THE NEXT STEPS FOR PEDESTRIAN PROTECTION TEST METHODS

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ABSTRACT

In most countries pedestrians and other vulnerable road users form a significant proportion of all road user 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. Therefore EEVC Pedestrian Working Groups (WGs 7, 10 and 17) have worked since the 1980's to produce test methods and criteria. Recently the European Parliament and Council approved a Directive, which reflects the EEVC WG17 test methods (in two stages), to require new cars to provide pedestrian protection.

Most test tools and procedures can be improved, as can be seen for example by the ongoing process of developing new and improved vehicle occupant dummies and their associated test procedures. The IHRA Pedestrian Safety Working Group (with input from EEVC WG17) and others are all contributing to this process by building on, and expanding the current test methods.

This paper discusses the way forward for the next generation of pedestrian test methods. It includes discussion of the options to increase the number of vehicle types and protected areas and to protect at higher speeds. Possible improvements to the test methods and tools, such as adding an upper body mass and flexible bones to the legform impactor, refining the impact conditions, and testing with a combination of dummy and subsystem tests, are also discussed.

INTRODUCTION

Pedestrians and pedal cyclists form a significant proportion of all road user casualties in most countries. There are two complementary ways of improving this situation: by preventing or reducing the severity of the collision and by making vehicles less injurious to pedestrians in accidents; ideally both of these should be used together. The EEVC Pedestrian Working Groups WGs 7, 10 and 17 have been working since the 1980's on the second of these two measures and have produced test methods and criteria suitable for developing and testing safer vehicles. Recently the European Parliament and Council approved a Directive (with two stages), which reflects the EEVC WG17 test methods, to require new cars to provide protection for pedestrians (vulnerable road users).

Most test tools and procedures can be improved, as can be seen by the ongoing process of developing new and improved vehicle occupant dummies and their associated test procedures, for example the THOR and World SID dummies. For pedestrian protection the IHRA Pedestrian Safety Working Group (IHRA PSWG) and others are all contributing to this process by building on and expanding the current test methods.

Following completion of their primary task of developing pedestrian test methods, EEVC WG17's new mandate includes providing a contribution to the work of the IHRA PSWG. Although WG17's mandate does not include a comprehensive programme of improving and expanding their test methods they are well placed to provide some guidance on the options and best ways that this could be achieved.

This paper discusses the way forward for the next generation of pedestrian test tools and methods.

OPTIONS FOR ASSESSING OR REQUIRING PROTECTION

The pedestrian protection provided by a vehicle can be assessed by using suitable test methods and appropriate injury risk curves for the injury parameters recorded by the test tools. If these are combined with suitable protection performance criteria, then it can be used in a regulation to require minimum standards of pedestrian protection as is the case with the EU Directive. It should be noted that the tests methods developed by WG10 and later refined by WG17 were, at the request of the European Commission, developed to be suitable for use in a regulation to require manufacturers to make vehicles with pedestrian protection.

Types of Test

Physical dummies. Test methods making use of physical pedestrian dummies might initially appear to be the most obvious test tool for assessing a car's pedestrian protection. Provided that the pedestrian dummy or dummies used have appropriate properties such as joints, etc. and instrumentation then every contact likely to cause serious or fatal injuries can be assessed from bumper contact through to head impact. Stature is the most important variable for head impact location in real life. Therefore, if the test method is intended to assess the whole area of a car that could be involved in a head impact, then a family of pedestrian dummies of different statures would be required. For the head impact area, as well as having to test each vehicle with this family of dummies, a number of tests would be required with each dummy at increments across the width of the car. In addition a pedestrian's stance and direction of motion will influence the nature and severity of each stage of the accident. For example in one case the shoulder might make first contact reducing the severity of the head impact but in a second case the kinematics might be such that shoulder contact is minimal giving a more severe head impact. However, some form of worst case setting of the dummies stance might overcome the need to reproduce this range in full. Nevertheless, even if it was decided that only one stance was necessary a dummy based test method require that a suitable family of dummies be developed and it would need a very large and expensive test matrix to be carried out for each car model to assess the protection provided.

Sub-system tests. As discussed above, test methods using impacts between the physical car and a pedestrian dummy have a number of disadvantages for use in a regulatory type test. Sub-systems tests have the following advantages over testing with 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 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.

On the other hand, although sub-system tests solve many of the problems of a regulatory test based on physical dummies, they also introduce their own problems:

- They are a simplification of the real situation.
- Appropriate test conditions and test areas must be provided for each sub-system test.
- The test conditions, test areas and any associated mark-up rules, look-up graphs or tables may become inappropriate with time, if vehicle styling goes outside the range considered or anticipated by their authors.

Mathematical modelling of pedestrian (or impactors) and car. There are at least six potential or already established uses for mathematical modelling for pedestrian protection:

1. To determine generic sub-system tests' impact conditions; these can be expressed with in a test method in look-up graphs or tables.
2. Interactively within a test method to determine impact conditions appropriate for the specific vehicle under test; this should be for both the shape and stiffness of the vehicle under test (not just shape as both will influence subsequent contacts).
3. As a completely virtual vehicle and pedestrian test approval tool.
4. To serve as a vehicle design and development tool for new models for:
   a. pre-development and concept studies
   b. definition of design guidelines and styling fix points
   c. determining and refining the energy absorption performance of the vehicle body parts in the pedestrian impact area.
5. To examine the effects of measures to meet the test requirements under a wider range of accident situations to identify and rectify any inadvertent negative effects.
6. To determine whether deployable protection devices work as intended, e.g. for a pop-up bonnet system the kinematics and timings for a range of vehicle impact speeds, pedestrian statures and motion.

