataset. This is a significant problem as this study is attempting to quantify the differences in protection provided by the different proposals. It is reasonable to expect that these differences would have an effect on casualties in the 'real world'. Therefore TRL decided to expand the number of fatal cases by adding additional cases from the IHRA dataset. This issue is discussed further in Section 4.1.8.

4.1.6 Use of more specific bonnet top injury locations

The IHRA dataset has a fairly limited set of injury-causing contact areas. The bonnet top is a single area. However the GIDAS dataset includes a number of bonnet top areas: bonnet front third, bonnet middle third, bonnet rear third, rear edge of bonnet, wing, and bonnet unspecified. After discussion with TUD, TRL broadly copied TUD's treatment of these areas. TUD assumed that the one third lower protection zone would correspond to the wing and rear edge of the bonnet, as these tend to be the difficult areas to make safe. However, as in the original study (Lawrence *et al*., 2004), TRL assumed that the *effective* lower protection zone would be 5 percent (of the bonnet top) smaller than the defined percentage. TRL therefore took appropriate percentages of these two areas as being in the lower protection zone (85 percent for the ACEA proposal and 60 percent for the TRL proposal). The front third of the bonnet (note this does not include the bonnet leading edge) was assumed to be at less than 1000 mm wrap around distance and therefore not part of the tested area. Other specified areas (i.e. middle and rear thirds) were assumed to be wholly within the higher protection zone. The 'bonnet unspecified' was treated as it was for the earlier, combined bonnet analysis.

As in the original study (Lawrence *et al*., 2004), consideration was given to whether the injuries to a given casualty would tend to be all in the lower protection zone or all in the higher protection zone. Some tendency for them to be grouped would be expected. Three options were to assume lining up of the lower protection zones across all car regions, assume lining up only within the bonnet top or assume lining up only within the bonnet sub-divisions. The middle option seemed to be the best compromise. Strictly, there is a fourth option, to assume no lining up even within a bonnet sub-region; however this was rejected as frequently multiple injuries will arise from one contact. This part of the analysis was handled by considering the least safe sub-regions first, those with the highest proportion of lower protection zone. The first relevant bonnet top injury then determined the result for the whole of the bonnet top.

In the original study the analysis was carried out with bumper, bonnet leading edge and bonnet top lined up and not lined up, and the average of the two methods was then used. Dropping the lined up option at this level only changes the benefits by less than one percent.

When the benefits estimated in the split bonnet analysis were compared with those obtained using the same data but treating the bonnet top as a single area, it was found that splitting the bonnet, with the associated changes, has reduced the calculated benefits by 1 to 6 percent, depending of the proposal and injury severity.

4.1.7 Confirmation of transition speed in ‘equivalent car speed’ method

In the original study (Lawrence *et al*., 2004) it was assumed that a car would provide protection at car impact speeds of up to 45 km/h, 5 km/h above the equivalent car speed of the test procedures. This is illustrated in Figure 2.1. The ‘equivalent car speed’ is the car speed that is assumed to be equivalent to the chosen sub-system test speed. This was partly justified by assuming that with pedestrian protection those still injured below the equivalent car speed of the test procedures would roughly compensate for those not injured above it (assuming in both cases that they had been injured by a tested area). Those still injured *in the calculation* are those not saved because of the remaining injury risk at lower velocities, derived from the manufacturers’ target values and hence from the acceptance criteria. Those protected above the equivalent car speed *in the calculation* are those hit at speeds between 40 and 45 km/h, less those still injured because of the remaining injury risk.

In this extension study this increase in the speed at which protection was assumed was checked, to see whether it was still appropriate when using the GIDAS dataset. The injury risks used for the comparison were those for the current phase two, the option with the lowest injury risks. It was confirmed that 5 km/h is still an appropriate value to use.

4.1.8 Addition of IHRA data for MAIS 5-6 ‘fatalities’

As was discussed in Section 4.1.5, it was found that the GIDAS dataset had a very small sample of ‘fatalities’ (i.e. MAIS 5-6), leading to significant problems in adequately quantifying the differences between the protection provided by the different proposals. It was therefore decided to add some of the fatalities from the IHRA dataset. MAIS 5-6 ‘fatalities’ were used for comparability, rather than true fatalities. It was decided that a total of about 100 ‘fatalities’ would be a reasonable sample. As the American cars in the IHRA dataset are likely to be the most dissimilar to European cars they were discarded. By comparing the two datasets a number of German cases were identified that appeared in both datasets. These also were discarded from the IHRA ‘fatalities’ dataset. This left 63 ‘fatalities’ from the IHRA dataset, giving a total of 98 ‘fatalities’ together with those in the GIDAS dataset. The expanded ‘fatality’ sample, by the country collecting the data, was 52 casualties from Germany (of which 35 GIDAS and 17 IHRA) and 46 casualties from Japan (from 44 accident cases).

If the results from this combined dataset are compared with those from the GIDAS only dataset, increases in the proportion saved of about 400 percent are obtained for ‘fatalities’ for the current phase two and the TRL proposal, and of about 175 percent for the ACEA proposals.

If the comparison is made back to the IHRA dataset, including the relatively small effect from the split bonnet, then only small reductions of about 14 percent (current phase two and TRL proposal) or 9 percent (ACEA September 2004 proposal) are obtained, for both fatalities and seriously injured casualties, with the GIDAS + selected IHRA 'fatalities' dataset.

