Pedestrian protection test procedures and design: Final report (April 1999 to June 2003)

Prepared for Vehicles Standards and Engineering Division, Department for Transport

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Executive Summary

Pedestrian casualties form a large proportion of road casualties in most countries. Research has shown that measures to improve car design, to mitigate pedestrian injuries in collisions, can be very effective in reducing the number of fatalities and serious injuries. Therefore as part of their target to minimise the number and consequences of road accidents the UK Department for Transport (DfT) has supported a continuing programme of research at TRL Limited on pedestrian protection. As part of this research programme TRL participated in the work of two pedestrian Working Groups (WG10 and WG17) of the European Enhanced Vehicle-safety Committee (EEVC) to develop the pedestrian test methods. The EEVC test methods consist of three principal test procedures each using different sub-systems impactors to represent the main phases of a car-to-pedestrian impact. The three impactor types are:

- A legform impactor representing the adult lower limb to indicate lateral knee-joint shear displacement and bending angle, and tibia acceleration, caused by the contact of the bumper.
- An upper legform impactor representing the adult upper leg and pelvis to record bending moments and forces caused by the contact of the bonnet leading edge.
- Child and adult headform impactors to record head accelerations caused by contact with the bonnet top.

Each impactor is propelled into the car and the output from the impactor instrumentation is used to establish whether the energy absorbing characteristics of the car are acceptable. The whole area of the bumper, bonnet leading edge and bonnet top likely to strike pedestrians can be assessed by carrying out several tests with each impactor.

The end of the previous DfT project, in March 1999, coincided with the delivery of an EEVC WG17 report to the European Commission. The EEVC WG17 report described the review and updating of the test methods developed by WG10. More recently the European Commission has produced a draft framework Directive that will introduce pedestrian protection in two stages. The first stage uses a combination of changes to the EEVC test methods and their performance criteria, which will make them easier to pass but provide less protection. The second stage requires pedestrian protection using the EEVC test methods and performance criteria or other measures which are at least equivalent (at least equal protective effects), subject to a feasibility assessment. This two-stage approach was first proposed by the European Automobile Manufacturers Association (ACEA).

The current project commenced in April 1999 and was completed in June 2003. The project has made a major contribution to the work of EEVC Working Group 17 to update and finalise their test methods and test tools (impactors). The decision of the European Commission to produce a draft framework Directive based on the recommendations of EEVC Working Group 17 is considered to be an acknowledgement of the progress made by the Working Group and indicates that the main aim of this project may be close to being achieved.

The work for this period is summarised in this final report and the following conclusions were drawn from this work:

A production version of the TRL legform impactor was developing and assessed. It was found to comply with the EEVC specification and to be a practical and robust test tool and was accepted as an approved EEVC test tool. TRL’s work on the EEVC WG17 dynamic legform certification test provided data that were used to finalise the EEVC WG17 certification method and the pass/fail requirements. An alternative dynamic certification method was also developed by TRL, which has the advantage of loading the impactor in a similar way to a car with a pedestrian friendly bumper.

TRL’s assessment of the TNO headform impactors showed that they complied with the EEVC specification and that they were practical and robust test tools that gave good repeatability. Consequently they were accepted as approved EEVC test tools.

TRL has published drawings of the legform and upper legform impactors to make the impactor designs publicly available, which will make them more acceptable for use in regulations.

The development of a validated biofidelic pedestrian computer model and an improved family of pedestrian-safe vehicle models enabled the EEVC WG17 upper legform test energies to be reviewed. The impact energies predicted by the improved models were broadly similar in trends and magnitude to those in the EEVC WG17 1998 test methods and have provided a more confident indication of the energy response for a pedestrian being struck by a vehicle.

The Honda Civic was the first production car acknowledged to have been designed to provide some measure of compliance with the EEVC test methods. Therefore the additional costs and protection provided by this car are of interest in demonstrating how demanding the first stage of the EU test requirements are. TRL assessed the Civic and concluded that it had provided a significant measure of pedestrian protection without apparent sacrifice of occupant protection, fuel economy, insurance rating or accident repair costs. The assessment shows that overall it achieves about 80 percent of the pedestrian protection recommended by EEVC WG17 and that it easily meets the protection requirements of the first phase of the draft Directive. The additional manufacturing costs for the Civic’s current pedestrian-protection features are estimated to be between £6.20 and £6.58 per vehicle, depending on the volume of vehicles produced. These estimated costs are also considered a reasonable estimate of the average cost to make this style of car meet the first phase of the draft Directive but it is considered likely that pedestrian protection may be more difficult to provide in some other styles of vehicles. Using the ‘Pareto Principle’ (the 80:20 rule) that it generally takes considerably more
effort to achieve the last few percent of a requirement, it is estimated that pedestrian protection would cost a total of around £32 if the Civic was further improved to provide the level of pedestrian protection required by EEVC WG17. The estimated benefits of full implementation for cars of the EEVC pedestrian test proposals, using two different calculation methods, would be to reduce the numbers of pedestrian fatalities by 10 to 18 percent and seriously injured casualties by 13 to 20 percent. The casualty reductions for the EU, estimated by the two calculation methods, would be an annual reduction of about 600 to 1,100 fatalities and 7,000 to 11,000 seriously injured casualties and would result in an annual financial benefit for the EU of about 3,200 or 3,300 million Euro. The estimated benefits of full implementation of the first phase of the draft Directive, using the same two calculation methods, would be a reduction of 3 to 10 percent of fatalities and 7 to 13 percent of seriously injured casualties. The casualty reductions for the EU, estimated by the two calculation methods, would be annual reductions of about 200 to 600 fatalities and 4,000 to 7,000 seriously injured casualties and would result in an annual financial benefit for the EU of about 1,700 or 1,800 million Euro.

A study has been completed to help design a possible future accident study to determine the real reductions in pedestrian casualties resulting from cars with pedestrian protection. Sources of accident data that could be used have been identified and recommendations have been made for the data to be collected. Recommendations have been made on the identification of real-world benefits of providing cars with pedestrian protection, and for investigating the patterns of injuries that would still occur, by means of accident studies. Estimates have been made of the sample sizes of casualties that would be necessary for these future accident studies and the dates when these samples might be available.

The mandate of the IHRA Pedestrian Working Group is to develop a series of worldwide harmonised test methods for passenger cars suitable for testing the whole area of the vehicle front likely to strike a pedestrian. If the IHRA test methods for the whole vehicle front were used in legislation to require protection then TRL estimate that the benefits would be to reduce the numbers of pedestrian fatalities by between 5 and 48 percent and the number of seriously injured casualties by between 7 and 33 percent. These ranges of benefits reflect the different accident speeds that legislators could require effective protection for and the two different methods used to calculate the benefits.

TRL have reviewed and modified the computer simulation model used by IHRA to determine provisional head-impact conditions for their headform test method. The main conclusion from this work is that both the modified and original IHRA pedestrian models and an alternative model have shoulder joints that demonstrate very poor shoulder biofidelity. Recommendations for further work have been made which include further modifications to the structure of the model’s shoulder.
1 Introduction

In most countries pedestrian casualties form a large proportion of road casualties. Research has shown that measures to improve car design, to mitigate pedestrian injuries in collisions, can be very effective in reducing the number of fatalities and serious injuries.

1.1 Previous research

The Department for Transport (DfT) has supported a continuing programme of research at TRL Limited on pedestrian protection as part of the DfT target to minimise the number and consequences of road accidents. This programme of research was started in the nineteen-seventies and continues to date. It has helped to provide an understanding of pedestrian accidents, has shown how cars can be improved and has contributed to the development of test methods suitable for use in regulations or standards to require pedestrian protection in vehicle designs. As part of this research programme TRL, along with other European research institutes, participated in the work of the two pedestrian Working Groups (WG10 and WG17) of the European Enhanced Vehicle-safety Committee (EEVC) to develop pedestrian test methods. These methods are suitable for use in regulations or standards to require new cars to be less aggressive to pedestrians in accidents.

Initially, impact tests using a pedestrian dummy were considered. However, some significant disadvantages of pedestrian testing using dummies for regulatory purposes became apparent. The repeatability of tests using pedestrian dummies is relatively poor, small variations in the initial dummy set-up will have an increasing influence on the impact severity and position on the car of dummy body parts, as the impact progresses. Also, if pedestrian dummies were used then a range of pedestrian dummies of different stature would be required to test all areas likely to be hit in real life. This is because the impact locations for key body parts such as the head are very dependent on the pedestrian’s stature, as well as the position of first contact across the vehicle’s width and the pedestrian’s motion before contact. It would also be very difficult to predict and control the impact locations of dummy body parts to test selected danger points accurately, particularly for the head. For test methods intended for legislative use, as in this case, sub-system test methods overcome these disadvantages. Sub-systems tests have the following advantages over full-scale dummy tests:

- They can easily be used to test the whole area likely to strike pedestrians.
- They can be aimed accurately at selected danger points.
- They give good repeatability.
- The tests cost less to perform.
- The test requirements are simpler to design to and to model mathematically.
- They can be more easily used in component development.
- The test severity can be adjusted (e.g. by energy cap) to take account of practical design limitations.

Therefore, EEVC WG10 developed sub-system test methods. These tests were designed for the fronts of cars, as they are involved in the majority of pedestrian accidents. These test methods were subsequently reviewed and updated by EEVC WG17.

The end of the previous DfT project, in March 1999, coincided with the delivery of an EEVC WG17 report (European Enhanced Vehicle-safety Committee, 1998) to the European Commission. The EEVC WG17 report described their review and updating of the test methods developed by EEVC WG10 and also included the test methods in a form suitable for inclusion in a regulation. The European Union has considered various options for requiring pedestrian protection based on the EEVC test procedures. One option was to introduce the EEVC test methods and performance criteria as an EU Directive to require pedestrian protection in new car designs. An alternative option for industry self-regulation was put forward by the European Automobile Manufacturers Association (ACEA) and following negotiations and revisions this was accepted by the European Commission as a second option for consideration by the European Union. This second, ACEA option has a two-stage implementation process (Commission of the European Communities, 2001). For the first phase, they have proposed a combination of changes to the EEVC test methods and their performance criteria, which will make the tests easier to pass but will provide less protection. The second phase requires pedestrian protection using the EEVC test methods and performance criteria, or other measures which are at least equivalent (at least equal protective effects), subject to a feasibility assessment.

