SAFETY ASSESSMENT OF THE NEW AND IMPROVED TEST METHODS FOR THE PROTECTION OF VULNERABLE ROAD USERS

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Publishable summary

The APROSYS project (Advanced PROtection SYStems) is an EC funded project on crash safety. Within APROSYS, SP3 studied pedestrian and pedal cyclist, or vulnerable road user (VRU) accidents, and within SP3, WP3.3 studied testing methods.

The current test procedures can be considered as ‘first generation’ test procedures. WP3.3 was tasked, in effect, with developing ‘second generation’ impactors and test procedures. The aim of this work was to reduce the number and severity of VRU casualties, by developing improved test procedures that could be used for future legislation and future (Euro) NCAP tests.

In this current report, a qualitative assessment of the APROSYS proposals for improved test procedures for vulnerable road users (VRU) has been carried out. In many cases the APROSYS proposals could prevent further VRU casualties beyond those prevented by current legislation. In some cases the proposals could allow the intended protection level to be achieved at lower cost.

At this time it would be difficult to carry out a full cost benefit for reasons including lack of baseline accident data, remaining gaps in the proposals and there being no studies to date on how compliance could be achieved.

Acknowledgement

Following participants contributed to this deliverable report.

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1 Introduction

The APROSYS project (Advanced PROtection SYStems) is an EC funded project on crash safety. Within APROSYS, SP3 is the Sub-Project studying pedestrian and pedal cyclist accidents. These road users are often referred to as vulnerable road users (VRU). The work of SP3 was divided into four work packages, of which WP3.3 was on Testing Methods.

The current test procedures, including both phase one (European Parliament and Council, 2003; Commission of the European Communities, 2004) and the new phase two in Europe (European Parliament and Council, 2009), can be considered as ‘first generation’ test procedures. So can the recently approved global technical regulation (GTR) (United Nations, 2009). They all use essentially the same impactors (apart from some differences in headform mass) and similar test procedures, as they are all derived from the test procedures developed by the European Enhanced Vehicle-safety Committee (EEVC) (2002). The Euro NCAP protocol (Euro NCAP, 2008) was likewise derived from the EEVC test procedures.

APROSYS SP3, and specifically WP3.3, was tasked, in effect, with developing ‘second generation’ impactors and test procedures. The improvements in knowledge and technology since the original tests were developed made it possible to develop impactors and tests that are significantly more biofidelic. Also, injury mechanisms can be simulated that were not simulated previously, and pedal cyclists can be considered as a distinct group. The aim of this work was to reduce the number and severity of VRU casualties, by developing improved test procedures that could be used for future legislation and future (Euro) NCAP tests.

The work of APROSYS SP3 WP3.3 led to several proposals for improvements to the test methods for VRU. These are described in a series of reports:

> Deliverable D3.3.3B (Compigne *et al*., 2009) adds an ‘upper body mass’ to the lower legform to allow testing of high bumpers, see Section 2.1.
>
> Deliverable D3.3.3C (Brüll *et al*., 2009) presents a method for using different test parameters for different types of vehicle and an improved headform design to allow angular accelerations to be measured, see Sections 2.4 and 2.5, and adds a new test for the rear edges of pop-up bumpers, see Section 2.7.
>
> Deliverable D3.3.3D (Meijer *et al*., 2008) presents a hybrid test procedure where the test procedures of later impact phases are derived from results of earlier phases, see Section 2.8.
>
> Deliverable D3.3.3E (Watson and Hardy, 2009) presents improvements to address the needs of pedal cyclists, see Sections 2.2 and 2.6.

These proposals were brought together in deliverable D3.3.3F (Hardy, 2009). That report describes each proposal and provides guidance on the further work that might be required to develop the method to the point where it could be used in legislative tests. In an appendix, the EEVC test procedures were modified to provide an APROSYS version of the VRU test procedures.

This current report, deliverable D3.3.3G, complements deliverable D3.3.3F by reviewing each proposal in turn to assess the likely or possible benefits of each proposal. The expected benefits would normally be in reduced VRU casualties. However, in some cases, vehicle manufacturers will benefit by being able to provide the intended level of protection for VRU at lower cost. In most cases, though, the reduction in casualties would only be achieved by increasing the manufacturers' costs.