For point one above, this has the advantage that the experts developing the test method would be best placed to determine whether the simulation results are appropriate. It is important to reflect in the vehicle model the level of pedestrian protection likely to be found in the real vehicles that the method is intended for. For example the EEVC test methods were developed for approving vehicles with pedestrian protection and therefore the simulated car used to determine the bonnet leading edge test energies used a family of generic cars that had a pedestrian friendly bumper and bonnet leading edge. If instead the sub-system test results were intended for comparing with the real life bonnet leading edge injuries found with current cars, then the car model would need to represent a car with current levels of pedestrian protection. This is because, for example, a more violent bumper impact might reduce the severity of the bonnet leading edge impact.

Point two, above, might be achieved with a relatively simple pedestrian and car model as it will only have to produce realistic kinematics. Point 3 would require sophisticated finite element models of the pedestrian (or the pedestrian sub-system impactor) and of the car being assessed. Both the software and a protocol for these two uses would need to be included in the test method to give consistent results. Alternatively, a series of validation corridors for both the pedestrian and car model could be provided against which the performance of any proposed or improved model could be judged. Provided that these validation corridors were appropriate a score system could be used to accept or reject proposed models.

For point four both the models and the levels of validation of them would be the chosen by the manufacturer and they could balance their confidence in the simulation results with an appropriate level of physical testing of materials, components and prototype vehicles.

Point five might again be at the manufacturers' discretion to cover their 'due care' responsibilities to identify and rectify solutions that pass the test but might be dangerous in real life (unsatisfactory solutions that the test methods or test tools are insensitive to).

For point six, both the validation of the pedestrian and vehicle models and the range of impact situations (vehicle speed, pedestrian stature, etc.) simulated would have to be sufficient to satisfy the approval authorities that the system will work as intended.

Combination of test methods. Features of the three main types of test listed above can be used in combination to find a 'best' test method solution. One example is the EEVC upper legform to bonnet leading edge sub-systems test. The upper legform to bonnet leading edge 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. This is because the impact velocity and effective mass of the parts of the pedestrian (typically thigh and / or pelvis) impacted by the bonnet leading edge vary with vehicle shape. Therefore, for this test the impact conditions were derived from a combination of tests between physical pedestrian dummies and instrumented car(s) and results of mathematical simulations of pedestrian and car. These results, in the form of look-up graphs, are included in the test method and are used to select the impact conditions appropriate for the shape of the car under test. This method has the advantage that the experts developing the test make an informed judgment on the best data to use; avoiding the need to use mathematical modelling or testing with a physical pedestrian dummy interactively within the test method. A proposal to update the energy look-up-graph was recently made, based on the results of simulations using a more biofidelic pedestrian model and an improved pedestrian friendly family of car shapes (Lawrence *et al.*, 2004). The pedestrian and car models can be seen in Figure 1 and Figure 2 respectively and the updated energy look-up graph can be seen in Figure 3.

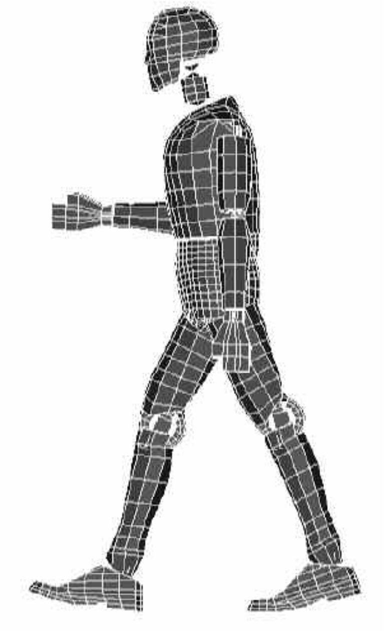


Figure 1. The finite element biofidelic pedestrian model.

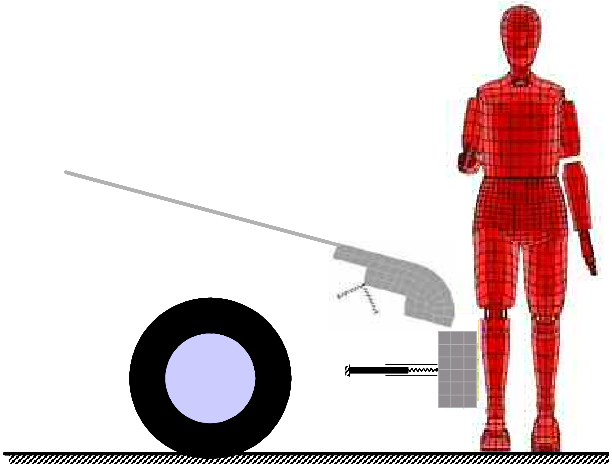


Figure 2. The adjustable-shape pedestrian friendly car and pedestrian models.