More recently the European Parliament requested the European Commission to produce a Directive for pedestrian protection and the Commission has produced a draft framework Directive (Commission of the European Communities, 2003). This draft framework Directive is essentially the same as the ACEA proposal but makes the protection a legal requirement rather than by industry self-regulation. Usually a Directive contains all the information required by the manufacturers, test houses and approval authorities. However, the framework Directive for pedestrian protection just contains the key test requirements and performance criteria, and uses a formalised and updated version of the ACEA proposal to separately describe the tests in more detail.

The EEVC test methods consist of three principal test procedures each using different sub-systems impactors to represent the main phases of a car-to-pedestrian impact. The three impactor types are:

- A legform impactor representing the adult lower limb to indicate lateral knee-joint shear displacement and bending angle, and tibia acceleration, caused by the contact of the bumper.
- An upper legform impactor representing the adult upper leg and pelvis to record bending moments and forces caused by the contact of the bonnet leading edge.
- Child and adult headform impactors to record head accelerations caused by contact with the bonnet top.
Each impactor is propelled into the car and the output from the impactor instrumentation is used to establish whether the energy absorbing characteristics of the car are acceptable. The whole area of the bumper, bonnet leading edge and bonnet top likely to strike pedestrians can be assessed by carrying out several tests with each impactor. For the bumper and bonnet leading edge the impactors represent adult statures which accident data show are more easily injured by these vehicle features. The longer and heavier legs of adults require more protection than those of children so bumpers and bonnet leading edges that are safe for adults in impacts up to the test speed will normally provide effective protection for children up to higher speeds.

1.2 Current project

This research project ‘Pedestrian protection test procedures and design’ commenced in April 1999 and will be completed in June 2003. The work in this period is summarised in this final report. The work included:

- Attending and participating in the EEVC WG17 meetings.
- Attending and participating in the IHRA Working Group where pedestrian test methods were being developed.
- Research work toward the pedestrian protection test procedures including:
  - Developing a production version of the TRL legform impactor and assessing it against the EEVC specification and test requirements. Using the new impactor to consider the provisional dynamic certification requirements for the legform impactor.
  - Developing a new dynamic certification method for the legform impactor.
  - Updating engineering drawings and producing a report on the legform and upper legform impactors for publication.
  - Carrying out an assessment of the new WG17 headforms.
  - Developing and validating a biofidelic pedestrian computer model and developing a family of pedestrian-safe vehicle models, and using them to review the EEVC WG17 upper legform test energies.
  - Developing and reviewing the IHRA and TNO mathematical models of pedestrian and car with special interest in the modelling of the human shoulder.
- Research towards understanding the consequences of requiring pedestrian protection in cars including:
  - Assessing the costs and effectiveness of the Honda Civic’s pedestrian protection and estimating the benefits of the EEVC and ACEA test proposals.
  - Producing an analysis of the societal implications (casualty reductions) of cars that would meet the IHRA pedestrian protection requirements.
  - Studying the design of a possible future accident investigation to determine the real-world benefit of cars engineered for pedestrian safety and to predict when there would be sufficient accident data involving safer cars to determine their efficacy.

2 Research in support of the EEVC pedestrian protection test procedures

2.1 Background

Pedestrian protection test methods were developed by Working Group 10 of the European Enhanced Vehicle-safety Committee. The aim of the group was to develop sub-system pedestrian test methods, which would be suitable for use in vehicle legislation. In 1991 a report was published describing the test methods that had been developed (Harris, 1991). At this time, the work of the Working Group was considered essentially complete, however, the test methods had not been fully assessed and production versions of the impactors had not been developed, so the Working Group continued until 1994. The final report of EEVC WG10 was produced in 1994 (European Experimental Vehicles Committee, 1994) and, after some further evaluation and refinement, it was used as a basis for an EC draft Directive in 1996 (European Commission, 1996).

Following a meeting in May 1997 of the former EEVC WG10 members, the EEVC Steering Committee set up EEVC WG17 on Pedestrian Safety, with two main aims:

- To review the WG10 tests methods and propose possible adjustments by taking into account new accident data and test results.
- To prepare the EEVC contribution to the IHRA Working Group on Pedestrian Safety.

Mr Lawrence, of TRL, was a member of EEVC WG10 throughout, and was appointed as the UK representative for WG17 and remains a member to date. TRL has made a major contribution to the work of EEVC WG17 and has helped in the review of the pedestrian protection procedures, which was essentially complete in 1998 (European Enhanced Vehicle-safety Committee, 1998).

Since then WG17 has worked to resolve the outstanding issues with the EEVC test methods and to contribute to the work of the IHRA Pedestrian Safety Working Group.

2.2 TRL’s contribution to EEVC WG17

Over the course of this project TRL has contributed research and advice to WG17. In addition to the work reported below TRL has also produced many committee papers and improvements to the test methods both technically and by clarifying wording and diagrams. More recently Mr Lawrence has also acted as Technical Secretary for the Working Group.

2.2.1 Developing a production version of the TRL legform impactor and assessing it against the EEVC specification and test requirements

Originally, within the work of EEVC WG10, the French research laboratory INRETS was responsible for developing the legform-to-bumper test procedure, however, their prototype legform impactor did not meet the Working Group’s specification. To assist, TRL first developed an alternative knee joint, which was accepted as
a promising alternative at the last meeting of EEVC WG10 in 1994. Following on from this TRL developed a prototype legform impactor, which included the TRL knee joint, and this impactor was manufactured from 1995 to 2000. One of the first tasks of EEVC WG17 was to consider the suitability of this prototype impactor for the EEVC bumper test. The Working Group concluded that it met all of their requirements with the exception of the need for a damper in the knee-joint shear system to prevent unwanted vibrations. As part of the work towards meeting this requirement TRL produced an experimental damped legform impactor, with a large damper. This experimental legform showed that it was feasible to introduce a damper and that it was effective in controlling the vibrations in the knee-joint shear system but a custom-made damper of a smaller size would be required for an impactor suitable for use in regulatory tests. This experimental damped legform impactor was also used to develop a provisional new dynamic certification procedure for the legform impactor. However, the experimental impactor was only produced to prove the principle of damping the knee and, because of this, the mass distribution was not corrected for the additional parts. Therefore, the dynamic certification values found from this experimental impactor were regarded as provisional.

Following on from this work, under the current project, TRL went on to develop a new production version of the damped legform impactor and to assess it against the EEVC specification. A series of dynamic certification tests were also carried out to refine the test’s pass/fail limits and a series of car impact tests were carried out to assess the robustness of the impactor. The report (Lawrence and Hardy, 2002a) describing this work is summarised below along with an explanation of how its findings were used by EEVC WG17.

The assessment of the new legform impactor showed that, in all respects, it met the EEVC WG17 specification and was well within the specified tolerances. Both the static shear and bending certification test results were found to fall within the EEVC WG17 corridors and lie close to the middle. The changes made to the design had increased the maximum shear displacement from a nominal ± 8 mm to a nominal ± 8.5 mm, which increased its ability to report overloading. The damped knee shear system met the EEVC requirement for the damper to prevent excessive vibrations of the shear displacement system. The 500 Ns/m damper was confirmed as having a suitable damping coefficient to achieve this. The assessment showed that the performance of the impactor would not be unduly affected by the effect of small manufacturing variations on the damper coefficient. The impactor was found to be robust and it suffered no damage in 30 tests. The provisional adjustment made by EEVC WG17 to the static shear certification corridor, to take account of the force generated by the damper, was assessed and a revised adjustment value was found but the difference between these two values was so small that no change to the corridor was required. A limited programme of dynamic legform certification tests was then carried out but this was not sufficient to confirm the certification method or its pass/fail values. The results of the dynamic certification and car tests showed that the test method gave good repeatability.

At this point in the TRL study, EEVC WG17 were required to finalise their test methods, therefore TRL produced an interim report for the Working Group to consider. As the TRL damped legform impactor met their specification it was accepted as an approved EEVC impactor by the Working Group. The unfinished dynamic certification method was included in the EEVC WG17 1998 report (European Enhanced Vehicle-safety Committee, 1998) with provisional pass/fail values indicated by the use of square brackets, because of the need of the Working Group to present its findings.

TRL carried out further dynamic legform certification tests and it was found that the acceleration measured was sensitive to variation in the Confor foam used to represent flesh. It was concluded that if this was found to result in unacceptably high failure rates in the future (when certifying impactors, and with flesh thought to be satisfactory) then the limits should be reconsidered or the test revised to make it less sensitive to the foam properties. A method was also proposed to approve up to four sheets of legform flesh material in the legform dynamic certification test. This would permit the certification test to be carried out after about twenty tests as intended by WG10, rather than the current limit of only five tests if the flesh is always replaced as recommended.

### 2.2.2 Developing a new dynamic certification method for the legform impactor

As described above in Section 2.2.1, as part of their work to develop the legform impactor TRL devised a provisional dynamic certification method. This provisional dynamic certification test method initially appeared attractive. However, later TRL concluded that the acceleration measured in the test was unduly sensitive to variations in the Confor™ foam used to represent human flesh.

In order to understand the problems with the current provisional dynamic certification test method and a derivative of it that uses a reduced mass certification impactor, TRL carried out further research. TRL also developed and assessed a new dynamic certification test method, and suggested provisional pass and fail values for it. This work was reported by Lawrence and Hardy (2002a) and is summarised below along with an explanation of how its findings were used by EEVC WG17.

Both the EEVC WG17 dynamic legform certification test of December 1998 and the derivative of it that uses a reduced mass certification impactor were found to exhibit high levels of variation in test outputs. Variation in the properties of the foam flesh of the impactor, with the risk of the foam ‘bottoming out’, was thought to account for much of the variation in test outputs.

The following conclusions and recommendations were made in the report concerning the EEVC WG17 provisional dynamic certification test method of December 1998:

- If the dynamic legform certification test were used in a regulation, with the pass-fail tolerances selected within the normally accepted range for certification tests, then
there would be a high failure rate when certifying impactors and flesh thought to be satisfactory. This would not be acceptable, due to the lack of simple remedies for most failures.