At this stage many of the proposals need further work to finalise them. In several cases further work would be required to understand what effect they would have on casualties. This study is therefore not a formal cost benefit analysis. It would be somewhat premature to attempt to quantify the costs and benefits at this stage. Instead the potential costs and benefits are briefly discussed.

2 Assessment of new and improved test methods

2.1 Use of upper body mass to test vehicles with high bumpers

2.1.1 Details of proposal for high bumpers

The lower legform used to test most bumpers is known to be less biofidelic when high bumpers are tested, such as those found on SUVs. The lower legform's kinematics will show a behaviour which doesn't correspond to the behaviour of a leg that is attached to the rest of the pedestrian's body. The legform tends rotate underneath a high bumper whereas the pedestrian's body pulls the leg over the bumper. To avoid this problem, bumpers above a certain height are tested with a different impactor, the upper legform, which was originally developed for testing the bonnet leading edge.

It has been known for some time that an 'upper body mass' could be used to correct the kinematics of a lower legform when high bumpers are tested. Several studies have using computer modelling, but Matsui and Takabayashi (2004) made a physical upper body mass and carried out comparisons with Polar 2 dummy tests. Upper body masses of 15, 20 and 25 kg, in an additional impactor segment, led to similar legform kinematics to the Polar 2 dummy's leg. This may have been intended solely as a research tool rather than as an improved impactor for legislative use.

The work of APROSYS SP3 has shown that significant improvements can be obtained with an upper body mass of only 5 or 6 kg. Also, this can be rigidly attached to the femur (upper leg) section, rather than requiring a movable joint. This is therefore far more practical, particularly for the routine testing that would be required of a legislative test tool. Two designs have been produced, one for attachment to the EEVC lower legform, which is the current legislative lower legform, and another for attachment to a 'second generation' lower legform, the Flex-PLI, that is currently nearing the end of its development phase. These two designs are reported by Compigne *et al*. (2009) and Bovenkerk and Zander (2009), respectively.

2.1.2 Assessment of proposal for high bumpers

The upper body mass attachment would only be used for testing vehicles with high bumpers, principally SUVs. In terms of numbers of vehicle models this is a significant vehicle class. However, this class forms a relatively small proportion of the cars on the roads of Europe, accounting for about 7 percent of new car sales. Any proposals for improved legislative tests are likely to have to be agreed as globally, as an update to the UNECE GTR or a proposed UNECE Regulation. Vehicles with high bumpers form a higher proportion of the vehicle fleet in some countries than they do in Europe. The USA has a particularly high proportion of vehicles with high bumpers, including pickup trucks that are frequently used for personal transport. NHTSA in the USA is also known to be studying the use of an upper body mass.

The benefit of an improved test tool depends on how deficient in pedestrian protection vehicles are that have been approved using the upper legform to high bumper test. Crucially, this impactor cannot simulate knees injuries in the way that the lower legform can. The upper legform is only monitoring the bumper stiffness whereas the lower legform can monitor the effect on the knee of the distribution of forces. To pass the upper legform test the manufacturer simply has to ensure that the bumper provides adequate crush depth of the required stiffness. Passing a lower legform test is more of a challenge, as the angle of knee lateral bending has to be controlled. With a conventional car the spoiler is used to control the movement of the tibia, and hence keep knee bending with accepted limits. However, SUVs aren't normally fitted with a spoiler because it would reduce their 'ramp angle' and hence compromise their off-road capabilities. It seems likely therefore that without the spoiler, SUV's, etc. will not provide same protection as conventional cars. However, it is the force exerted by the bumper combined with the inertia of parts of the leg above and below the knee that 'drives' the bend to bend. If the bumper is designed to pass the upper legform test the contact force at the bumper will be significantly lower than in most SUVs type-approved before the pedestrian legislation. The knee bending angle / bending moment will therefore be less than it would have been. The risk of knee ligament injuries would therefore be reduced.

Beyond this, it would be difficult to quantify the benefits of using the lower legform, with an upper body mass, in place of the upper legform. The current legislative tests in Europe are still relatively recent and, as pre-legislation type-approvals have not yet been withdrawn for non-compliant vehicles, there are still vehicles being sold that wouldn't comply with the existing test. Also many SUVs are outside the scope of the existing legislation, which only covers cars (and car-derived goods vehicles) to 2.5 tonnes gross vehicle weight. It seems likely, therefore, that it will be many years before any detailed accident databases have enough data to allow the risk of using the upper legform test to be investigated.