Recently the IHRA Pedestrian Safety Working Group have adopted a similar method for their head test procedure where the results of mathematical modelling of impacts between pedestrian and a range of car shapes have been used to produce look-up tables for the headform test conditions (velocity and angle) depending on the shape of the car under test.

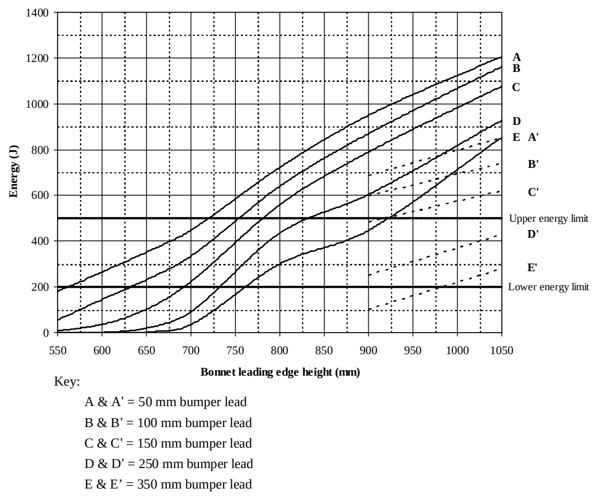


Figure 3. Upper legform impact energy curves for use with a straight edge at 40° to the vertical (proposed for use in phase two of the EU Directive).

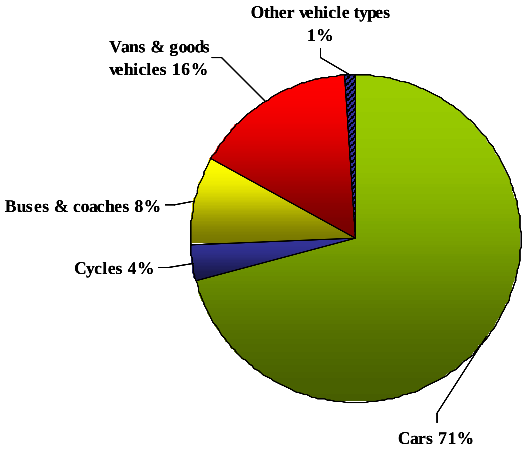
However, other combinations might be considered. One option might be to use a physical pedestrian dummy to test the bumper and bonnet leading edge and a sub-system headform test method for the bonnet top, windscreen and windscreen frame. Alternatively, a more complex sub-systems impactor might be developed to test both the bumper and bonnet leading edge in one test. This might consist of a leg or legs and a simplified hip and upper body mass. With suitable instrumentation on the leg (tibia and femur), knee and hip this might be used to assess all vehicles except those with very high bonnet leading edges. However, one advantage of a sub-systems test approach is that the impactor can be repeatably propelled into the car. Any increase in the weight, number of impactor components and number of joints would make the task of impactor propulsion increasingly difficult. Nevertheless, such a combination impactor should have the advantage of responding to the actual shape and stiffness of the vehicle under test.

Scope of Tests

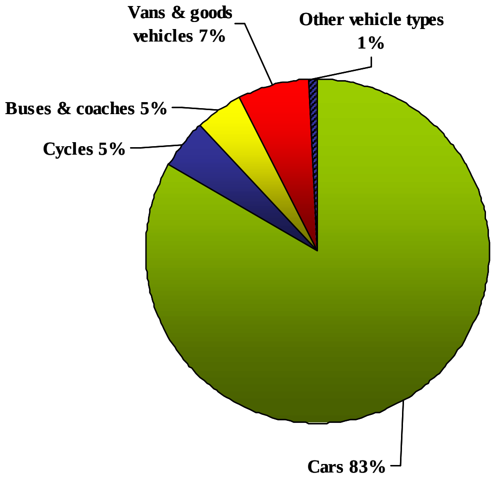
The potential for regulatory pedestrian protection measures to reduce the number of pedestrian and vulnerable road user casualties will be dependent on the proportion of accident situations (vehicle types, protected areas and speeds) where effective protection is provided. This in turn is dependent, amongst others things, on the:

- Number of vehicle types required to provide protection
- Number of accident scenarios covered
- Level of protection required
- Speed range in which the protection is effective

Obviously as the above are increased the larger the proportion of casualties that can be saved. However, to be both feasible and cost effective some limitations are likely to be required. Vehicle types most frequently involved in pedestrian accidents can be found from accident data. Figure 4 shows the distribution of pedestrian casualties in Great Britain by type of vehicle.