- If the EEVC WG17 (Dec 1998) dynamic legform certification test were used in a regulation, the certification impactor mass should be reduced to 9 kg. The following test limits could then be recommended: a knee bending angle of between 6.2 and 8.3 degrees, a knee shear displacement of between 2.8 and 5.7 mm and a tibia acceleration of between 90 and 250 g. These wide tolerances would have limited effect in controlling the performance of WG17 legform impactors in tests into cars.

- If the EEVC WG17 retains the certification test of Dec 1998, with either the 16 or 9 kg certification impactor, then the sources of variation should be investigated, with a view to making it more consistent, which would reduce the failure rate or allow working within tighter limits.

The following conclusions and recommendations were made in the report for the new dynamic certification test method:

- An alternative dynamic impactor certification test has been developed. In this test the legform impactor is propelled into a steel leaf spring that represents a car bumper. The steel leaf spring elastically deforms, thereby extending the duration of the impact and limiting the compression of the impactor’s foam flesh. It is recommended that this test be adopted by EEVC WG17, in place of the test specified in the December 1998 test procedures.

- Within the time and resources available it was not possible to carry out sufficient tests to enable robust test limits to be established for the alternative dynamic impactor certification test. If it is necessary to select final test limits for the alternative dynamic impactor certification test, without further delay, then the limits chosen should have relatively wide tolerances, to reflect the uncertainty and to reduce the risk of causing a high failure rate. The following test limits would be recommended: a knee bending angle of between 5.2 and 7.2 degrees, a knee shear displacement of between 3.5 and 4.5 mm and a tibia acceleration of between 100 and 140 g.

- If the setting of final test limits for the alternative dynamic impactor certification test can be delayed then it is recommended that the above test limits should be regarded as provisional values.

- The alternative dynamic impactor certification test is specified, in a form that can be incorporated into the EEVC WG17 test procedures, in an Annex to this report.

- A recommendation is again made to permit the approval of up to four consecutive sheets of Confor™ foam flesh material, in order to reduce the frequency of legform certification tests.

The recommendations in this report were considered by EEVC WG17 in their 11th and 12th meetings in May and September 2002. The Working Group concluded that the new certification method appeared promising and had the advantage of loading the impactor in a similar way to a car with a pedestrian friendly bumper. Nevertheless, because robust test limits were not available for the new method, the Working Group decided to retain the current test method but with a reduced certification mass of 9 kg. Following consideration of the TRL recommended pass/fail limits based on a significant number of TRL test results using a 9 kg impactor mass, and additional certification results provided by the Japanese industry, the Working Group decided to make adjustments to the pass/fail values proposed by TRL. The Working Group also recommended that further testing with the new method should be undertaken until there was sufficient data to confirm or reject the method and if found satisfactory to select robust pass corridors.

The above work has shown that the TRL damped legform impactor is a suitable test tool for use in safety regulations or legislation. It therefore joins the TRL upper legform impactor as an approved EEVC impactor.

### 2.2.3 Updating engineering drawings and producing a report on the legform and upper legform impactors for publication

TRL was responsible for developing the EEVC upper legform to bonnet leading edge impactor and the final version of the legform impactor used to test the bumper area.

As already noted, the European Commission is currently considering using the EEVC test methods in some form of regulation or requirement for pedestrian protection features in new car designs. Suitable test tools as well as test methods are required for safety regulations or legislation. The development of the approved TRL legform and upper legform impactors, and the TNO headform impactors make the test methods more suitable for use in regulations. In the United States of America drawings of test devices are held, maintained and administered by the appropriate government agency. The European Commission has called for drawings of the EEVC impactors to be made available and TRL has offered to provide drawings, however, the EC have no facility for maintaining and administering drawings. Ideally the EC should set up such a system, which should include the assessment of any proposals to improve the impactors and approve or reject them. This would result in the use of standardised impactors, would regulate any changes, and should help reduce test variation and also prevent undue dependence on a single supplier. However, in the absence of an EC system for drawings TRL, have published engineering drawings of the legform and upper legform impactors to make the impactor designs publicly available, which will make them more acceptable for use in regulations.

The drawings have been published by bundling them with a report that provides some background information about the EEVC test methods and the development of the impactors (Lawrence and Hardy, 2002b). This report includes the current engineering drawings and parts lists of the two impactors produced by TRL. The drawing sets contain all the information required to manufacture the impactors and will also be of help in constructing...
2.2.4 Carrying out an assessment of the new WG17 headforms

The original EEVC WG10 pedestrian headform impactors, designed by the German research laboratory BASf, were made from bowling balls with steel inserts and a rubber skin. Later, the dummy-manufacturing arm of the Dutch research laboratory TNO made commercially available improved headform impactors based on the BASf designs; these were also made from bowling balls. These TNO headforms were extensively used for testing to EEVC WG10 from about 1995 to 2001. However, there were a number of minor problems with these headform impactors. The phenolic resin of the bowling ball was brittle and its low density made it difficult to achieve the desired mass and position of centre of gravity. It was also difficult to manufacture ‘good’ batches of skins, the skin clamps were difficult to use and the accelerometer mount suffered from vibration.

The EEVC WG10 review and update of the pedestrian test methods developed by WG10 resulted in a new specification for the adult and child headform impactors and a new dynamic headform certification procedure. To improve the headform impactors, WG17 changed the material specified for the impactor sphere to aluminium alloy, and the skin material and thickness was changed to match that used for the heads of occupant dummies. TNO designed and manufactured new child and adult headform impactors to meet the WG17 requirements. The new headforms had an improved skin-clamp system and improved accelerometer mountings. The new headform certification test was chosen because it was more representative of the use of the headforms in vehicle tests. The biomechanical link from the old certification drop-test was transferred to the new dynamic certification test by WG17 in two stages. Firstly, the new headforms with skins that performed near the middle of the old WG10 certification drop-test corridor were developed. Secondly, impact conditions and pass/fail requirements were determined from these headforms’ performance in the new dynamic certification test.

The Working Group asked TRL to perform an independent assessment of these new headform impactors and dynamic certification procedure. The report of the TRL assessment (White and Lawrence, 2000) is summarised below along with an explanation of how its findings were used by EEVC WG17.

The new headforms were assessed against the EEVC WG17 specification for dimensions, mass and mass distribution. Specific areas for assessment were their performance in the WG10 drop certification test, in the new EEVC WG17 dynamic certification test, in repeatability tests against a simulated bonnet top and in comparative tests with the old TNO phenolic resin headform impactors against real cars. To facilitate the headform impactors’ development by TNO, intermediate results of this assessment were reported to TNO as they emerged and to the December 1999 meeting of WG17. It was confirmed that the new TNO impactors met dimensional, inertial and mass tolerances, although the mass of the adult headform was significantly above the nominal value. For both impactors the positioning of the fore/aft accelerometer seismic mass was found to have been based on a misinterpretation of the positional tolerance, because the WG17 specification was ambiguous. (Later WG17 improved the definition and the impactor design was revised.) The skin thickness of both prototype impactors were adjusted outside of the WG17 provisional tolerance in order to meet the original EEVC WG10 drop test certification requirement. It was recommended that the WG17 provisional thickness be revised to the current nominal skin thickness of the prototypes assessed by TRL, of 11.5mm and 14mm for the child and adult headform impactors respectively.

It was concluded that the new impactors gave peak resultant accelerations within the limits defined for the WG10 drop certification test with the new skins fitted, but the child headform impactor results were close to the lower limits. It would be beneficial for TNO to produce skins that perform closer to the middle of the corridor, which can be achieved by using a slightly harder compound, before they are used to specify the new dynamic certification requirement.

TRL devised a suitable lightweight headform support and positioning system from netting for the dynamic certification test. However, it was difficult to use and it was recommended that a more user-friendly lightweight design be produced.

The dynamic certification procedure was found to give repeatable results within the initially defined targets for head injury criterion (HIC$_{30}$) of between 500 and 2000. It was recommended that TNO should use the results from these tests, and further tests using their improved impactors and further production batches of headform skins, to refine the acceptance range of results for certification of the impactors and skins.

Repeatability tests performed using a simulated bonnet top confirmed that both impactors and the test procedure gave highly repeatable results. Comparative tests were performed using the old (WG10) and new (WG17) headform impactors against real cars. The comparative tests to the bonnets with the old and new adult headform impactors showed that they gave very similar results. Both the new and old child headform impactors gave good repeatability when used to test a car. However, the new child headform impactor gave higher results than the old design. The new softer child skin was thought to be the cause of this change. There is little biomechanical data for children, and none that could be used to determine which of the two child headform impactors most closely
represents real life. However, the new child headform had many advantages and used the same material and flesh thickness as used for the head on the six-year-old Hybrid III dummy. This difference may be reduced if slightly harder skins are produced to achieve a performance closer to the middle of the drop certification corridor (an alternative cause of the difference was found later, see penultimate paragraph of this section).

There was evidence that 3 kHz ‘ringing’ could be excited in the fore/aft axis of the accelerometer mounting of the new adult headform impactor when the dynamic certification test was performed, although there was no indication of this during the real car, repeatability and drop certification tests. Due to its frequency, this ‘ringing’ is unlikely to be excited in tests to cars and most of its effect will be removed by the required filtering. It was not therefore considered essential that this be further investigated.

As already noted, an interim report on the progress of the headform assessment was presented at the December 1999 WG17 meeting. Following presentations from TRL and TNO of headform assessments, the headforms were accepted by EEVC WG17. TNO and TRL were given responsibility for finalising the dynamic certification requirements for the headform impactors. The final TRL report on the headform assessment (White and Lawrence, 2000) was presented to WG17 in November 2000.

In the May 2002 meeting of EEVC WG17 both First Technology Safety Systems (FTSS) and TRL presented papers discussing possible errors in measuring linear headform acceleration in the presence of headform rotation. (TNO’s dummy manufacture and sales activities, including pedestrian headforms, had been transferred to FTSS in September 1999.) It was agreed that the potential error could be further reduced by changing the positioning of the seismic masses of the three accelerometer elements and new positions and tolerances were agreed to achieve this.