As explained above, there are conflicts when designing SUVs and similar vehicles to pass a lower legform test. These may be difficult to resolve without using deployable systems. These systems could add significant cost to these vehicles. At least one system with a deployable lower bumper or spoiler has been developed, though not to a production-ready standard. This system was tested within this APROSYS project (Vetter, 2008). Such systems could therefore potentially increase the feasibility of meeting the requirements of a bumper test that used a modified lower legform.

2.2 Bumper test procedure for pedal cyclists

2.2.1 Details of proposal for bumper test

In APROSYS deliverable D3.3.3E, Watson and Hardy (2009) report on computer simulations that they carried out to compare the kinematics of pedal cycle accidents with those of pedestrian accidents. Two initial positions of the pedal cycle were considered, with the impacted side pedal and foot in the top position and the bottom position of the pedalling action.

In the top position the knee is initially bent by around 90° and they found that impact was therefore very different to an impact with a nearly straight leg. For the future, testing with a bent knee legform was recommended, however neither the EEVC legform nor the Flex-PLI that is currently being developed could easily be modified to set the knee at the correct angle. Further work would therefore be needed to develop a bent knee legform. Also, further work would be required to determine the correct test height and to develop appropriate injury risk curves.

With the foot in the lowest position the impact is much more similar to an impact into a pedestrian. The biggest difference then is that the pedal cyclist's leg is about 100 to 150 mm higher at impact than a pedestrian's leg. Additional tests with the lower legform raised up by that amount were therefore proposed.

2.2.2 Assessment of proposal for bumper test

The benefits for pedal cyclists of testing bumpers with the legform at the correct height have not been established. Specifically, if cars are designed to pass the existing legislative test, how many pedal cyclist casualties would be saved by introducing the additional pedal cyclist tests with the same acceptance criteria? Impacting the lower legform at around the knee height is likely to be the worst case. Firstly, this allows both the femur and tibia sections to rotate, with minimum restraint being provided to this rotation. This therefore maximises the knee bending angle. The same may be expected for real world accidents. Secondly, the EEVC legform has the tibia accelerometer positioned close to the knee, with conventional cars impacting at about this height. Moving the impact lower would reduce the measured acceleration. It's therefore difficult to see how the additional test for pedal cyclist impacts would lead to improved safety as it should be less onerous than the existing test. It would however, be worth testing at the increased height to check this supposition. Where the pedal cyclist test would be expected to provide increased benefits, by being more onerous, is when testing vehicles with high bumpers. If, in the pedestrian test, the bumper is impacted by the femur section, then the corresponding pedal cyclist test may have the knee impacting the bumper, increasing both the knee bending angle and the measured tibia acceleration. However, many of these vehicles are not currently tested with the lower legform. It is therefore probably sensible to consider the pedal cyclist test as providing additional benefits to that of using a lower legform with an upper body mass, as described in Section 2.1.

In most cases the pedal cyclist requirements would have little impact on vehicles costs, as similar methods and technologies would be involved. There wouldn't be many, if any, vehicles were the additional requirements for pedal cyclists caused a deployable system to be used that would otherwise not have been.

2.3 Extension of headform test to windscreen area

2.3.1 Details of proposal for headform test area

The EEVC originally set a mandate for WG10 to develop tests up to the base of the windscreen, because testing A-pillars was not considered to be feasible. However, changing car designs have since led to a greatly increased proportion of pedestrians' heads impacting the windscreen area. APROSYS SP3's proposals have therefore included extending the potential test area to the full windscreen frame and windscreen. As currently, this would be subject to a cut-off by wrap around distance (WAD). This limit is 2100 mm, and no change is currently proposed for pedestrians. However, further modelling of the 95th percentile male stature might lead to an extension being proposed to this limit. See also Section 2.6 concerning the limit for pedal cyclists.

2.3.2 Assessment of proposal for headform test area

APROSYS SP3 is not, of course, the first to make this proposal, and nor have they developed hardware to facilitate testing it. It is simply included as part of a package of proposals for the headform test.