Thus, this combined 'fatality' dataset is considered to be a reasonable compromise. On the one hand it would be preferable to have a still larger 'fatality' sample, and on the other it would be preferable to have more recent data with a highest content of European cars.

4.1.9 Calculation of benefits for the ACEA proposals

The other main change was the inclusion of the ACEA proposals, initially that of September 2004, but this was then replaced with that of December 2004 (see Appendix B), in the benefits calculation. The benefit analysis needs to discriminate between the different test proposals to reflect differences between the proposals in the protection that would have been provided. In the main feasibility study it was sufficient to discriminate between the current phase two (i.e. EEVC WG17) and the TRL proposal by using different residual injury risks to reflect the different acceptance criteria. However, the ACEA proposals have a lower headform test speed and no bonnet leading edge test. The database analysis program used for the main feasibility study had been developed from an earlier study (Lawrence *et al.*, 2002) in which discrimination between test proposals had been applied by having different safe speeds in different test zones. This feature had been left in the program so it was easy to apply it again in the current study.

The test speed is not necessarily the same as the equivalent car speed, as the pedestrian's head may impact at a different speed to the vehicle impact speed. The ratio of head impact speed to vehicle speed, sometimes called 'k', has been subject to debate over a number of years. TRL's opinion is that a value of about 1.0 is correct for the shorter pedestrians likely to hit their head on the bonnet top of typical European cars with short bonnets. It is understood that the TUD analysis has used a value of 'k' of 0.8, giving a higher vehicle impact speed. A number of studies have supported a lower value but often they use computer models that are not sufficiently biofidelic. However, either value of 'k' can be supported by research literature. TRL also included a 5 km/h allowance to reflect the manufacturers' margin on crush depth, see Section 4.1.7. The choice of 'k' would be expected to have little effect on relative effectiveness estimates, *provided the sample size is adequate*, as the same value is used for all three test proposals. However, the GIDAS sample has very few saveable 'fatalities' so the choice of 'k' could potentially have had a large effect.

The acceptance criteria and residual injury risks obtained from them are shown in Table 4.1, for all test proposals. Those injury risks used in the analysis are shown in bold; for the lower legform and upper legform tests the criterion with the higher injury risk was taken in each case.

Since the main study, the database analysis program has been further developed for a different project. The improved version was used to obtain the estimates for the ACEA December 2004 proposal reported here, and for the current phase two and the TRL proposal that are compared with it. Some of the comparisons reported in Sections 4.1.1 to 4.1.8, however, were obtained with the earlier version. The revised program makes an 'exact' calculation of the effect of injury risks; this aspect no longer uses a random number function as described in main study report. Also, the program now runs significantly faster, so it was practical to increase the number of passes through the database to further reduce variability caused by the use of the random number function (which is now used only to determine whether a casualty is impacted by the higher or the lower protection zone). These changes improve the consistency of the analysis, which is desirable when comparisons are being made between different proposals that provide benefits of similar magnitude.

Table 4.1. Injury causing parameters, acceptance criteria proposed and injury risks used in the analysis based on manufacturer's targets at 80 percent of the acceptance criteria

Test tool and parameter	Acceptance criterion / injury risk				
	Current phase two	TRL proposal: main area	TRL proposal: relaxation area	ACEA 12/04 proposal: main area	ACEA 12/04 proposal: relaxation area
Lower legform, knee bending angle	15° / 5.4%	19° / 10.2%	19° / 10.2%	19° / 10.2%	19° / 10.2%
Lower legform, tibia acceleration	150 g / **9.0%**	190 g / **18.9%**	250 g / **48.3%**	170 g / **13.1%**	250 g / **48.3%**
Upper legform, sum of forces	5 kN / 10.3%	6.25 kN / **20.2%**	7.5 kN / 36.8%	not tested	not tested
Upper legform, bending moment	300 Nm / **11.8%**	375 Nm / 18.3%	510 Nm / **40.3%**		
Headform, HIC	1000 / **7.0%**	1250 / **15.5%**	2000 / **63.8%**	1000 / **7.0%**	1700 / **42.3%**

4.2 Results of updated cost benefit analysis

The current cost benefit analysis differs from that of the main feasibility study (Lawrence *et al*., 2004) in a number of ways that were described in Section 4.1.

Although the main focus of the current study is to estimate the relative effectiveness of the ACEA (December 2004) proposal with BAS, it was easy to obtain other results to update those of the main feasibility study. The tables have been shaded to emphasise the cells that should be considered when comparing the current phase two against the ACEA proposal with BAS. These TRL estimates given in the tables below only consider the benefits of BAS in frontal impacts.

In Table 4.2 the estimated proportional reductions in vulnerable road user casualties are given. In these estimates the proportions of serious casualties that would be saved have been reduced to reflect the assumption that fatalities 'saved' would still be seriously injured.