Fatalities



Seriously injured casualties

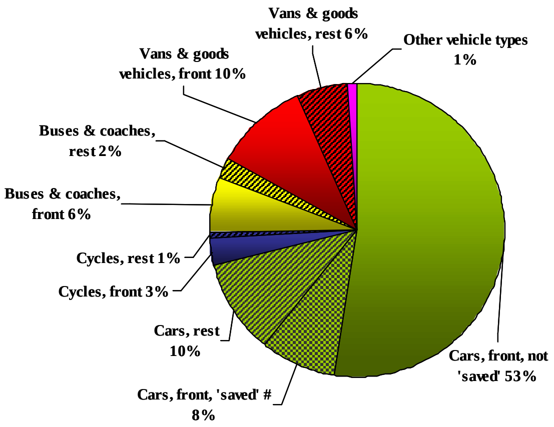
Figure 4. Proportions of vehicles involved in fatal and serious pedestrian accidents in Great Britain (1997-2001)

An analysis such as this can be used to help focus protection efforts on the vehicle types with the most potential to reduce the number of casualties; however, the number of vehicles within each sub-division of the fleet would influence the costs. For highly motorised countries the distribution shown in Figure 4 may be appropriate, but for less highly motorised countries the distribution might be very different so that the vehicles types covered by a test method should ideally be tailored to the countries for which it is intended. From the Figure 4 it can be seen from GB accident data that the car should have the first priority in terms of reducing casualties, however, including other vehicle types would further increase the potential savings. Ideally a detailed break-down of accident data for each country covered by the test methods, should be used to identify which vehicle categories it would be most effective to target.

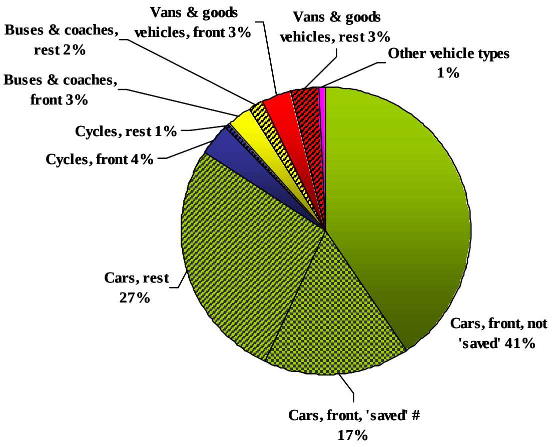
The accident scenarios covered. Test methods, tools and protection criteria can be developed for a number of accident scenarios to require protection on the vehicle including:

- restricted front - with some restrictions or exemptions based on feasibility or cost concerns. Note that the mandate for the EEVC test methods deliberately excluded the 'A' pillars due to feasibility concerns, however, new technology such as air bags may soon make protection in this area practical
- whole front – including the windscreen, dashboard top (can be hit by going through the windscreen) and the windscreen frame, including the 'A' pillars
- side-swipe, which often results in direct contact between the head and the 'A' pillar
- rear – reversing, running over, crushing against walls or pedestrian or cyclist running into the rear of the vehicle

A detailed break-down of accident data could be used to identify which vehicle types and accident scenarios it would be most effective to target for improved test methods. Fortunately the EU pedestrian protection Directive is expected to have significant benefits and these should be taken into account when trying to decide future priorities. As previously noted, ideally, the accident data used should be for the countries covered by the test methods. Nevertheless an indication of the vehicle types and accident scenarios to be targeted can be obtained from the analysis of accident data from Great Britain illustrated in Figure 5. Also included are the estimated savings that will ultimately result from the protection provided by Phase Two of the EU Directive.



Fatalities



Seriously injured casualties

#TRL estimate of the proportion of current casualties that could be prevented if all cars meet the EEVC WG17 2002 requirements

Figure 5. Proportions of vehicles involved and impact directions in fatal and serious pedestrian accidents in Great Britain (1997-2001).

Protection criteria along with appropriate test methods and tools can be applied to each test area to:

- save a specific proportion of the population taking into account the normal variation in strength found in the population. The EEVC protection criteria are intended to save about 80 percent of the population at the test speed (note that different criteria may be used in phase two of the Directive). Reducing the injury risk would increase savings but would make protection more difficult and expensive, increasing it would have the reverse effect, for example see in Figure 6 the injury risk curve used by EEVC WG17 to select their head injury protection criterion.
- save the more frail or elderly population
- save specific life threatening injuries

- save disabling injury or those that reduce quality of life
- require protection for different pedestrian body regions contacting the same area due to a combination of variation in pedestrian stature and / or vehicle size. For example: child femur to normal bumper, adult femur to high bumper and child pelvis, abdomen, chest or head to bonnet leading edge

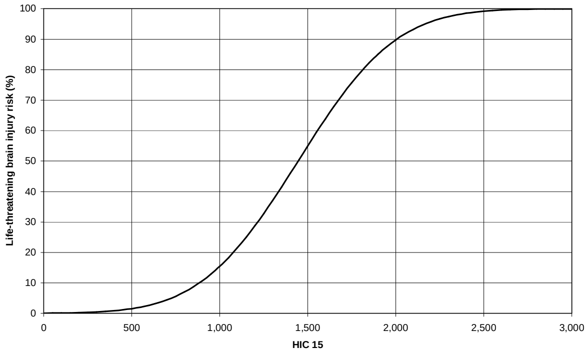


Figure 6. Example of injury risk curve for life-threatening brain injury, derived from Mertz, 1993.