FTSS and TRL also presented papers giving their dynamic certification results to help finalise the pass/fail values for the dynamic certification test in the May 2002 meeting of EEVC WG17. In addition, FTSS reported the results of a ‘Round Robin’ headform certification study where adult and child headforms had been subjected to dynamic certification tests at four different test laboratories. Although the same headform, skin and accelerometer were used at each test laboratory and the same seven points on the skin were tested, the results showed significant differences between each facility. In the September 2002 meeting of WG17, a study of the equipment and procedures of two of the test laboratories involved in the Round Robin was reported by TNO. They could find no cause for the different results found in the Round Robin. Because of the time constraints to finalise the test methods for use by the EC, WG17 selected pass/fail dynamic certification values for the two headforms, based on the data supplied in the May meeting and some additional certification data supplied by the car manufacturers. Nevertheless, this cannot be considered a satisfactory solution and it cannot be resolved until the cause of these differing results is fully understood.

The above work has shown that the TNO headforms (which are now supplied by FTSS) are suitable test tools for use in safety regulations or legislation. The headforms have therefore been approved and join the TRL legform impactor and upper legform impactor as approved EEVC impactors. The development of these impactors is considered crucial in making the EEVC test methods suitable for use in regulations.

2.2.5 Review of the EEVC WG17 upper legform test energies

Part of the task of WG17 was to review the test energies of the pedestrian upper legform to bonnet leading edge sub-system tests. This task was completed in 1998 and made use of the results from a series of simulations using a TRL developed pedestrian and vehicle model in the Finite Element code LS-DYNA3D (Lawrence and Hardy, 1998), these simulations were subsequently called ‘PHASE I’ by TRL. This work was undertaken as part of the previous TRL pedestrian project for the DfT.

Following on from this, under the current project, TRL continued improving the pedestrian and vehicle models with the aim of making the pedestrian model more biofidelic and the vehicle model more representative of a modern pedestrian friendly vehicle. Initially an improved biofidelic pedestrian model was produced (subsequently called the ‘PHASE II’ biofidelic model). This work was reported by Neale along with a description of the development and validation of the original PHASE I pedestrian model that was used by Lawrence and Hardy for the WG17 review (Neale, 2000). Subsequently the biofidelic pedestrian and the vehicle models were improved and called the PHASE III models and were used to review the 1998 EEVC WG17 upper legform test energies for the upper legform to bonnet leading edge test method. This work was reported to EEVC WG17 in their May and September 2002 meetings. Neale reported both phases of this new work (Neale et al., 2001) and his report is summarised below.

The upper legform sub-system test is designed to assess the aggressiveness of the bonnet leading edge in car-to-pedestrian impacts, which is highly dependent on the vehicle shape. To address the influence of vehicle shape on the aggressiveness of the bonnet leading edge, a family of energy curves is referred to in the sub-system test. These curves specify the impact energies of the bonnet leading edge test as the vehicle shape varies, as described by the bonnet leading edge height and bumper lead.

Although the original TRL ‘PHASE I’ simulations results used a model that was more sophisticated than the lumped mass models normally used for this type of work, it was recognised that it could be improved further. Therefore, a study was undertaken to develop the pedestrian model to make it more representative of a human, and to improve the car model to make it more representative of a modern car but with pedestrian friendly performance.

The report describes further improvements to the PHASE II pedestrian model, the development of an improved pedestrian friendly car model, a review of the
upper leg to bonnet leading edge impact energies and recommendations on how they could be used in a sub-systems test method.

The alterations to the PHASE I generic vehicle model, used to interact with the pedestrian model, were to the profile and structure of the model. Modifications were made to the PHASE II pedestrian model, these involved changes to the model’s stance to achieve a more natural walking stance, in addition to changes to the structure of the modelled pelvis to improve its biofidelic response. In recognition of the changes implemented, the model was renamed the PHASE III model, and was subsequently used in the second review of the upper legform impact energies that is presented in the report.

The impact energies predicted by the PHASE III biofidelic pedestrian and vehicle model were broadly similar in trends and magnitude to those predicted by the original pedestrian dummy and vehicle model. However, at lower bonnet leading edge heights (700 mm and below) almost all the impact energies predicted by the PHASE III model were higher than those predicted by the PHASE I model. At higher bonnet leading edge heights (800 mm and above) the impact energies have almost all decreased, when the second energy review is compared with the first. These differences are thought to be due to a combination of changes to the pedestrian model to make it more biofidelic, changes to the leg and feet positions to make the pedestrian model’s stance reflect a typical walking position and changes to the simulated car to make it more representative of a real car.

To establish what influences some of these changes in pedestrian stance and simulated car had on the energy predictions, a series of parametric studies was conducted. The effects on impact severity of the other changes to the pedestrian model to make it more biofidelic (which included using flexible leg and pelvis bones and an additional joint in the spine) have also been discussed.

As a consequence of this study, a second energy review has been completed of the upper legform sub-system test energies; this has provided a more confident indication of the energy response for a pedestrian being struck by a vehicle. Proposals for new upper legform energy curves suitable for use in sub-system test methods have been produced using the new energy data. Suggestions have been made that the bonnet leading edge reference line should be determined using a straight edge at 40° to the vertical, instead of the current 50° angle. Therefore, two versions of the new energy curves have been produced, one for each angle.

Proposals for a change in the straight-edge angle used to define the bonnet leading edge reference line have also been considered in the light of data, obtained from the model, on the location of the centre of the bonnet leading edge impact. These data also support reducing the angle, therefore TRL recommended that the EEVC WG17 test methods be revised to require an angle of 40 degrees to the vertical.

Additional findings from this work indicate that there are numerous parameters that can influence energy predictions. It was recommended that additional work be conducted to isolate which of these are of greatest importance and establish the magnitude of influence that they have on energy predictions. Such a study could help to determine limits of impact energies in contrast to the current process which aims to characterise a set of upper legform impact energies for a precisely defined set of impact conditions (i.e. pedestrian stance, pedestrian joint stiffness, vehicle profile etc). There are other related topics that could be studied further, and these are listed in the report.

2.3 September 2002 updates of the WG17 test methods

The 1998 report of EEVC WG17 (European Enhanced Vehicle-safety Committee, 1998) described their review and updating of the WG10 test methods. However, there were still a few provisional items in the test methods, which needed to be confirmed or revised. In addition some new issues had been identified from using the test methods and from subsequent research. The work by TRL, reported above, was aimed at finalising many of these outstanding issues. In the May 2002 meetings of WG17 it was decided to produce a document summarising the changes and recommendations to the test methods agreed by the group. It was agreed that these ‘updates’ be listed under three headings of:

- **‘Updates’** - changes considered necessary by WG17 in order to remove the brackets in the 1998 test methods, to take out mistakes or to fill the ‘gaps’ in certain definitions.
- **‘Recommendations’** - not really necessary, but they improve the consistency and/or interpretation of the text.
- **‘Other topics’** – areas needing further consideration/research.

The contents of this document were agreed in the May 2002 meeting and the retiring chairman, Mr Janssen of TNO, produced a draft document as his last duty for WG17. In the September 2002 meeting of WG17, under the new Chairman, Mr Cesari of INRETS, the content of the document was agreed and a final version was produced by TRL (EEVC Working Group 17, 2002). The chairman of WG17 formally supplied this document to the EC. The EC included all of the updates and those recommendations that were finalised in their draft framework Directive. More recently the Mr Lawrence in the role of Technical Secretary revised the 1998 EEVC WG17 report to include the September 2002 updates and those recommendations accepted for inclusion by the EC. This updated report was used to replace the original version on the EEVC website in May 2003 (European Enhanced Vehicle-safety Committee, 2002).

Below is a list of the changes made to the test method; a brief indication for the reasons for the changes is given in italics.

2.3.1 Changes affecting more than one test method

- **Annex II – Use of 40 km/h and 11.1 m/s revised. For consistency of units with following annexes.**
2.3.2 Legform to bumper test method

- Annex III – The legform impactor shall be fitted with foam cut from one of up to four consecutive sheets of Confor ™ foam flesh material produced from the same batch of manufacture (cut from one block or bun of foam), provided that foam from one of these sheets was used in the dynamic certification test and the individual weights of these sheets are within ± 2 percent of the weight of the sheet used in the certification test. In order to reduce the frequency of legform certification tests.
- Annex III – Figure 3 added showing the planes and tolerances of angles for the legform impactor at impact. Conical tolerances replaced by separate tolerances for angles in two planes. To clarify the application of the tolerances to the test and make it easier to check compliance.
- Annex VII – Legform bending certification test method revised to require that no support be provided to the femur section or the metal tube. The bending moment applied at the centre of the knee joint, due to the weight of the metal tube and other components (excluding the legform itself), shall not exceed 25 Nm. To avoid friction errors and limit the effects of the weight of the metal tube on the knee ligaments.
- Annex VII – Text and Figure 1 changed to extend bending certification corridor. To control knee joint bending stiffness over a larger range so the impactor is more suitable for use outside the EEVC test methods when higher knee bending performance criteria are used.
- Annex VII – Revised legform dynamic-certification performance requirements and certification impactor mass. To reflect the performance of the production version of the impactor and reduce crushing of the legform skin and flesh.
- Annex VII – Title of Figures 3 and 4 changed from ‘test set-up’ to ‘top view of test set-up’. To improve clarity.
- Annex VII – Revised Figure 5b, the legform dynamic certification impactor face drawing. Flange radius increased to improve consistency of dimensions and reduce need for blending.

2.3.3 Upper legform to high bumper test method

- Annex II – Improved Figure 1b showing marking of the Lower Bumper Reference Line. To match the diagram to the requirement for the straight edge to be in contact with the ground.

2.3.4 Upper legform to bonnet leading edge test method

- Annex V – Improved wording in Figure 5 to define 200 J limit. To remove inconsistency with text when car dimensions give exactly 200 J.