Table 4.2. Estimated proportional reductions in numbers of vulnerable road user casualties, by severity, that would be obtained by implementation of the various options

Road user type	BAS fitment	Current phase two		TRL proposal		ACEA proposal	
		Fatal	Serious	Fatal	Serious	Fatal	Serious
Pedestrians	no BAS	0.083	0.166	0.068	0.139	0.040	0.122
	BAS fitted	0.134	0.210	0.120	0.187	0.097	0.171
Pedal cyclists	no BAS	0.030	0.067	0.025	0.056	0.015	0.049
	BAS fitted	0.049	0.085	0.044	0.076	0.035	0.069

In Table 4.3, estimates of effectiveness of the various options, relative to the current phase two without BAS, are given. On these estimates, both proposals with BAS match the current phase two benefits. Estimates are given later that combine both severities. The estimates for pedal cyclists are very similar to those for pedestrians, as the same assumption of saving half of the proportion of pedestrians saved is made for both the secondary safety and the BAS benefits. Small differences have arisen because pedal cyclists have a different ratio of fatalities to seriously injured casualties.

Table 4.3. Estimated effectiveness of each option, relative to the current phase two requirements without fitment of BAS

Road user type	BAS fitment	Current phase two		TRL proposal		ACEA proposal	
		Fatal (%)	Serious (%)	Fatal (%)	Serious (%)	Fatal (%)	Serious (%)
Pedestrians	no BAS	100	100	82	84	48	74
	BAS fitted	161	127	145	113	116	103
Pedal cyclists	no BAS	100	100	82	84	48	73
	BAS fitted	161	127	145	113	116	104

From the proportions shown in Table 4.2 and the estimated current numbers of casualties in the European Union (see main study report) the annual reduction in casualties can be estimated. See Table 4.4. These estimates are for all casualties saved, whether currently reported or not.

Table 4.4. Estimated annual reduction in numbers of vulnerable road user casualties in the European Union (EU-25), by severity, that would be obtained by implementation of the various options

Road user type	BAS fitment	Current phase two		TRL proposal		ACEA proposal	
		Fatal	Serious	Fatal	Serious	Fatal	Serious
Pedestrians	no BAS	750	29,215	614	24,579	361	21,520
	BAS fitted	1,207	37,118	1,087	32,953	872	30,233
Pedal cyclists	no BAS	104	7,702	85	6,478	50	5,650
	BAS fitted	167	9,817	151	8,717	121	7,982
Vulnerable road users	no BAS	854	36,917	699	31,057	411	27,171
	BAS fitted	1,375	46,935	1,238	41,670	993	38,215

From these estimates of casualties saved, estimates have been made of the financial benefits; these are shown in Table 4.5. Note that the casualty costs used were reduced to reflect the inclusion of non-reported casualties that will tend to have lower severity injuries. This is described in the main study report. As well as the benefits of avoided fatal and serious injuries the 'BAS fitted' rows include saved slight casualty costs for the cases where the impact would have been avoided. As well as giving the financial benefits the use of casualty costs provides a convenient way of combining the benefits of saving fatalities and seriously injured casualties. Hence a single relative effectiveness value can be obtained for each proposal, see Table 4.6.

Table 4.5. Estimated annual financial benefit to pedestrians in the European Union (EU-25) that would be obtained by implementation of the various options

Road user type	BAS fitment	Current phase two (€ million)	TRL proposal (€ million)	ACEA proposal (€ million)
Pedestrians	no BAS	4,389	3,661	2,879
	BAS fitted	6,387	5,737	5,059
Pedal cyclists	no BAS	983	823	673
	BAS fitted	1,478	1,334	1,204
Vulnerable road users	no BAS	5,372	4,483	3,552
	BAS fitted	7,865	7,071	6,263

Table 4.6. Estimated financial effectiveness of each option, relative to the current phase two requirements without fitment of BAS

BAS fitment	Current phase two (%)	TRL proposal (%)	ACEA proposal (%)
no BAS	100	83	66
BAS fitted	146	132	117

It can be seen that both the TRL and ACEA proposals with BAS give greater benefits than the current phase two without BAS. Although, theoretically, the current phase two with BAS would, as would be expected, give the greatest benefit, it must be remembered that one of the conclusions of the main feasibility study was that it was not considered to be feasible for the manufacturers to achieve the current phase two requirements.

In Table 4.7 the estimated benefit per car, over its lifetime, is given for the three main options. Costs were only obtained for the TRL proposal, in the main feasibility study. As BAS is considered to have virtually no cost, given that most of the hardware is needed anyway for ABS, and that there are additional benefits to car occupants from having it, the table also gives a cost benefit ratio for the TRL proposal with BAS option.

Table 4.7. Estimated benefits to vulnerable road users, consumer cost to benefit ratio and lifetime benefits per car sold, from implementation of the current phase two, or the TRL or ACEA proposals with BAS

	Current phase two	TRL proposal with BAS	ACEA proposal with BAS
Benefit (€ million)	5,372	7,071	6,263
Cost to benefit ratio #	n/a	6.4	n/a
Lifetime benefit per car (€)	364	480	425