The benefits of this proposal could be considerable, in terms of reducing VRU casualties. There are two main groups of beneficiaries. Firstly, VRU hit conventionally by the front bumper, and then rotating onto the bonnet, to hit their head beyond the current test zone, would benefit. Secondly, those VRU that are hit in 'side-swipe' accidents, where the first significant impact maybe with the A-pillar, would benefit. The latter depends, however, on any deployable systems used being capable of being triggering in this accident mode. A system using a bumper impact activated trigger would lose out on the additional benefit. Hardy (2005) estimated that a further reduction of about seven percent of all pedestrian fatal and serious casualties could be obtained assuming tests equivalent to the EEVC were used (i.e. a 40 km/h test speed and a HIC 1000 acceptance criterion). For 35 km/h and HIC 1700 (revised EU phase two and GTR equivalent, assuming the additional requirement was for the same acceptance criterion as in the lower protection zone on the bonnet), the benefits were estimated at about 2½ percent of all pedestrian fatal and serious casualties. In both cases the percentage benefits would be higher percentages if taken as proportions of those hit by cars rather than by all vehicles. The estimated benefits for the EU-25 were annual reductions in casualties of 500 fatalities and 11,000 seriously injured casualties for EEVC standard protection and 200 fatalities and 4000 seriously injured casualties for a revised EU phase two, lower protection zone standard.

2.4 Use of vehicles classes when obtaining headform test parameters

2.4.1 Details of proposal for using vehicle classes

Current legislative and Euro NCAP test procedures use the same headform test parameters (impact angle and velocity) irrespective of vehicle shape. The test procedures are intended to provide protection at 40 km/h vehicle impact speed. BASt (Glaeser, 1991) developed the original EEVC test procedure and specified a 40 km/h test speed. The IHRA Pedestrian Safety Working Group used computer modelling to attempt to obtain test parameters that depended on the vehicle class. This was not resolved before the group closed, as there were issues with the consistency and reliability of the model used. However, the Japanese pedestrian headform test uses 32 km/h for all vehicle classes, based on their analysis of the IHRA data (for a 40 km/h vehicle speed).

APROSYS SP3 (Carter, 2006) are proposing using more vehicle classes than IHRA. The work of Brüll *et al*. (2009) supports the view that the impact speeds and impact angles of real world head impacts vary by vehicle shape. They therefore propose using vehicle class to determine the headform impact speed and angle.

2.4.2 Assessment of proposal for using vehicle classes

Whether the proposals of Brüll *et al*. (2009) for test parameters based on vehicle class are seen as improving VRU safety or not depends on how the specific proposals compare with the existing requirements. The current proposals are not complete in this respect, even for the adult test, as developing the improved headform (Section 2.5) was their priority. There are no proposals for the child test, as yet. Also, if the principle of different test parameters for different vehicle classes is accepted, there could be further reviews and checks using alternative models, to check the robustness of the parameters proposed. This should include checking how well the proposed parameters match those that would be obtained for the extremes of each vehicle class.

Of the three vehicle classes for which test parameters have been provided to date, the class with the largest influence is likely to be family cars. For the adult headform test 10 m/s at 64° is proposed compared with 11.1 m/s at 65° for the EEVC test and 9.7 m/s at 65° for the revised EU phase two and the GTR. This therefore increases the test speed by about 3 percent and the test energy by 6 percent, compared with the legislative tests. This will therefore increase the number of casualties prevented.

However, for the roadster class 8 m/s at 56° is proposed, and for the SUV class 5 m/s at 87°, which for both would represent significant reductions in the impact severity. Assuming these proposed parameters are correct, reducing the test speeds would lead to a significant reduction in the protection provided at vehicle speeds higher than 40 km/h. However, this is a somewhat complicated issue as the impact location also varies with impact speed. Impacts at vehicle speeds well above 40 km/h may not be survivable anyway due to injuries to other vulnerable body regions, such as the thorax or abdomen. In the case of the SUV class it is possible or even likely that the current test speed could be reduced significantly from the current 9.7 m/s without a significant increase in head injuries, provided it wasn't reduced all the way to 5 m/s.

The pedestrian test procedures have concentrated on some specific phases of the pedestrian impact where injury frequency and / or severity justify making them a priority. However, other injuries occur, such as thorax and abdomen injuries, and these can also be life-threatening injuries. The headform impact test is designed to provide protection to pedestrians' heads, and the protection provided by a vehicle is therefore optimised for the head. Nevertheless other body regions such as the thorax should benefit from increased crush depths. If low head impacts speeds for a given vehicle class are matched by low thorax impact speeds then the thorax should be reasonably protected. However, if the kinematics of the impact are such that the head is hitting the bonnet at low speeds while the thorax still impacts at more typical speeds then an increase in the proportion of life-threatening thorax injuries might result from a decrease in the headform impact velocity. This possibility should be considered before the headform impact velocity is reduced.