2.3.5 Headform to bonnet top test method

- Annex II – New method and figures added to extend the Bonnet Rear Reference Line when it does not intersect with the Bonnet Side Reference Lines. To remove the gap in the boundary of the headform test area when the car shape is such that the reference lines do not intersect.
- Annex II – Sphere used to determine bonnet rear reference line now chosen by reference to the wrap around distance at the vehicle centreline. Avoids change of sphere across the width of the vehicle that would cause discontinuities in the reference line.
- Annex VI – Provisional headform skin thickness replaced with confirmed values for child and adult headforms. To reflect adjustments made to the new headform skins to achieve a pass in the old WG10 drop certification test in order to maintain the biomechanical link.
- Annex VI – Provisional moment of inertia values confirmed for child and adult headforms. No adjustment needed for new headform designs.
- Annex VI – New wording and Figures 1 and 2 specifying the child and adult headform impactors. To reflect the new aluminium impactor design.
- Annex VI – New positions and tolerances for the seismic masses of the accelerometers in relation to the centre of the sphere and to the centre of gravity, in the child and adult headform impactors. To minimise possible errors in measuring linear headform acceleration in the presence of headform rotation.
- Annex VII – Change of certification impactor velocity for the adult headform and provisional velocity for the child impactor confirmed. To reflect the velocity required to produce a HIC of approximately 1000 in headforms that pass the old WG10 drop certification test.
- Annex VII – Revised acceleration limits in headform certification tests. To reflect peak accelerations obtained in certification tests with the new headforms.
- Annex VII – Change of CAC for the headform certification test from 500 g to 1000 g. To reduce the risk of clipping the signal.

3 IHRA Pedestrian safety Working Group

3.1 Background

In May 1996, at the initiative of the National Highway Traffic Safety Administration (NHTSA), a meeting of the Enhanced Safety of Vehicles government focal points was held to discuss the need for international harmonised research for motor vehicles. Following this meeting, a series of International Harmonized Research Activities (IHRA) Working Groups were established, each covering
a specific topic or theme, one of which was pedestrian protection. The UK government has made a commitment to support this work. The Ministry of Transport of Japan was selected to lead the IHRA Pedestrian Safety Working Group. The European Union (EU) requested the EEVC to nominate two experts to represent the EU on the IHRA Pedestrian Safety Working Group. The EEVC nominated Mr Janssen from TNO, the chairman of EEVC WG17, and Mr Lawrence from TRL. More recently Mr Cesari from INRETS has replaced Mr Janssen. Funding for Mr Lawrence to participate in the work of the IHRA Working Group is provided by the UK government as part of this research project. The EU also contributes towards the costs of travel and meeting time for the two European representatives. Several of the other members of the IHRA Pedestrian Safety Working Group, including the Japanese chairman, are also members of the longstanding International Organization for Standardization pedestrian Working Group, ISO WG2.

The mandate of the IHRA pedestrian Working Group is to develop harmonised pedestrian test methods for passenger cars. The first meeting was held in Tokyo in July 1997 and a further twelve meetings will have been held by the end of May 2003.

In the earlier meetings there was a considerable exchange of information, particularly of accident data and information on the available EEVC and ISO test methods. The group decided to develop sub-system test methods to reflect the worldwide vehicle population and accident situation. As a result, their test methods may cover a larger range of vehicle shapes and sizes, test velocities, test areas and pedestrian body parts than the EEVC and ISO procedures. The initial priorities have been to develop a test method for head injuries caused by impacts with the car bonnet, windshield and windshield surround, and a test method for leg injuries caused by bumper impacts. However, they have agreed that test methods for other body regions needing protection should be progressed in parallel. The body regions being considered for test procedures are: head, chest, abdomen, pelvis and possibly the neck for both child and adult, and also the adult femur, knee and tibia. To aid this process, standardised information sheets were developed to record accident data and information on the available test methods and test tools. The intention is to use data from computer simulations to determine the impact conditions for this larger range of vehicle sizes, vehicle impact areas and pedestrian body parts.

The IHRA group decided to:

a Develop test methods based on EEVC, ISO or any other suitable test methods but extended to cover a wider range of vehicle shapes, different and possibly higher impact speeds and a larger test area (including the windshield, A pillars and windshield upper frame).

b Develop impactors, test methods and injury criteria, in addition to the EEVC and ISO ones, to represent other body parts likely to suffer serious or life threatening injuries.


To date, the Working Group has concentrated its efforts on producing child and adult headform test procedures. It is intended that the headform impact conditions should be specified within the test methods. Vehicle shape, impact velocity and pedestrian stature are thought to have an effect on the head impact velocity, impact angle and vehicle part hit. Therefore for the free-flight child and adult headform sub-systems test methods under development by IHRA, the impact conditions should ideally be adjusted for each vehicle shape and each test site selected. As already noted, it was intended to use computer simulation results to determine the head impact conditions. However, an initial simulation study carried out by the IHRA Working Group using three lump-mass models, in MADYMO code, showed a wide variation between the models in predicted head impact conditions for the same vehicle shape and vehicle impact velocity.

The Working Group agreed that the initial simulation results were not suitable for use in the final test methods but that they could be included in the adult draft test method as provisional information, with the range in the results indicated. It was agreed that work should be undertaken to ascertain the cause of the variations and to improve the models. The improved models could then be used to find the most appropriate headform impact conditions, for a range of pedestrian statures over a suitable matrix of vehicle shapes and impact speed, to provide data for use in the final test methods. However, it is not clear if there is sufficient funding available for all of this additional simulation work.

3.2 TRL’s contribution to IHRA Pedestrian Safety Working Group

Much of the contribution from the European representatives has been in the form of providing information and experience gained during the development of the EEVC test procedures. TRL also assisted in the drafting of the headform test methods by helping to transfer the IHRA ideas into test rules by the use of suitable text and diagrams. Two research tasks undertaken by TRL to help the IHRA Working Group are summarised in the following sections, the first in Section 3.2.1 below and the second in Section 4.1.

3.2.1 Development and review of the IHRA and TNO mathematical models of pedestrian and car

The IHRA Pedestrian Safety Working Group is in the process of developing a sub-system head impact test procedure for assessing the aggressiveness of vehicle fronts to pedestrian head impacts. It has been decided that many details of the head impact test procedure will be based on predictions obtained from mathematical models of a pedestrian and vehicle used to simulate vehicle to pedestrian accidents. The predictions from the model will be used to relate the sub-system head impact test conditions to the head impact conditions in vehicle-
pedestrian accidents. To obtain an understanding of the confidence that could be placed in the results of simplified multi-body pedestrian simulations the IHRA Pedestrian Working Group used three MADYMO pedestrian models to simulate a matrix of vehicle shapes and impact velocities. Under the same impact conditions each model was found to predict significantly different head impact conditions. Following a review of the predictions from the three pedestrian models, the IHRA Pedestrian Working Group decided to further improve the most promising model, as developed by the Japan Automobile Research Institute (JARI). The improved model could then be used to refine the provisional test conditions in the IHRA head impact test procedure. However, although the JARI model suffered fewer obvious problems than the other two models reviewed, inconsistencies were discovered in its predictions, raising concerns on the model’s biofidelic response and accuracy. The main concerns about the model’s predictive capabilities related to the biofidelity of the model’s shoulder, which is anticipated to have an important influence on the impact severity of the head with the vehicle front in vehicle-pedestrian impacts (IHRA Pedestrian Safety Working Group, 2001).

To address this concern, TRL has undertaken a study funded by the DfT to review and develop the JARI pedestrian model. This work was reported by Neale in his ESV paper (Neale et al., 2003a) and in more detail in a report for the DfT (Neale et al., 2003b). The reports describe the results of an initial review of the JARI pedestrian model to identify possible limitations that could affect the accuracy of its predictions. An alternative pedestrian model developed by TNO was also briefly reviewed to compare the complexity of this model with the JARI model. TRL then made improvements to the biofidelic structure of the original JARI model to enhance its predictive capabilities. Car-to-pedestrian impacts were then simulated, using the JARI car model with the original and improved JARI pedestrian models and the TNO pedestrian model, in order to validate them against corridors derived from Post Mortem Human Surrogate (PMHS) tests. The models were also used to determine the differences in predicted head impact conditions and to compare the models’ outputs. The following conclusions were drawn from this work:

- The modified JARI pedestrian model was found to have slightly better shoulder biofidelity than the original JARI pedestrian model. The TNO shoulder was found to have slightly better biofidelity than either the original or modified versions of the JARI pedestrian model.
- In comparison to test data from PMHS shoulder impacts, all the models demonstrated very poor shoulder biofidelity and all simulated responses were too stiff in comparison to PMHS shoulder responses. The best predicted acromion sternum displacements were on average ten times smaller (36 mm lower) than that measured.
- The poor biofidelity of the simulated shoulder responses is attributed to the pedestrian models not simulating abnormal compressions and deformations of the shoulder during severe impacts. This would include bending and relative displacement of the bones forming the shoulder complex, compression of the shoulder joint, compression and bending of the rib cage and complex articulations, shearing and stretching in the thoracic and cervical spine.
- Simulated vehicle-pedestrian impacts were into vehicle fronts with bonnet leading edge heights ranging between 641 and 839 mm. For simulated vehicle-pedestrian impacts into the same vehicle front the difference in the predicted head impact velocities and head impact angles from the original and modified JARI models ranged between values of 0.3 – 0.9 ms\(^{-1}\) and 3.3 – 9.6° respectively. The differences in the predicted head impact velocities and head impact angles from the JARI and TNO pedestrian models for simulated vehicle-pedestrian impacts into the same vehicle front were as high as 3.9 ms\(^{-1}\) and 17.1° respectively.
- Despite consistent differences in the shoulder biofidelity of the pedestrian models, none of the models consistently predicted either the highest or lowest head impact velocities and head impact angles. Consequently it is not possible to state if improving the biofidelity of the simulated shoulder will increase or reduce predicted head impact velocities and head impact angles.
- It is not possible to say from this work if the TNO model provides a superior model to the JARI model for developing the IHRA head impact test procedure. However, significant differences were observed in the TNO and JARI pedestrian models’ kinematic behaviour for simulated impacts into a high-profiled vehicle front with a bonnet leading edge height of 839 mm. It is suggested that the predictions from both pedestrian models should be validated against measured data from PMHS impact tests into high-profiled vehicles in order to gauge which model provides the most accurate biofidelic response.