 # Costs were only obtained for the TRL proposal.

In Section 3.1 the potential benefits of BAS in non-frontal impacts were discussed. However, because of the considerable uncertainties involved, TRL decided not to include these non-frontal benefits in the calculations to produce the estimates in the tables above. To have fully included the benefits of BAS in non-frontal impacts would have involved considerable effort to modify the spreadsheet used. However, it was possible to make some rough estimates in order to compare with the estimates of relative effectiveness contained in ACEA's December 2004 offer. These estimates by TRL used the proportions of fatalities and seriously injured casualties in non-frontal impacts that TUD anticipated saving (both five percent) and of impacts avoided (of all severities) of eight percent. TRL's estimates of relative effectiveness for the ACEA December 2004 proposal, including frontal and non-frontal BAS, compared with the current phase two, are then 123 percent for fatalities, 107 percent for seriously injured casualties and 122 percent for all severities together (i.e. financial benefit). The increases in relative effectiveness obtained by including non-frontal BAS benefits are seven percent, three percent and five percent respectively (see frontal only BAS estimates in Tables 4.3 and 4.6); these increases will be the same for all proposals. The relative effectiveness estimates are very close to those of TUD contained in the ACEA December 2004 offer, described as "using the method and dataset of the Commission contractor" (i.e. TRL), of 124 percent, 108 percent and 122 percent respectively.

5 Discussion

5.1 Cost benefit analysis

In these benefit tables and the analysis used to produce them, the baseline for all the estimates was car designs that were being made a few years ago and that therefore appear in the accident data. These were cars designed with virtually no thought to pedestrian safety, and without BAS. Because of the inevitable lag between car sales and the accidents they are involved in, these baseline cars are no longer exactly the same as current cars. Some changes not intended to protect pedestrians may nevertheless be of benefit. There are increasing numbers of cars on the road with some measure of pedestrian protection and that have scored well in Euro NCAP tests. These changes in current cars will reduce the future benefits that will be obtained by any of the test proposals for phase two. This will also reduce the relative effectiveness of the TRL and ACEA proposals as a proportion of the current phase two benefit. However, the difference between these proposals in absolute terms (casualties or financial) with be roughly the same.

This TRL report is an input into the wider discussions as to what could replace the phase two requirements of the current pedestrian protection Directive and associated EC Decision. Benefits of alternative proposals are compared with those of the current phase two. For the BAS benefit estimates in the current study, the baseline has therefore been taken to be the situation as it was when the current Directive was first being developed. This was before BAS were fitted to new cars and, therefore, the estimates for the benefits of BAS in this study have all been for a change from a zero fitment rate to a 100 percent fitment rate.

It should be stated that all of the results given above are subject to considerable uncertainty as virtually all of the analysis is based on assumptions that are very simplistic compared with the real world. The same is true of the accident data used in the analysis. Much of the precision with which results have been transferred from the spreadsheet is therefore spurious. However, if the results had been rounded to adequately reflect the uncertainty it might have been more difficult to compare different options. As stated in Section 3, though, the uncertainties associated with the BAS data are considered to be somewhat greater than with the rest of the data and analysis, which is why the estimates concerning BAS should be regarded as only being 'indicative'.

The most important results of the current study are the effectiveness estimates relative to the benefits of the current phase two, see Table 4.6. Both the TRL and ACEA proposals, with BAS, give greater benefits than for the current phase two without BAS. However, the comments above should be taken into account.

The relative effectiveness of BAS (in frontal impacts) on top of the TRL proposal is now estimated to be 48 percent of the current phase two, compared with the estimate of 6 percent made in the main feasibility study. This is obviously a very significant change. Most of the difference has occurred from an increased BAS benefit. This was discussed in Section 4.1.2 but, to recap, the main reasons are that the original study only considered the benefit from reduced velocity impacts within the tested area, the average speed change is greater than assumed and the case-by-case method gives greater realism. The changes in estimated secondary safety benefits have been much smaller, with the benefits estimated for the current phase two being reduced by 30 percent and those for the TRL proposal being reduced by 26 percent. The largest contribution to this is probably the use of the GIDAS database. This change would have been greater had the GIDAS data have been used exclusively, but as previously stated the fatality sample size was too small.

It can be seen in Figure 4.1 that casualties saved would occur up to 45 km/h, according to the equivalent car speed methodology used by TRL. However, even in these speed ranges, there is still significant potential for BAS. The additional benefit of fitting BAS reduces with the more effective test proposals but not by much. This finding differs with the assumption made in the main feasibility report. This is because BAS can provide protection (reduced injury risk) for all injury causing contact areas; much of the benefit of BAS arises from saving injuries caused by non-tested areas of the car and by ground contacts, areas where secondary safety will not provide any protection.

The benefits of BAS, as the proportion of casualties that would be saved, are about the same for fatalities and seriously injured casualties. As the analysis is predicting a lower rate of fatalities ‘saved’ the relative effectiveness of BAS is much greater for fatalities than for seriously injured casualties. Had the GIDAS data been used without the addition of fatalities from IHRA to increase the fatality sample size then the estimate of fatalities saved would be lower still and hence the relative effectiveness much higher. It is understood from discussions with TUD that their estimates (based only on GIDAS data) show a very high relative effectiveness for fatalities. However, in the authors’ opinion the number of fatal cases in the GIDAS database is too small to produce meaningful estimates for the savings of fatalities, particularly when the small number of fatal accidents at survivable speeds is taken into account.

The even greater uncertainties associated with estimates including the benefit of BAS in non-frontal as well as frontal impacts were discussed in Section 3.1. Nevertheless, there will definitely be additional benefits arising from this. Rough estimates were given an the end of Section 4.2 of relative effectiveness for the ACEA December 2004 proposal including non-frontal BAS benefits.