Protection speed can be selected to save the desired proportion of accident casualties using data found in detailed accident studies. It should be noted that this protection or vehicle speed is not necessarily the same as the sub-system test speed, as pedestrian kinematics can cause body parts to impact at higher or lower speeds than the initial vehicle speed. The cumulative impact speed distributions found from the IHRA pedestrian accident dataset can be seen in Figure 7. The number of casualties that could potentially be saved by a selected protection speed is dependent on a number of factors including the proportion of injuries caused by the tested areas, the injury risk chosen for the protection criteria and the degree of bottoming out of vehicle deformation at speeds in excess of that used in the test. Nevertheless, it is likely that the simplified assumption that all current injuries caused by parts of the car that will be protected in future will be saved in accidents up to or slightly in excess of the protection speed will produce a reasonable estimate of the potential savings in casualties. Using this assumption the potential injury reduction can be estimated from the IHRA pedestrian accident dataset or similar accident data for cars without pedestrian protection.

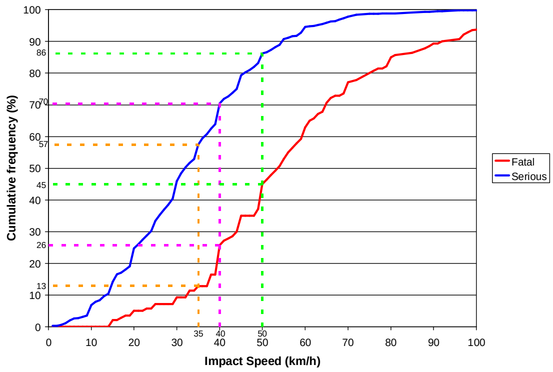


Figure 7. Cumulative impact speed distribution, from the IHRA pedestrian accident dataset, by casualty severity, with values for specific vehicle speeds

IMPROVEMENTS TO TEST METHODS AND TOOLS.

For regulatory use it is important that the test methods and tools are simple, accurate, repeatable and robust. To achieve this normally requires some simplification and compromise in reproducing the accident conditions in both the test method(s) and tool(s). Ideally when these test methods and the chosen protection criteria are applied to vehicles this simplification and compromise will result in the overall improvement in safety intended. However, if inappropriate, they will fail to provide the protection intended. A further problem for test methods is that the design, technology and styling of vehicles are constantly changing. Therefore it is important that the test methods are insensitive to such changes or that they are regularly reviewed.

Considerable effort has been expended by the EEVC experts in developing the current test methods and tools. Therefore in future it may be better to capitalise on this existing knowledge by refining and improving these test methods and tools rather than developing alternatives.

In real life each pedestrian accident is unique in some way so that there are an almost infinite number of real accident situations. Therefore for a regulatory test some simplifications and reduction in scope are necessary. To provide the best cost to benefit ratio care must be taken to make sure that these simplifications and reduction in scope are reasonable, whilst providing the best savings; this optimum compromise is referred to as a ‘reasonable worst case’ in this paper. These simplifications can take a number of forms, from limiting the protection speed, selecting protection criteria to protect all but the weakest and focusing on vehicle types and vehicle parts most frequently involved.

Sub-Systems Tests

Sub-systems tests are intended to produce a simplified representation of each phase of a pedestrian accident. Not only does this method of an individual test for each contact produce a simple and repeatable procedure, but it also has the advantage that they can be used to represent a whole range of accident situations, with a limited number of tests and tools. For example, two headform procedures can be used to test the whole bonnet top area. Provided that the test method represents an appropriate ‘reasonable worst case’ then measures to meet the test requirements will provide effective protection in a large number of real life accident scenarios, including a range of pedestrian statures, pedestrian crossing speeds and directions, vehicle speeds, directions of travel and vehicle types that would require an unfeasibly large programme of tests were the vehicle to be tested with a family of pedestrian dummies.

Improvements to sub-systems test may well come from:

- Improved understanding of accident scenario and injury mechanisms, to select more appropriate ‘reasonable worst case’ test conditions and worst case injury types, for representation in the test methods. For example for the bumper, there are a number of potential injury mechanisms depending on the pedestrian’s stature and the shape and stiffness of the vehicle. The injuries caused by the bumper are typically to the tibia and knee for the adult, and for the child they can also include the femur and pelvis. An improved understanding could confirm or adjust the current EEVC conclusion that the adult leg is more vulnerable to injury than the child leg, from the bumper, which was their rationale to simplify the test by just having an adult test tool.
- Improved understanding of the impact conditions at each main point of contact which might be found from accident data, Post Mortem Human Surrogate (PMHS) tests and computer simulations.
- Taking into account the effect of saving initial injuries on subsequent impacts. For example protection measures that save tibia fractures and knee joint injuries could influence the nature and severity of subsequent injuries such as the head impact. (As this cannot be found from analysing accidents for current cars, computer simulation would probably be the most suitable method. It was for this reason that a pedestrian friendly bumper was included in the simulated car shapes used to derive the EEVC upper legform test energies.)
- Taking advantage of areas where higher protection is considered feasible by specifying lower injury risk protection criteria to protect more of the population, and / or by protecting at a higher speed. These can revert to lower levels where protection is more difficult.
- New and improved biomechanical data for both injury risk and impactor properties (including those derived from mathematically models or from accident reconstructions for properties difficult to measure directly or where live characteristics such muscle tension, blood pressure, etc. are deemed important).
- Sensitivity analysis - to find limitations of current tools and identify what type of improvements are needed. For example, would the legform impactor be improved by the addition of an upper body mass for high bumpers and would it encourage more appropriate protection measures if it had flexible bones?
- Expanded test area and / or vehicle types and protection of more pedestrian body parts. These might include child femur and pelvis and adult and child abdomen and chest.
- Work by others – IHRA, ISO, JARI, etc.
- Feedback from the performance of new cars that meet the requirements of phase one or phase two of the EU Directive in real life pedestrian accidents to identify any remaining problem areas. The results of good and poor monitoring test results could be used for example to see if they result in different injury patterns.