The following recommendations were made:

- Further modifications need to be made to the structure of the JARI model’s shoulder in order to improve the biofidelic response of the shoulder during severe shoulder impacts. This will improve the confidence in the model’s predicted head responses in vehicle-pedestrian simulations.
- Additional vehicle-pedestrian simulations should be completed with the TNO and JARI pedestrian models over a greater range of vehicle shapes to determine the range of differences in the predicted head impact behaviour. This will help in determining the sensitivity that exists in the predicted head impact behaviour and help to understand the important anatomical structures that contribute to this response.
- Predictions from the JARI and TNO pedestrian models should be compared against measured results from vehicle-pedestrian impacts over a greater range of vehicle-pedestrian impacts. The comparisons should concentrate on validating the dynamic behaviour of the head’s response in view of the intended use of the JARI pedestrian model for developing the IHRA sub-system head impact test procedures.
Finally, once the biofidelity of the model is considered acceptable it should be used to determine the head impact conditions so that the current provisional values in the IHRA sub-system head impact test procedure can be updated.

4 Research towards understanding the consequences of requiring pedestrian protection in cars

TRL undertook three research studies to provide an understanding of the consequences of requiring pedestrian protection in cars.

The first was an analysis of the benefits in terms of percentage reductions in the number of serious and fatally injured casualties, if cars had pedestrian protection that met the IHRA requirements.

The second study covered two areas, firstly to assess the costs and effectiveness of the Honda Civic, a car with a significant level of pedestrian protection. Secondly to assess the benefits of introducing either the EEVC or the ACEA test proposals. In this context the effectiveness of the Civic was measured in terms of the protection it offered against the level of protection required by the two test proposals.

The third study was to design a possible future accident investigation to determine the real-world benefit of cars engineered for pedestrian safety and to predict when there would be sufficient accident data involving safer cars to determine their efficacy.

4.1 The societal implications of cars that would meet the IHRA pedestrian-protection requirements

For this task, TRL expanded and up-dated the IHRA database of accident data obtained from in-depth accident studies in Japan, Europe and the USA and then calculated the percentage of fatalities and serious injuries that could be potentially saved by the IHRA procedures. TRL then produced a report of this work for inclusion as a chapter in a detailed IHRA progress report (IHRA Pedestrian Safety Working Group, 2001) and a more concise summary, which was included in the IHRA report for the ESV conference in 2001 (Mizuno and Ishikawa, 2001).

The more detailed report of the estimate made by TRL of the potential benefits in terms of casualty reductions, from vehicles that have been made to meet the pedestrian impact test requirements under development by the IHRA Pedestrian Safety Working Group, is summarised below (IHRA Pedestrian Safety Working Group, 2001).

Measures to protect pedestrians will also be of benefit to other vulnerable road users such as pedal cyclists and motorcyclists.

The Working Group is producing test methods and test tools suitable for the whole of the vehicle front likely to strike a pedestrian. Protection is therefore assumed for all impact locations in frontal impacts. As protection requirements for the vehicle and the potential savings of pedestrian injuries are very dependent on the impact velocity selected for the test methods, benefits for three speeds (30, 40 and 50 km/h) have been estimated. These are equivalent vehicle speeds, which will not necessarily be the actual sub-system test speeds.

Benefits have been estimated for fatalities and seriously injured casualties. The latter are defined here as casualties of MAIS 2 to 5 who are not fatally injured.

The IHRA accident dataset was the primary data source, but as it did not identify fatalities, this information was sought and gratefully received from the organisations that had originally contributed the data. Where necessary, national statistics from Great Britain were also used.

The estimates of the proportions of pedestrians saved are derived from a chain of estimates, starting with all the pedestrians fatally or seriously injured. A proportion of these will be injured by vehicles within the scope of the test procedures, mainly by cars. Of these, a proportion will be injured by the impact type that the test procedures are simulating, namely a frontal impact. Of these, a proportion will be injured at a speed at which the test procedures can provide protection. Of these, a proportion of casualties will be injured by the vehicle rather than by the ground.

For each speed, two methods were used to calculate the proportions injured at speeds at which the test procedures could provide protection: a) A simplified assumption that those casualties ‘prevented’ above the equivalent vehicle speed will match those ‘not prevented’ below, similar to the method of Lawrence (Lawrence et al., 1993). An assumption that the safety measures will shift the distribution of the relative proportions of fatalities, seriously injured casualties and slightly injured casualties upward in impact speed, similar to the method of Davies and Clemo (1997). They assumed that a speed of 25 km/h was ‘safe’ with current cars; the same speed is used in this current study.

Preventing some injuries to a pedestrian will not necessarily benefit the pedestrian; if they should receive a fatal injury from the ground contact then the result will be the same, however much improved is the vehicle. Fatalities were assumed to be ‘saved’ if all injuries could be potentially prevented for which the AIS severity was the maximum (MAIS) for that casualty. For seriously injured casualties it was assumed that the serious casualty could be potentially ‘saved’ if all the AIS 2 to 5 injuries were caused by car contact. However, casualties with both car contact and ground contact injuries in the AIS 2-5 range were counted as being 20 percent ‘saved’, to reflect that there was some benefit in reducing the number of serious injuries.

It is assumed in the estimates shown in Table 4.1 that fatalities ‘saved’ would still be seriously injured.

The estimates by the two methods differ markedly, particularly in their relative benefits for the two severities, demonstrating that estimates of this type are not precise. The ‘safe within the equivalent vehicle speed’ method will tend to underestimate the potential for saving lives, as most fatalities occur above the equivalent vehicle speed. Conversely, the speed-shift method tends to over-estimate the potential for saving lives, as cars are likely to be optimised to just pass at the test speed, with little in-hand to provide protection at higher speeds.
### Table 4.1 Potential reductions in pedestrian fatal and serious casualties due to cars passing IHRA test methods, as a percentage of pedestrians injured by all vehicle types

<table>
<thead>
<tr>
<th>Method</th>
<th>Fatal (%)</th>
<th>Serious (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent vehicle speed (km/h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safe within equivalent vehicle speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>40</td>
<td>14</td>
<td>27</td>
</tr>
<tr>
<td>50</td>
<td>26</td>
<td>33</td>
</tr>
<tr>
<td>Speed-shift</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>40</td>
<td>35</td>
<td>19</td>
</tr>
<tr>
<td>50</td>
<td>48</td>
<td>29</td>
</tr>
</tbody>
</table>

#### 4.2 Assessing the costs and effectiveness of the Honda Civic’s pedestrian protection and the benefits of the EEVC and ACEA test proposals

Japan has one of the highest pedestrian casualty rates of the world’s highly motorised countries. Honda is the first manufacturer to announce that they are producing production cars with significant pedestrian protection features, and the new Honda Civic, first made available in 2001, has been designed with pedestrian protection particularly in mind.

The EEVC pedestrian test methods were used by Honda to help them develop and assess the Civic. The EEVC pedestrian test methods, if used unchanged in EU test requirements, would require pedestrian protection, effective at impact speeds of up to at least 40 km/h, over the whole of the vehicle front outer surface, up to and including the base of the windscreen. In the past, car manufacturers in the form of their trade body, the European Automobile Manufacturers Association (ACEA), have argued that the costs of making and operating pedestrian friendly vehicles will be very high and that the number of casualties saved will be low, giving a very high cost to benefit ratio. However, other studies have indicated that the costs and benefits of these measures are close to balancing, with two studies showing a net benefit and one a net dis-benefit. Car manufacturers have suggested that a first stage of EU test requirements should be less demanding than the EEVC requirements and they have proposed a two-stage implementation process referred to here as the Negotiated Agreement with ACEA (Commission of the European Communities, 2001). Therefore, as the first production car acknowledged to have been designed to provide some measure of compliance with the EEVC test methods, the additional costs and protection provided by the Honda Civic are of interest in the debate on how demanding a first stage of EU test requirements should be.

The TRL study of the Honda Civic evaluated the added benefits of this design to pedestrians, and the additional cost to the vehicle manufacturers to develop and produce the vehicle along with any additional operating costs. The test programme consisted of a series of pedestrian tests using the EEVC WG17 test methods to establish the level of conformity of the Honda Civic (model year 2001) with the EEVC requirements. Tests were also carried out with a 3.5 kg headform to establish the level of conformity of the Honda Civic with the requirements of the first phase of the Negotiated Agreement with ACEA. A study of the additional costs of the Civic’s pedestrian features was carried out jointly by a major supplier of automotive components and their independent automotive consultancy. In addition, a limited programme of changes to the Civic’s design was carried out with the intention of improving its performance. The revised features were re-tested to determine if any changes (improvements) to their pedestrian protection had been achieved.

Estimates have been made in the past of the benefits to be obtained from reducing pedestrian casualties in the EU by implementing the original EEVC pedestrian protection proposals. The opportunity was taken to use the latest accident data to produce benefit estimates for the updated EEVC test methods and for the first phase of the Negotiated Agreement with ACEA. Though estimates are made in absolute terms of casualties saved and the resulting financial benefit, the primary purpose of the study was to provide a comparison between the two proposals, in terms of the relative effectiveness of the first phase of the Negotiated Agreement. To inform this study, an approximate injury risk curve for the legform knee bending was developed.

Lawrence reported this work (Lawrence et al., 2002); the conclusions from this work were:

- Estimates have been made of the costs of providing pedestrian protection based on examination of the Honda Civic, and of the benefits that would result from implementation of proposed pedestrian protection test procedures.
- Testing has confirmed that the Civic has been provided with a significant measure of pedestrian protection. This has been achieved without apparent sacrifice of occupant protection, fuel economy, insurance rating and accident repair costs.
- Tests to the Honda Civic show that overall it achieves about 80 percent of the pedestrian protection recommended by EEVC WG17 and that it easily meets the protection requirements of the first phase of the Negotiated Agreement with ACEA. However, it should also be noted that a car that just fails to meet the EEVC WG17 performance criteria would provide almost 100 percent of the protection, but it would not receive approval. In the case of the Civic, although it has been illustrated that its pedestrian protection capability represents 80 percent of the risk reduction associated with the EEVC WG17 level, the degree of compliance with EEVC WG17, particularly in relation to the child headform tests, was still very low.
- The Civic gave far lower test outputs in the ACEA 3.5 kg headform test at 35 km/h, than in the EEVC 2.5 kg headform tests at 40 km/h. It can be concluded that a bonnet just meeting the ACEA 3.5 kg head requirement...
may still be dangerous for young children who have a lower effective head mass.