5.2 Revision of phase two

This study has looked at the benefits of both the TRL and ACEA (December 2004) proposals. The estimates provided and the above discussion will inform the debate and eventual decision. It would not be appropriate for this report to make a recommendation as that is essentially a political and not a scientific decision.

TRL accepts that there is considerable debate about what it would be feasible for the manufacturers to provide in a revised phase two. TRL still believes that the proposal made by TRL in the main study report would improve the feasibility, although still be challenging. However, TRL restates its opinion that it would not be feasible for manufacturers to provide protection to the current phase two requirements.

If it should be decided to accept the ACEA December 2004 proposal or something close to it, there could be consequences for injuries caused by the bonnet leading edge, as this area is not tested in their proposal. Accident data show that injuries caused by the bonnet leading edge have reduced and are now at a low level. See, for instance Hannawald and Kauer (2004a and 2004b). However, the cars concerned still mostly fail the upper legform to bonnet leading edge test. The changes to this test method proposed in the main feasibility report would reduce but probably not completely resolve this conflict. It may be that the upper legform test is inadequate, particularly on more rounded bonnets. However, another possibility is that the initial impact of the pedestrian’s leg with the generally stiff bumpers of modern cars is acting to reduce the severity of the bonnet leading edge impact. The bonnet leading edge test was developed to test cars that had a safe bumper and the test energy is set higher accordingly. Also, if a stiff bumper causes a tibia fracture then the fracture would change the way the pedestrian interacts with the bonnet leading edge. There is the possibility that changes to improve the bumper could result in a reduction in tibia injuries at the expense of an increase in bonnet leading edge injuries. Another possibility is that in future some manufacturers might design extra stiffness into this area unintentionally or to compensate for reductions in stiffness that they have to make elsewhere, for example to meet the legform test requirements. If it is concluded that the changes proposed in the main feasibility report are insufficient to resolve feasibility concerns for the bonnet leading edge then TRL would recommend that a less demanding test requirement be used rather than a monitoring only test or a no-test option. This is because this option would minimise the risk of an increase in bonnet leading edge injuries occurring as a consequence of a reduction in tibia injuries. However, as a minimum, the following suggestions are strongly recommended:

- The bonnet leading edge test should at least remain in phase two as a monitoring only test, as it is in phase one. This would provide some disincentive to prevent manufacturers making the area any stiffer than it is now, and would encourage safer designs. This could be the current test, the revised test in the TRL proposal or a further adjustment of that.
- There should be a scheduled review of the accident data at some time in the future. This could look at accident data from cars that complied with phase one or phase two, to see whether injuries from the bonnet leading edge had increased significantly (specific vehicles' bonnet leading edge injury rates could be compared with the monitoring test results). This would probably need on-the-spot accident data, such as that from the GIDAS study, so it would take several years before enough data would have accumulated. TRL suggest that the earliest practical review date is likely to be about 2010 provided that sufficient on-the-spot accident data are obtained.
- Parts of the test procedures should be modified if the bonnet leading edge test is dropped or remains monitoring only. The definition of the bonnet top test area and the headform test site selection rules mean that for most vehicles (cars) child head protection starts at the 1000 mm wrap around distance. However, for large vehicles, a child headform test area starting at 1000 mm would overlap with the bonnet leading edge test, so the head test area is instead started further back (one headform diameter behind the bonnet leading edge reference line). This was included because it was thought unreasonable to require one area to meet two different protection requirements. However, if the upper legform test is removed or remains monitoring only in phase two of the Directive then it would be more appropriate to require that all vehicles provide child head protection starting from the 1000 mm wrap around line.

The definition for high bumpers in the current phase two of the Directive is based on impactor suitability (the lower legform impactor only being suitable for impacts at or below knee height). However, the ACEA proposal of December 2004 defines a high bumper vehicle by its use. Although a definition by vehicle use may be less appropriate, it may be the only feasible solution for vehicles that need to have a high ramp angle for off-road use (if removable or adjustable spoilers as proposed by TRL are considered not to be feasible).

The 1500 mm wrap around distance used to define the transition between the child and adult headform tests is set approximately in the middle of the zone shown by accident data to be where both child and adult heads can hit (overlapping occurs between 1400 and 1700 mm). Although changing this transition to 1700 mm is thought to be a retrograde step it would bias protection towards children rather than adults and align with the Japanese head test requirements. In practice a sudden transition from child to adult test areas results in designs with an area about the transition line that is safe for both child and adult pedestrians. As well as not matching the accident situation, increasing the child to adult transition from 1500 mm to 1700 mm will mean that many more European-style vehicles will have a bonnet length such that there is no longer an adult test area and therefore they will offer reduced protection for the shorter adult. This change may also have a negative effect on feasibility because for many vehicles providing protection for a lighter headform in the base of the windscreen area may be more difficult, as the stiffness needed to meet the HIC criterion will be lower.