Combined ‘Dummy’ and Sub-Systems Tests

One of the advantages of using a pedestrian dummy or dummies in a test method is that they can take account of both the shape and stiffness of the car under test, within their biomechanical and instrumentation limits, as the impact progresses. Therefore, they are more likely to be insensitive to changes likely to occur over time in vehicle styling, engineering and body construction. However, as discussed previously, for the head contact a dummy based test method would require an unfeasibly large programme of tests where the vehicle was tested with a family of pedestrian dummies. A further disadvantage of testing with dummies is that, unlike sub-system impactors, it is probably not feasible to propel them into the car in a realistic and repeatable fashion. Nevertheless, it is possible that some combination of dummy and sub-system testing could be devised to take advantage of the benefits of these two methods whilst avoiding their disadvantages. This might involve testing the bumper and bonnet leading edge with an adult dummy and possibly with a second smaller dummy to represent the most at risk smaller stature, combined with a child and adult headform sub-system test. A further simplification of this idea might be to use an impactor that represents a cut-down dummy, with a simple mass representing the torso of the pedestrian with instrumented pelvis and with a single instrumented leg attached. It might be feasible to propel a cut-down dummy into a stationary car, thus overcoming a further disadvantage of testing with dummies.

DISCUSSION AND RECOMMENDATIONS

Physical pedestrian dummies might initially appear to be the most obvious test tool for assessing a car's pedestrian protection. However, real life pedestrian accidents have a large number of variables which can make dummies less appropriate. In addition pedestrian dummies are likely to give poor repeatability and reproducibility because they are subjected to far more violent impact situations with larger motions than occupant dummies. Therefore they will be more sensitive to differences in the interactions of the many components that make up a complete dummy. Any inadvertent variations in setting the initial conditions, such as the dummy's stance, will as the impact progresses have an increasing influence on the impact severity and position on the car of dummy body parts.

It can be concluded that it would be very difficult to produce a suitable family of dummies to test the whole area of a vehicle that could be involved in a head impact in real life. Amongst other problems each stature would have to meet different biomechanical requirements to reproduce real life. For example, for good head impact kinematics, the correct flexibility of the torso and neck will be more important for a child hit high on the body by the front of the vehicle whereas for an adult, the legs and hips might be more important. In addition, using a family of dummies to test the whole area of a vehicle that could be involved in real life accidents would require a test programme of unacceptable size. Therefore it is reasonable to conclude that a test method to test all the areas of a vehicle likely to injure pedestrians in real life, based on physical dummies, would not be feasible. However, dummies will continue to be very useful for research and for testing the performance of deployable protection measures such as pop-up bonnets.

Dummies have the advantage that they can respond to both the shape and stiffness of the vehicle under test as the impact progresses. In this way, provided that they are sufficiently biofidelic, impacts with the bumper will correctly affect the nature of the subsequent impacts with the bonnet leading edge and following that with the bonnet top or windscreen. However, if it is required to test in a realistic way a vehicle that would cause injuries in the initial stage of the contact, then the biofidelity requirements for the dummy would have to include frangible bones and joints, etc. This is because it is very likely that injuries such as a broken tibia or femur would influence the kinematics and impact conditions of subsequent contacts. Obviously this would not be necessary if used to test vehicles with adequate pedestrian protection.

For pedestrian protection, sub-systems test methods offer many advantages over dummies. However, by their nature, the impactors are a simplification of real life and their impact conditions must be specified, unlike in a pedestrian accident where the nature and severity of the individual contacts are a function of the accident circumstances and the shape and stiffness of the car involved. Therefore great care should be taken to ensure that the simplifications and impact conditions are appropriate when developing sub-system test methods. To provide protection to the selected proportion of the pedestrian population requires appropriate protection criteria to achieve the intended injury risk and impact conditions for the selected 'reasonable worst case'. The IHRA Pedestrian Safety Group have, for example, carried out a programme of mathematical simulations to find the head impact velocity for a range of vehicle shapes. However, the IHRA study produced a wide range of results for the same nominal impact situation, because they used three different models which introduced different types of variation. If it is assumed that these variations reflect real life, then taking an average of these values would provide protection in only about 50 percent of real accidents at the intended protection accident speed. This demonstrates the need to select a 'reasonable worst case' and carry this through every aspect of developing sub-systems tests (it is for this reason that IHRA also give the standard deviation of their results).

Care should be taken when using injury trends from current cars to set priorities for reducing specific injury types, because such targeted protection could just result in transferring injuries to another part of the body. For example, early work on pedestrian bumpers, where only the stiffness and not the shape was modified, were found to save lower leg fractures at the expense of increasing knee joint injuries. Knee joint injuries are more likely to result in disablement. It is for this reason that the EEVC legform impactor and protection criteria are intended to protect against both lower leg fractures and knee joint injuries, despite the fact that injury trends for current cars would give first priority to preventing lower leg fractures.