- Recommendations have been made to assist in specifying and certifying the ACEA 3.5 kg headform.
- The Civic’s pedestrian protection features have been identified and estimates have been made of the additional manufacturing costs of the vehicle of £6.20 to £6.58 (€10.02 to €10.63) depending on the volume of vehicles produced. These estimates were made by an independent consultancy and supplier of vehicle components and crash systems.
- It is considered that £6.20 to £6.58 (€10.02 to €10.63) is also a reasonable estimate of the average cost to make this style of car meet the first phase of the Negotiated Agreement with ACEA.
- It is considered likely that pedestrian protection may be more difficult to provide in some other styles of vehicle, and costs will depend on manufacturers’ willingness to balance the trade-off between engineering and styling requirements.
- Based on the analysis of the Civic’s pedestrian protection, and taking into account the scope for further improvement, it is estimated that the total cost for the Civic to meet the EEVC WG17 level of pedestrian protection would be around £32 (€52). This figure has been extrapolated from the cost of the current Civic using the ‘Pareto Principle’ (the 80:20 rule) that it generally takes considerably more effort to achieve the last few percent of a requirement. Although it is thought that this is an overestimate of the additional extra costs for the Civic to just meet the EEVC WG17 performance requirements, it would cover the additional effort needed to provide the normal manufacturer’s safety margin so that they can be confident that all examples of the car would pass on initial type approval and for any conformity of production tests.
- The modifications made by TRL to the Civic’s bonnet to wing edge joint gave improved results reducing the HIC from 2023 to 1216 at one site and from 1775 to 1507 at the second. Measurements of the available crush depth show that there is scope for further improvements.
- The modifications made by TRL to improve the bonnet to wing edge joint were considered to be compatible with existing manufacturing methods, to have no detrimental effect on the vehicle’s functionality and have very small additional costs.
- The modifications made by TRL to the Civic’s bumper made little improvement, however, the results provided information that might help to further improve the only part of the bumper which exceeded the EEVC WG17 criteria (by a small margin).
- Tests with and without the spoiler support bracket suggested that the legform-to-bumper test method could be improved by the addition to the legform of a lower tibia accelerometer and performance criterion to limit spoiler stiffness to a safe level.
- The IHRA pedestrian accident dataset has been used to estimate the benefits of full implementation for cars of the EEVC pedestrian test proposals and of the first phase of the proposed Negotiated Agreement with ACEA. The estimated benefits are sensitive to the method and assumptions made. The two principal methods used, the ‘uninjured up to the equivalent car speed’ and the ‘speed-shift’ methods, differed in the way that the proportions of pedestrians hit at speeds where protection could be provided were calculated. The ‘speed-shift’ method was found to predict higher savings for fatalities and lower savings for seriously injured casualties than the ‘uninjured up to the equivalent car speed’ method.
- The estimated benefits of full implementation for cars of the EEVC pedestrian test proposals, using the ‘uninjured up to the equivalent car speed’ calculation method, would be to reduce the numbers of pedestrian fatalities by 10 percent and seriously injured casualties by 20 percent. Using the alternative ‘speed-shift’ calculation method, the estimated benefits would be to reduce the numbers of pedestrian fatalities by 18 percent and seriously injured casualties by 13 percent.
- The estimated benefits of full implementation of the first phase of the proposed Negotiated Agreement with ACEA, using the ‘uninjured up to the equivalent car speed’ calculation method, would be a reduction of 3 percent of fatalities and 13 percent of seriously injured casualties. Using the alternative ‘speed-shift’ calculation method, the estimated benefits would be a reduction of 10 percent of fatalities and 7 percent of seriously injured casualties.
- It was not possible to obtain the actual number of serious pedestrian casualties in the EU to a consistent definition. Therefore an estimate was made, based on the number of fatalities in the EU and the GB fatality to serious ratio, that there were 53,000 serious pedestrian casualties annually in the EU to the GB serious definition.
- The estimated benefits of the EEVC proposal in the EU are annual reductions of about 600 fatalities and 11,000 seriously injured casualties, using the ‘uninjured up to the equivalent car speed’ calculation method. Using the alternative ‘speed-shift’ calculation method, the estimated benefits are annual reductions of about 1,100 fatalities and 7,000 seriously injured casualties. The casualty reductions estimated by the two calculation methods would result in an annual financial benefit from the EEVC proposals of about 3,200 or 3,300 million Euro respectively.
- The estimated benefits of the first phase of the proposed Negotiated Agreement with ACEA in the EU are annual reductions of about 200 fatalities and 7,000 seriously injured casualties, using the ‘uninjured up to the equivalent car speed’ calculation method. Using the alternative ‘speed-shift’ calculation method, the estimated benefits are annual reductions of about 600 fatalities and 4,000 seriously injured casualties. The casualty reductions estimated by the two calculation methods would result in an annual financial benefit from the first phase of the Negotiated Agreement with ACEA of about 1,700 or 1,800 million Euro respectively.
The estimated benefits of the EEVC proposal in the UK are annual reductions of about 90 fatalities and 1,800 seriously injured casualties, using the ‘uninjured up to the equivalent car speed’ calculation method. Using the alternative ‘speed-shift’ calculation method, the estimated benefits are annual reductions of about 160 fatalities and 1,200 seriously injured casualties. The casualty reductions estimated by the two calculation methods would, in both cases, result in an annual financial benefit from the EEVC proposals of about 320 million pounds.

The estimated benefits of the first phase of the proposed Negotiated Agreement with ACEA in the UK are annual reductions of about 30 fatalities and 1,100 seriously injured casualties, using the ‘uninjured up to the equivalent car speed’ calculation method. Using the alternative ‘speed-shift’ calculation method, the estimated benefits are annual reductions of about 90 fatalities and 650 seriously injured casualties. The casualty reductions estimated by the two calculation methods would result in an annual financial benefit from the first phase of the Negotiated Agreement with ACEA of about 170 or 180 million pounds respectively.

The relative effectiveness of the first phase of the Negotiated Agreement with ACEA compared with the EEVC proposal, using the ‘uninjured up to the equivalent car speed’ calculation method, is estimated to be 32 percent for the reduction in the numbers of fatalities and 63 percent for the reduction in the numbers of seriously injured casualties. This equates to 61 percent for killed and seriously injured casualties (KSI). Using the alternative ‘speed-shift’ calculation method, the relative effectiveness is estimated to be 55 percent for the reduction in the numbers of fatalities, and 54 percent for the reduction in the numbers of seriously injured casualties, which equates to 54 percent for KSI.

In financial terms, for fatalities and serious casualties combined, the relative effectiveness of the first phase of the Negotiated Agreement with ACEA compared with the EEVC proposal for the EU is 52 percent using the ‘uninjured up to the equivalent car speed’ calculation method. Using the alternative ‘speed-shift’ calculation method, the relative effectiveness is estimated to be 55 percent.

An injury risk curve has been derived for AIS 2+ injuries to the knee area as a result of lateral knee bending. However, this is not validated, especially for application to knee bending angles obtained with pedestrian legform impactors.

Approximate relationships have been determined between legform test impact speed and bending angle, and between legform test impact speed and tibia acceleration. At about 34 - 35 km/h the bumper area of a car that passes the requirements of the first phase of the Negotiated Agreement with ACEA is estimated to be as safe as the bumper area of a car that passes the EEVC requirements would be at 40 km/h.

4.3 A study to design possible future accident investigations to determine the real-world benefit of cars engineered for pedestrian safety

As already discussed, the Working Groups EEVC WG10 and WG17 have developed test procedures that ensure that vehicles that pass the tests will provide at least a minimum level of protection to pedestrians. The EEVC test procedures have been used as the basis for a Negotiated Agreement between the European Commission (EC) and the car manufacturers’ trade body (ACEA). As recently announced by the EC, this Negotiated Agreement will form part of the draft EC Directive, which will in time be finalised as an EC Directive. This Directive will almost certainly provide for a two-stage approach, as in the draft EC Directive. The first phase will provide a lower level of protection for pedestrians than the EEVC proposals. Later, the second phase should provide the full EEVC level of protection or something equivalent.

The main purpose of the study was to suggest the best methods of carrying out real-world accident studies in the future, in order to examine the safety provided for pedestrians by cars designed to the proposed first phase and the second phase requirements. This work was reported in detail by Hardy (2002) and is summarised below.

The whole process of providing pedestrian protection should be considered to be a cyclic process, as it has been in other areas of safety. To ‘close the loop’ there will be a need to use accident studies to examine pedestrian safety in accidents involving cars with pedestrian protection features. These studies will hopefully demonstrate the benefits thus obtained. These will be the ‘real-world’ benefits, which may differ from those estimated in advance. They will also reveal whether any aspect of the protection being provided is not performing as it should, or is creating problems elsewhere. Finally, they can help to decide priorities for extensions of the test procedures, to other areas of the vehicle, other vehicle types or higher impact speeds. Accident studies can then inform a further round of research and implementation.

A number of issues and concerns with the potential real-world effects of the pedestrian test procedures have been identified that could be investigated by future accident studies. Accident data sources that could be used in such accident studies have been identified. Recommendations have been made on how to identify the real-world benefits of providing cars with pedestrian protection, and for investigating the patterns of injuries that would still occur, by means of accident studies. Estimates have been made of the sample sizes of casualties that would be necessary for these future accident studies and the dates when these samples might be available.

Several sources of data could be used to provide worthwhile data on cars designed with pedestrian protection features. Adequate samples for these will be available at different times. Also, it is not possible in some cases to know when the sample will become adequate statistically, as this itself depends on the inherent statistical variation in the data. It is therefore proposed that an accident study should be on-going over many years, but reporting at intervals.
These various investigations would, however, share a need for data on the pedestrian protection provided by most models of car found on the road, especially those with significant pedestrian protection. As a minimum, it would be necessary to categorise car models as 'standard' (i.e. typical of current car models), or conforming to the proposed first phase or the second phase requirements. There may be benefit in estimating a safety score for each model, on a continuous scale. Given that the accident data sources may all be available from other projects, provision of the car model data may account for a large proportion of the costs involved with the proposed accident studies.

It is recommended that the effect of pedestrian safety features on cars should be investigated by using changes in the proportions of killed and seriously injured casualties (KSI) to all casualties and killed to all casualties, in the GB national accident data (Stats 19 data). It may be possible to demonstrate a statistically significant effect for KSI to all casualties as soon as the end of 2003 for cars conforming or equivalent to the first phase of the proposed test procedures. It is more likely to take until 2005 or 2006, and may take until 2007 and 2008, even if the level of benefits is as has been predicted. However, to quantify the benefit as a percentage of casualties ‘saved’ to within ±2 percent of all pedestrian casualties would take until about 2012 to obtain a large enough sample.