Those parts of the TRL proposals that were regarded as improvements to the test procedures, rather than feasibility adjustments, should also be included in the revised test procedures as appropriate (some of these items may not be relevant, depending on the final decision about the revised phase two requirements). Full details are given in the main report; these proposals for improvements, in brief, are:

Legform test:

- Add a shoe thickness allowance so that the foot end of the impactor is required to be 25 mm from the ground at first contact
- Halve the legform height and verticality (in the longitudinal plane) tolerances at first point of contact to ± 5 mm and ± 1°
- Increase the knee bending angle performance criterion from 15° to 19°
- Add new requirement for the relative humidity of the legform to be controlled to 35 ±15% in the vehicle test and to 35 ±10% in the legform dynamic certification test (limits subject to confirmation by EEVC WG17)
- Add new requirement for accuracy of impact speed measurement (±0.02 m/s suggested)
- Introduce a code of practice to prevent misuse of movable or removable spoilers on off-road vehicles

High bumper test:

- Test high bumpers only with the upper legform impactor, i.e. withdraw the option for manufacturers to choose between testing with the legform or the upper legform impactor
- Revise the definition of the 'Upper Bumper Reference Line' so that the centreline of the upper legform impactor is aligned with the centre of the bumper structure
- Permanent towing eyes positioned beneath a high bumper, in such a position that they are not contacted by the upper legform impactor in the test, should be set back at least 120 mm behind the front face of the bumper
- Add new requirement for the relative humidity of the upper legform to be controlled to 35 ±15% in the vehicle test and to 35 ± 10% in the upper legform dynamic certification test (limits subject to confirmation by EEVC WG17)
- Add new requirement for accuracy of impact speed measurement (±0.02 m/s suggested)

Bonnet leading edge test:

- Change the angle of the straight edge used to determine the bonnet leading edge reference line from 50 degrees to the vertical to 40 degrees
- Replace the current upper legform test energy graph and interpolation rules with the revised ones proposed and adjust the velocity curves as necessary
- Add new requirement for the relative humidity of the upper legform to be controlled to 35 ±15% in the vehicle test and to 35 ± 10% in the upper legform dynamic certification test (limits subject to confirmation by EEVC WG17)
- Add new requirement for accuracy of impact speed measurement (±0.02 m/s suggested)

Child and adult headform test:

- Replace the 2.5 kg child headform impactor with the current 3.5 kg headform impactor, including certification limits and test point selection requirements based on its size
- Add new requirement for accuracy of impact speed measurement (±0.02 m/s suggested)

Deployable systems:

- Suggestions were made for testing deployable systems in Section 7.2.7 of the main report. These include suggestions for marking up and choosing test points. These could either be put in the test procedures or could be part of an agreed interpretation document.

Although this study has been concerned with phase two it should be noted that many of the above improvements, such as the change of bonnet leading edge reference line marking procedure and test energies, could usefully be applied to phase one testing, by legislation, interpretation or agreed good practice.

The recommendations for relative humidity are made because relative humidity is known to influence the properties of the Confor foam flesh used in the legform and upper legform. It should therefore only be necessary to control the relative humidity of the impactor, not of the whole test environment. This should be borne in mind when drafting a requirement for relative humidity in the test procedures, as controlling the whole test environment could be very expensive for many test houses. As an example, TRL has developed a method of conditioning an impactor, transporting it in a sealed box to the test location and then carrying out the test with the minimum of delay, before the relative humidity has significantly adjusted to the new environment.

There is not yet an agreed minimum standard for BAS. If the revised phase two package includes BAS then there should be agreed standards for BAS. This should ensure that vehicles fitted with BAS provide the level of benefits that were assumed in the benefit calculations. If the maximum threshold deceleration were set at the 6.0 m/s^2 used by TUD then the typical threshold would be around or below the deceleration assumed by TRL (effectively 5.0 m/s^2 as the mean of estimates for 6.0 & 4.0 m/s^2 was taken). It is possible that customer resistance to BAS could lead manufacturers, for instance, to put a limit on the additional deceleration that is provided by BAS above the deceleration ‘requested’ by the driver. Such modifications should not prevent BAS providing an equivalent level of benefits to that assumed in the benefit calculations.

6 Conclusions

1. From considerations of test details such as test velocity and acceptance criteria it can be seen that the proposal of ACEA (December 2004) for a revised second phase represents a modest improvement on the protection provided by phase one, but still falls short both of the current phase two and of the TRL proposal (excluding consideration of brake assist).
2. TRL has compared the TRL (June 2004) and Technical University of Dresden (TUD) effectiveness studies for methodology and has made suggestions to ACEA / TUD for improvements to their analysis.
3. TRL has improved its own analysis, partly by taking advantage of more detailed and more representative data provided by TUD.
4. The accident data provided by TUD are considered to have too small a sample of fatal accidents to be used alone to estimate the effectiveness of the TRL and ACEA proposals relative to the current phase two of the Directive.
5. The benefits estimated by TRL for the TRL and ACEA December 2004 proposals, as a percentage of those of the current phase two, are 83 percent and 66 percent respectively (excluding consideration of BAS).
6. Questioning of TUD has led TRL to conclude that the GIDAS accident data are not of sufficient quality to permit reliable estimates to be made of the effectiveness of brake assist systems (BAS). Nevertheless, TRL has produced indicative estimates of the effectiveness of BAS by using the data 'as if correct'.
7. BAS offer significant benefits to many vulnerable road users. Whereas the passive safety measures cannot protect against injuries caused by the ground or by non-tested areas, BAS can reduce the impact severity and hence injury risk for all contact areas.
8. The indicative financial benefits estimated for the TRL proposal and BAS (in frontal impacts) together, as a percentage of those of the current phase two, are 132 percent.
9. The indicative financial benefits estimated for the ACEA December 2004 proposal including BAS in frontal impacts, as a percentage of those of the current phase two, are 117 percent.
10. There are additional benefits to be obtained from BAS in non-frontal impacts, though the magnitude of these benefits is very uncertain. A reasonable estimate is that the financial benefits of each proposal as a percentage of those of the current phase two would be five percent higher when this extra benefit is included.
11. These estimates of the effectiveness of BAS are for a change in the fitment rate of BAS from zero to 100 percent.
12. It is recommended that if fitment of BAS becomes part of a package of changes to the phase two requirements then minimum standards for BAS should be agreed.
13. If a proposal for a combination using BAS is accepted for a revised phase two then the following are strongly recommended:
    a. Those parts of the TRL proposals that were regarded as improvements to the test procedures, rather than feasibility adjustments, should also be included in the revised test procedures.
    b. The bonnet leading edge test should at least be retained as a monitoring only test.
    c. The changes to the second phase should include a scheduled review of the real-world injuries caused by the bonnet leading edge of cars meeting phase one or phase two requirements for the bumper, once sufficient accident data are available.