Another disadvantage of sub-system test methods is that they do not automatically take account of the shape and stiffness of the car under test. Instead the impact conditions for each impactor have to be specified in the sub-system test method. These impact conditions can be found from the results of real or simulated pedestrian impacts using a range of car shapes. If the test methods are intended to be used to approve pedestrian safe cars, then the cars used to derive the sub-system test impact conditions must also be pedestrian friendly, as with the EEVC test methods. If this is done then the impact conditions will only become inappropriate if significant changes are made to vehicle shape, styling, engineering and body construction methods in the future.

The possibility of using a cut-down pedestrian dummy or a legform impactor combined with an upper body mass has been mentioned previously. Currently the IHRA Pedestrian Safety Working Group are carrying out research to see if and when a legform impactor needs an upper body mass for testing high bumpers. They are also producing a specification for a legform impactor with flexible leg bones. JARI has already developed a prototype flexible legform which is likely to meet or be able to be made to meet this specification. If this or a similar impactor were to be combined with a suitable upper body mass and instrumentation then it might be suitable for testing both the bumper and bonnet leading edge. Such an arrangement would have the advantage of automatically adjusting to the shape and stiffness of the car under test. However, adding a suitable upper body mass with appropriate instrumentation will be a complex task requiring further research and development effort.

Clearly the flexible ‘bones’ in the JARI legform have the potential to significantly improve the biofidelity, however, they increase the complexity of the tool and may well have negative implications for robustness or accuracy. The suitability of the JARI prototype legform for use as a regulatory tool in terms of repeatability, robustness and instrumentation accuracy has yet to be assessed.

Many of the options to improve the current sub-system test methods have been discussed; of these it is thought best to concentrate on improving the current test tools and methods to make them more biofidelic and realistic, and on developing new test methods and test tools for other parts of the vehicle or other parts of the pedestrian’s body. However, if they are intended to be ultimately used in a regulation then these improvements should not be at the expense of repeatability, accuracy of measuring injury risk and robustness of the method and test tools.

Mathematical simulation of the human and the car have a lot to offer in developing pedestrian test methods and cars to meet them. In the EEVC pedestrian test methods, mathematical simulation has been used by appropriate experts to derive impact conditions for the sub-system tests in the form of test conditions and look-up graphs. In the future, a more direct inclusion of mathematical models in regulations is thought to be valuable. In a first instance this could be to derive vehicle specific test conditions. However, WG 17 has concerns about the feasibility of specifying the necessary expertise needed for this kind of modelling within a robust procedure.

It is the view of WG17 that the current standards of simulation and data for validating the models are not yet suitable for virtual approval methods to replace physical testing.

The potential for pedestrian protection measures to reduce the number of pedestrian and vulnerable road user casualties can be improved by widening the scope or increasing the level of protection required. It can be seen from the data in Figure 5 that casualties not saved by the EU Directive, in impacts involving the front of cars, form the largest remaining group of vulnerable road user casualties in GB.

It is important that improved test methods be targeted not only at the largest group of casualties but also take into account the costs and feasibility of providing protection. It might be argued that because the EU Directive has already made the ‘easy savings’ for the car front it would be more effective to target a new vehicle type. Although there is some truth in this argument there is some scope to further improve the car front by providing protection on the windscreen frame and, for vehicles with very short bonnets, on the roof. It can also be seen from this Figure that accidents where the first contact is to the side or the rear are relatively small in number compared with those where the first contact is to the front. Because of this, including these accident scenarios should probably be given a lower priority. Nevertheless, many of the pedestrians struck first by the side of the vehicle are likely to receive serious injuries from the ‘A’ pillars or upper windscreen frame, in a frontal direction, as they fall or bend over the vehicle. Therefore frontal protection to the windscreen frame may also provide protection for many of these cases. Although it is currently thought not to be feasible to provide significant protection on the ‘A’ pillars, protection on the upper windscreen frame and adjacent glass and on the roof of short bonneted vehicles is likely to be feasible and this might provide further worthwhile savings in casualties. Protection measures for ‘A’ pillars are under development (air-bags), although reliable pedestrian pre-impact sensor trigger systems for such devices are thought to be some years away. However, the availability of a suitable method for testing ‘A’ pillars would help the development of ‘A’ pillar airbags and possibly the provision of low speed protection through ‘A’ pillars having some local deformation capability. The data in Figure 5 also suggest that it would be worthwhile to develop test methods for the fronts of buses, coaches and goods vehicles, and it is suggested that this should be the next priority.

Increasing the standard of protection required to protect a larger proportion of the population would obviously increase the potential savings. The current injury risks in the EEVC protection criteria are already low, so the benefits would be comparatively low. A typical injury risk curve is given in Figure 6, and it can be seen that it flattens out at low injury risks; therefore the protection required would have to be increased significantly with associated feasibility and cost issues. Therefore it is recommended that protection measures be kept at an injury risk of about 20 percent, because reducing them further would give little benefit at high cost. Preventing life threatening injuries is obviously the first priority when selecting protection criteria, but quality of life is also important. Therefore, priority should also be given to preventing injuries that are detrimental to quality of life, such as injuries to joints likely to result in diminished mobility, or injuries likely to result in mental impairment.