Hospital and Stats 19 linked data such as the SHIPS database should be used to look at the pattern of remaining injuries with safer cars. To obtain a sample of 100 casualties in the SHIPS database would take until about 2009 for cars conforming to the first phase of the test proposals, and to about 2016 for cars conforming to the second phase.

Police fatal accident files should be used to look at the pattern of fatal injuries that still occur with safer cars. To obtain a sample of 100 fatalities with available post-mortem reports in the police fatal accident files database would take until about 2012 for cars conforming to the first phase of the test proposals, and to about 2018 for cars conforming to the second phase.

On-the-spot accident data should be used to look at the pattern of remaining injuries with safer cars. OTS data are more detailed than data from other sources, allowing some issues to be examined that could not be examined with other data sources. However, at the rate of the current UK OTS project it would take many years, until about 2022, to obtain a useful sample. It is therefore recommended that data be pooled with data from similar studies in other countries.

Some car designs will meet particularly the second phase requirements by using active pedestrian protection devices such as air bags. Both on-the-spot and the police fatal accident files should be used to study how well active devices perform in the real world. It may also be possible to make use of the Special Crash Investigation project so that the OTS team could study them outside of their normal area.

The proposals presented here should be regarded as suggestions only. Researchers carrying out future studies should be free to improve on them as they see fit. In particular, they will need to ensure that proper account is taken of possible interfering factors so that their conclusions are robust.

Of the four sources of data that the proposed accident study might use, only the national accident data (Stats 19) can be taken for granted as continuing to be available into the future. It is likely that the SHIPS hospital data will continue to be available, but it may be necessary to carry out the process of linking to Stats 19 as part of the proposed accident study. Both the current Police Fatal Accident Files Project and the On-The-Spot project will soon reach the end of their current contracts. It is recommended that these both be continued, so that the data are available when required. If the Police Fatal Accident Files Project was to be discontinued it would be possible to purchase copies of police accident files instead. However, if an on-the-spot project were not available at the time it would be difficult and less efficient to set one up specifically to study pedestrian accidents.

The estimates of sample sizes and availability made in the study are based on chains of assumptions and some results may be quite sensitive to these assumptions. Implementation dates may be varied for the first phase or the second phase, or the standard of protection, for the second phase particularly, may be varied. Revised estimates can, if necessary, be obtained by TRL by updating the assumptions in a spreadsheet.

The initial rise in cumulative pedestrian casualties will be very steep, so often it would be simpler and more cost effective to wait a few extra months rather than make strenuous efforts (e.g. in gathering vehicle information) in order to acquire the required sample sizes at the earliest opportunity.

The cars awarded three Euro NCAP stars for pedestrian protection had been involved in too few accidents, as at the end of 2001, to obtain any indication of their real-world safety.

5 Conclusions

1. The research undertaken in this project has made a major contribution to the work of EEVC Working Group 17 in finalising the few provisional items in the test methods and resolving new issues identified. This further refinement of the test methods has made them even more suitable for use in regulations to require minimum standards of pedestrian protection for vehicles.

2. The European Commission has now produced a draft framework Directive to require pedestrian protection, based on the recommendations of EEVC Working Group 17. The broad technical requirements of this draft Directive have been agreed in principle with the European Parliament and this decision acknowledges the progress made in producing the test methods and tools and indicates that the main aim of this project may be close to being achieved.

3. The assessment of the TRL legform impactor showed that it complied with the EEVC specification and that it was a practical and robust test tool that gives good repeatability. The report of its development and assessment resulted in it being accepted as an approved EEVC test tool.
4 TRL’s work on the EEVC WG17 dynamic legform certification test provided data that were used to finalise the EEVC WG17 certification method and the pass/fail requirements. An alternative dynamic certification method was also developed by TRL, which has the advantage of loading the impactor in a similar way, to a car with a pedestrian friendly bumper.

5 The assessment of the TNO headform impactors showed that they complied with the EEVC specification and that they are practical and robust test tools that give good repeatability. The report of their assessment resulted in them being accepted as approved EEVC test tools.

6 Suitable test tools as well as test methods are required for safety regulations or legislation. The development of the approved TRL legform and upper legform impactors, and the TNO headform impactors has been crucial to the adoption of the EEVC test methods as a draft Directive.

7 Publishing the drawings of the legform and upper legform impactors has made these impactor designs publicly available which will help make them more acceptable for use in regulations.

8 The development of a validated biofidelic pedestrian computer model and an improved family of pedestrian-safe vehicle models enabled the EEVC WG17 upper legform test energies to be reviewed. The impact energies predicted by the improved models were broadly similar in trends and magnitude to those in the EEVC WG17 1998 test methods and have provided a more confident indication of the energy response for a pedestrian being struck by a vehicle.

9 The additional costs and protection provided by the Honda Civic (model year 2001) are of interest because it was the first production car acknowledged to have been designed to provide some measure of compliance with the EEVC pedestrian test methods.

10 The assessment of the Civic showed that it provided a significant measure of pedestrian protection without apparent sacrifice of occupant protection, fuel economy, insurance rating or accident repair costs. The assessment showed that overall it achieves about 80 percent of the pedestrian protection recommended by EEVC WG17 and that it easily meets the protection requirements of the first phase of the draft framework Directive.

11 The additional manufacturing costs for the Civic’s current pedestrian protection features are estimated to be between £6.20 and £6.58 per vehicle depending on the volume of vehicles produced. These estimated costs are also considered a reasonable estimate of the average cost to make this style of car meet the first phase of the draft Directive but it is considered likely that pedestrian protection may be more difficult to provide in some other styles of vehicles.

12 Using the ‘Pareto Principle’ (the 80:20 rule) that it generally takes considerably more effort to achieve the last few percent of a requirement, it is estimated that pedestrian protection would cost a total of around £32 if the Civic was further improved to provide the level of pedestrian protection required by EEVC WG17.

13 The estimated benefits of full implementation for cars of the EEVC pedestrian test proposals, using two different calculation methods, would be to reduce the numbers of pedestrian fatalities by 10 to 18 percent and seriously injured casualties by 13 to 20 percent. The casualty reductions for the EU, estimated by the two calculation methods, would be an annual reduction of about 600 to 1,100 fatalities and 7,000 to 11,000 seriously injured casualties and would result in an annual financial benefit for the EU of about 3,200 or 3,300 million Euro.

14 The estimated benefits of full implementation of the first phase of the draft Directive, using the same two calculation methods, would be a reduction of 3 to 10 percent of fatalities and 7 to 13 percent of seriously injured casualties. The casualty reductions for the EU, estimated by the two calculation methods, would be an annual reductions of about 200 to 600 fatalities and 4,000 to 7,000 seriously injured casualties and would result in an annual financial benefit for the EU of about 1,700 or 1,800 million Euro.

15 A study has been completed to help design a possible future accident study to determine the real reductions in pedestrian casualties resulting from cars with pedestrian protection. Sources of accident data that could be used have been identified and recommendations have been made for the data to be collected. Recommendations have been made on the identification of real-world benefits of providing cars with pedestrian protection, and for investigating the patterns of injuries that would still occur, by means of accident studies. Estimates have been made of the sample sizes of casualties that would be necessary for these future accident studies and the dates when these samples might be available.

16 The mandate of the IHRA Pedestrian Safety Working Group is to develop a series of worldwide harmonised test methods for passenger cars suitable for testing the whole area of the vehicle front likely to strike a pedestrian. If the IHRA test methods for the whole vehicle front were used in legislation to require protection then TRL estimate that the benefits would be to reduce the numbers of pedestrian fatalities by between 5 and 48 percent and the number of seriously injured casualties by between 7 and 33 percent. These ranges of benefits reflect the different accident speeds that legislators could require effective protection for and the two different methods used to calculate the benefits.

17 TRL have reviewed and modified the computer simulation model used by IHRA to determine provisional head impact conditions for their test methods. The main conclusions from this work are that the modified and original IHRA pedestrian models and an alternative model have shoulder joints that demonstrate very poor shoulder biofidelity; all were too stiff in comparison to PMHS shoulder responses.
Recommendations for further work have been made which include further modifications that need to be made to the structure of the model’s shoulder in order to improve the biofidelic response of the shoulder during severe shoulder impacts.

6 Acknowledgements

The work described in this report was carried out in the Biomechanics Group of TRL Limited. The author is grateful to Brian Hardy and Mary Legg who helped with the quality review and auditing of this report.

7 References


Abstract

Pedestrian casualties form a large proportion of road casualties in most countries. Research has shown that measures to improve car design, to mitigate pedestrian injuries in collisions, can be very effective in reducing the number of fatalities and serious injuries. Therefore, as part of their target to minimise the number and consequences of road accidents, the UK Department for Transport has supported a continuing programme of research at TRL Limited on pedestrian protection. TRL’s research has mainly been in support of its participation in the two pedestrian Working Groups of the European Enhanced Vehicle-safety Committee (EEVC). EEVC WG10 developed pedestrian test methods suitable for use in legislation and WG17 updated and finalised them.

The current project commenced in April 1999 and was completed in June 2003. The project has made a major contribution to the work of EEVC WG17. The decision of the European Commission to produce a draft framework Directive based on the recommendations of EEVC WG17 is considered to be an acknowledgement of the progress made by the Working Group and indicates that the main aim of this project may be close to being achieved. TRL’s work for this project relating to the EEVC test methods is summarised in this report along with TRL’s input to the work of the IHRA Pedestrian Working Group. The mandate of the IHRA Working Group is to develop a series of worldwide harmonised pedestrian test methods.

Related publications

TRL538 Development and drawings of the TRL pedestrian legform and upper legform impactors by G J L Lawrence. 2002 (price £200, code Y)
PR19 Cost and benefits of the EEVC pedestrian impact requirements by G J L Lawrence, B J Hardy and R W Lowne. 1993 (price £35, code H)
LR718 The trajectories of pedestrian dummies struck by cars of conventional and frontal designs by V J Jehu and L C Pearson. 1976 (price £20)
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