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Appendix A. Comparison of TRL & TUD cost benefit & BAS effectiveness calculations

The following document was prepared by TRL and sent to TUD and ACEA on 14 September 2004. It is included here as it was sent. Some of the comments are now known not to be correct, see Section 2 of this Addendum report. References below are to TRL's June 2004 report.

Comparison of TRL & TUD Cost Benefit & BAS Effectiveness Calculations @ June 2004, with proposals for changes

Property	TRL	TUD	Comments
Basic approach	To produce best estimates consistent with the need to avoid excessive complexity. In practice benefits are more likely to be slightly over-stated (see report, Section 10.3). BAS part used 'conservative' TUD data.	To produce 'conservative' estimates of benefits, i.e. err on low side.	The intention of TUD seems to be to err in the direction of being less favourable to their sponsors, so that their conclusions are more robust. However, the headline estimate is the effectiveness of BAS in closing the gap between the proposal (phase one) and the current phase two. Low (conservative) estimates of benefits are likely to make BAS appear more effective. However, there are also conservative estimates in the BAS part of the calculation.
Database	IHRA: Accident years 1985-98, mean 1993, median 1995	GIDAS / MUH Accident years 1991-	IHRA larger but GIDAS more recent & more European. TRL will use GIDAS if sample size, etc. is adequate.
Unknown codes in data	If necessary data were not available then casualty was excluded	If data not available a conservative approach was taken, e.g. unknown area would be taken as non-tested area	TRL thinks it more accurate and therefore preferable to exclude incomplete casualty records
Fatalities	True fatalities used. Saved if all AIS = MAIS injuries saved.	MAIS 5-6 used. MAIS 5 potentially saved but MAIS 6 at best will go to MAIS 5 and still be 'fatal'.	TUD report shows MAIS 5-6 and fatalities speed distributions are a good match. Numbers are fairly similar in IHRA database. Difference probably not significant although true fatalities would be preferable. However, if TRL uses GIDAS data do we still use same saved assumption or must all AIS 5 & 6 injuries be saved?
Road user type	Pedestrian and pedal cyclist benefits, based on GB data and assumption of 50% relative effectiveness for P/C	Pedestrian only	This only affects absolute benefit, not BAS benefit as proportion of proposal – phase one, because BAS factor was part of 50%. With different assumptions for BAS equipped car to P/C this could make a difference.
Car frontal proportion	GB national data (frontal using 'first point of contact')	GIDAS proportion (frontal is 12 o'clock CDC). This uses direction of impact rather than area hit.	National data has large sample size with little chance of sampling bias. GIDAS team more expert than police, but would area hit be more relevant than impact direction? No clear preference; anyway this can only affect absolute benefit, not BAS benefit as proportion of proposal – phase one.

Car frontal sample	IHRA pedestrian dataset is all car frontal, but definitions vary	Frontal selected as 12 o'clock CDC	Choice of frontal sample will have some effect on proportion of injuries caused by tested areas; however, this isn't likely to be that large.
Cases / injuries attributed with BAS benefit	Within method BAS was applied to injuries caused by the tested area. Benefit to non-tested areas including ground stated in text but not quantified.	BAS benefit for casualty calculated independently of whether casualty was saved, hence benefit for all car frontal are potentially included	BAS benefit needs to be estimated for all car frontal cases. TRL could modify it's calculation to roughly estimate BAS benefit irrespective of injury causing area. However, see next.
Application of BAS benefit	BAS benefit applied as an across-the-board average change of 2 km/h in the 'Equivalent Car Speed' (ECS) and 'Speed-shift' (SS) calculations. Value of 2 km/h based on limited data from TUD study.	BAS benefit of reduced impact velocity applied case-by-case to globally derived injury risk function (IRF)	TRL agrees that a case-by-case approach is much preferable, and now has the data to be able to do this. However, TRL is concerned that the use of IRF could make the BAS benefit very sensitive to the precise function used, as these are simple two (?) parameter curves that may not adequately reflect the complexity of the data. TRL will consider alternative methods such as a banding approach. TUD should also consider the robustness of their approach.
Injury Reduction	Fatal > Serious Serious > Slight	One AIS severity	TRL thinks that the TUD assumption is overly pessimistic. Possibly the TRL assumption is slightly optimistic but we think it's the more realistic of the two. To be fair, TRL has not yet looked at TUD's reference 18.
Tested area	Benefits only for injuries caused by the tested area, irrespective of the body region. Case-by-case analysis (for ECS, combined with speed sensitivity). Small benefit assumed (20%) for casualty where only some injuries of severity were saved.	Benefits only for injuries caused by the tested area, irrespective of the body region. No benefit assumed for bonnet HIC 2000 area. Case-by-case analysis.	Minor differences; both used case-by-case analysis. Excluding benefits for lower protection zones would cause bigger errors for a TUD calculation on the TRL proposal, so TUD may wish to allow some benefit in these zones.