It can be seen from Figure 7 that the potential savings from pedestrian protection measures increase disproportionately with increased vehicle impact speed; therefore ideally a high test speed would appear attractive. However, the crush depth in the vehicle required to provide protection also increases disproportionately with speed. There will be practical limits on the depth of crush that it is feasible to provide in a vehicle. Although the rules of physics can be used to estimate the crush depths required to meet the protection criteria at any selected test speed, it is very difficult if not impossible to obtain consensus on what is the highest speed at which it is feasible to provide protection. This is because the judgment depends on the perceived practical limits of the materials and construction methods used to make vehicles and what costs and functional and aesthetic compromises are deemed acceptable, by vehicle manufacturers and ultimately by society. However, new technologies such as airbags and pop-up bonnets, which provide extra crush depth by deploying during or just before pedestrian impact, may increase the ‘feasible’ speed. Ultimately, the speed selected for protection measures is a choice for society or their political representatives, however, it must remain within what is practical to provide in terms of vehicle crush depth. It is recommended that the approach of the IHRA group is adopted for this, where impact conditions for a range of speeds up to 50 km/h are being provided, so that the final decision can be made by the appropriate authorities.

CONCLUSIONS

1. Testing with physical pedestrian dummies might initially appear to be the most obvious test tool for assessing a car’s pedestrian protection, but there are a number of good reasons why this would be an impractical method when the wide range of variables that occur in real life accidents are taken into account. However, dummies will continue to be very useful for research and for testing the performance of deployable protection measures such as pop-up bonnets.

2. For pedestrian protection, sub-systems test methods offer many advantages over dummies. However, great care should be taken to ensure that the simplifications in the test methods and tools are appropriate.

3. The possibility of using a cut-down pedestrian dummy or a legform impactor combined with an upper body mass for assessing the bumper and bonnet leading edge in one test or for testing vehicles with high bumpers has been discussed. It is thought that this method offers some advantages, provided that it is found to be feasible to propel such a large impactor.

4. One of the disadvantages of sub-system test methods is that the impact conditions for each impactor have to be specified in the test method. These impact conditions can be obtained from the results of real or simulated pedestrian impacts using appropriate vehicles. Therefore if the test methods are intended to be used to approve pedestrian safe cars, then the cars used to derive the sub-system test impact conditions must also be pedestrian friendly, as with the EEVC test methods.

5. It is recommended that future research be concentrated on improving the current test tools and methods to make them more biofidelic and realistic, and on developing new test methods and test tools for other parts of the vehicle and other areas of the pedestrian’s body.

6. To provide protection to the selected proportion of pedestrian accidents requires impact conditions that represent the selected range of accident scenarios or the worst case within that range as well as appropriate protection criteria.

7. Considerable effort has been expended by the EEVC experts in developing the current test methods and tools. Therefore in future it may

be better to capitalise on this existing knowledge by refining and improving these methods and tools rather than developing alternatives.

8. Care should be taken when using injury trends from current cars to set priorities for protection to reduce specific injury types, because such targeted protection could result in transferring injuries to another part of the body.

9. Mathematical simulation of the human and the car have a lot to offer in developing pedestrian test methods and cars.

10. Mathematical simulations have been used by experts to specify impact conditions for the EEVC sub-system tests. In the future, a more direct inclusion of mathematical models in regulations is thought to be valuable. However, WG 17 has concerns about the feasibility of specifying the necessary expertise needed for this kind of modelling within a robust procedure.

11. It is the view of WG17 that the current standards of simulation and data for validating the models are not yet suitable for virtual approval methods to replace physical testing.

12. There is some scope to further improve the car front by providing protection on the windscreen frame and, for vehicles with very short bonnets, on the roof.

13. The availability of a suitable method for testing ‘A’ pillars would help the development of ‘A’ pillar airbags and possibly the provision of low speed protection through ‘A’ pillars having local deformation capability.

14. It would be worthwhile to develop test methods for the fronts of buses, coaches and goods vehicles, and it is suggested that this should be the next priority.

15. The potential savings from pedestrian protection measures increase disproportionately with test speeds in excess of those currently being considered; however, the crush depth required to provide protection also increases disproportionately with speed. It is recommended that impact conditions for a range of speeds are provided in any new test methods, so that the final decision can be made by the appropriate authorities. However, the speed ultimately selected must remain within what is feasible to provide in terms of vehicle crush depth.

16. It is recommended that protection measures be kept at an injury risk of about 20 percent, because reducing them further would give little benefit at high cost. Preventing life threatening injuries is the first priority but priority should also be given to preventing injuries that are detrimental to quality of life, such as injuries likely to result in diminished mobility or mental impairment.

REFERENCES

Lawrence G J L, Hardy B J, Carroll J A, Donaldson W M S, Visvikis C and Peel D A (2004). *A study on the feasibility of measures relating to the protection of pedestrians and other vulnerable road users – Final report.* TRL Project Report available from the European Commission: http://www.europa.eu.int/comm/enterprise/automotive/pagesbackground/pedestrianprotection/pedestrian_protection_study.pdf.

Mertz H J (1993). *Anthropomorphic test devices.* In: Accidental Injury - Biomechanics and Prevention. (Eds A M Nahum and J W Melvin.) New York: Springer-Verlag. pp 66-84.