Speed sensitivity	ECS method: No benefit assumed for impact speeds above 45 km/h (more than test procedure's ECS of 40 km/h to allow for manufacturer's crush depth margin and to maintain assumption of earlier studies that casualties saved above ECS were ≈ casualties not saved below ECS, in tested area). SS method: The proportional casualty severity against speed distribution is shifted to higher speeds	No limitation of benefits by speed. Consequentially there was no discrimination to reflect the different phase one and phase two headform test speeds.	Both TRL methods limit benefits by speed, because manufacturers will only build in crush depths that are adequate to pass the tests. Pedestrian impacts at much higher speeds will therefore 'bottom out' causing high loads and hence injuries, similar to those of current car designs. The TUD analysis is therefore overly optimistic on this point, though this does tend to compensate for the injury reduction assumption. However, having the wrong speed distribution of benefit will cause errors in calculating the BAS benefit, because that also varies with speed and so the interaction will be sensitive to speed. TRL thinks that TUD should add speed sensitivity to their analysis. Even though the TRL methods are already more realistic the TRL ECS method could be improved further for calculations involving BAS.
Discrimination between phase one and current phase two	TRL 2002 Headform speed. Bonnet third – random, 50% risk BLE tested area. Legform criteria – converted to speed difference. Phase one effectiveness (of phase two): ECS 32% fatalities 63% serious, SS 55% fatalities 54% serious.	Bonnet areas likely to be HIC 2000 - no benefit assumed. BLE tested area. Phase one effectiveness (of phase two): 75% fatalities 80% serious	It is fundamental to calculating the effectiveness of BAS in closing this gap that the difference in injury reduction is taken account of adequately. While TUD's bonnet area assumption is 'conservative' the lack an allowance for headform speed or an allowance for the different legform criteria means that TUD's estimate is too optimistic about the effectiveness of phase one.
Discrimination between current phase two and TRL proposal	Difference in acceptance criteria allowed for as % not saved, from injury risk curve. Lower protection areas allowed for by random selection, with reduction in proportion selected to allow for transition areas. TRL proposal effectiveness (of current phase two): ECS 83% fatalities 84% serious, SS 75% fatalities 76% serious.	n/a	No allowance for BLE energy changes. Application of injury risks to serious and fatal injuries separately, taking no account of slight injuries, is somewhat crude for obtaining absolute benefits, but it should give a reasonable estimate of the comparative benefits of phase two and the TRL proposal. *Effectiveness proportions not directly comparable with TRL 2002 due to refinements of method.* Will TUD make estimates for TRL proposal?

Appendix B. ACEA proposal of December 2004 – passive safety measures

European
Automobile
Manufacturers
Association

17 December 2004

DIRECTIVE 2003/102/EC - PHASE 2

FINAL ACEA OFFER FOR PHASE 2 AND ASSESSMENT OF ITS EFFECTIVENESS

1. Passive safety measures

1.1 Child headform impactor-to-bonnet top test procedure

- 35 km/h; 3.5 kg; impact angle of 50°.
- WAD 1000 to 1700 mm. Boundary line concept.
- HIC 1000, 2/3 of the test area.
- HIC 1700, 1/3 of the test area (split 1/3 // 2/3 to be applied to the whole HFI test area).

1.2 Adult headform impactor-to-bonnet top test procedure

- 35 km/h; 4.5 kg; impact angle of 65°.
- WAD 1700 to 2100 mm. Boundary line concept.
- HIC 1000, 2/3 of the test area.
- HIC 1700, 1/3 of the test area (split 1/3 // 2/3 to be applied to the whole HFI test area).

1.3 Upper legform impactor-to-bonnet leading edge test procedure

No test. Possibility of monitoring, as in Phase 1.

1.4 Legform impactor-to-bumper test procedure

- 40 km/h, whole bumper area.
- Maximum tibia acceleration: 170 g.
- Maximum knee bending angle: 19°.
- Maximum knee shear: 6 mm.
- Relaxation zone (bumper test width up to 264 mm in total) for testing with a tibia acceleration protection requirement of 250 g.

1.5 Vehicles with high bumpers

Application to vehicles with approach angles ≥ 25° **and** with a ground clearance under the front axle ≥ 180 mm. Choice of the procedure to be used (LFI-to-bumper test (see above) or ULFI-to-bumper test) left to the manufacturer. In this case, test speed of 40 km/h, maximum sum of forces ≤ 7.5 kN and maximum bending moment ≤ 510 Nm.