On the cost side, reducing headform impact speeds for some vehicle classes would allow the manufacturers to reduce the cost of complying with the pedestrian requirements. In some cases this might lead to significant savings. Maintaining a low bonnet may be a design target in the roadster class particularly, which could mean that a pop-up bonnet is used. A reduced test speed might allow a cheaper, wholly-passive (non-deploying) solution.

One significant advantage of the proposal is that it rewards good vehicle designs that reduce head impact speeds. This can create a 'win-win' situation where the pedestrian gains greater protection and the manufacturer reduces their costs.

2.5 Measuring and using headform angular accelerations

2.5.1 Details of proposal for using headform angular accelerations

There are two parts to this that have been combined here, within the series of proposals made for the main pedestrian headform test. Firstly, Bovenkerk *et al*. (2008b) found that rotation of the head had a large influence on injury severity, so it was decided to develop a headform capable of correctly measuring angular accelerations. As well as rotational sensors, this required the use of an additional mass to mimic the influence of the neck and body, so that the measured angular accelerations were representative of those of a pedestrian impact. Secondly, a FE head model was developed by ULP and evaluated within APROSYS SP5 (Deck *et al*., 2007). This effectively acts as a calculation algorithm, as the linear and angular headform accelerations are used as inputs, and it provides outputs relating to skull fracture, subdural or subarachnoid haematoma (SDH), and diffuse axonal injury (DAI). In a legislative test these outputs would be compared with defined acceptance criteria. Of these, DAI at the moderate level was predicted better using the FE model than by HIC.

2.5.2 Assessment of proposal for using headform angular accelerations

The proposed use of angular accelerations and the FE head model offers potential for reducing lower-severity head injuries. The current legislative test procedures use HIC, with the criterion being HIC 1000 in the main area, though it's higher in a 'lower protection zone'. While HIC can be related to the risks of head injuries of various severities, it is most credible when used to determine the risk of life-threatening (i.e. AIS 4+) brain injuries. The current tests are therefore not fully addressing lower severity head injuries. This is inconsistent, given that the bumper test is designed to address AIS 2 injuries such as simple tibia fractures. Nevertheless, HIC 1000 represents a reasonably low risk of AIS 4+ injuries. Moreover, in order to achieve less than HIC 1000 in a legislative test the vehicle manufacturers will typically design for about 80 percent of that, or HIC 800. This is probably providing significant reductions in AIS 2-3 injuries for vehicles that pass the current test, but this reduction is difficult to quantify. At some point accident studies should be able to quantify the benefits of the current test procedures in reducing head injuries of various severities, but currently there will be too few VRU accidents involving such vehicles to make such estimates practicable. Since the proposed APROSYS test procedure can only provide additional benefits if it prevents injuries that will still occur with the current test procedure, it is not currently possible to quantify the potential benefits of an improved test.

To achieve significant proportion of these potential improvements would require appropriate countermeasures on the car. At this stage of research it isn't known what the manufacturers would need to do to achieve the proposed criteria. However, for a VRU head to bonnet impact their options would be quite limited. For a vehicle occupant, rotations might be controlled by controlling the distribution of forces onto the occupant. The same is the case with the pedestrian lower legform impactor. For the headform to bonnet impact, however, the best option would probably be to soften the bonnet to reduce both linear and angular accelerations. This would, of course, mean that greater crush depth would be required, which would have significant design implications, and cost implications. Also, there are limits to how soft a bonnet can be made without other requirements being compromised. Changing the bonnet or windscreen angle might at best have a small effect on angular accelerations, given that only relatively small changes in angle might be allowed within a given design concept. Reducing vehicle-to-head friction might reduce angular accelerations, but this may not be practical. Having a test procedure that could in theory prevent many injuries may achieve little if compliance with the proposals isn't feasible, as such a procedure would be unlikely to be accepted for legislation. Also, it could possibly be argued that, for a given crush depth, greater overall benefit might be achieved by providing protection from severe injuries at high speeds than from protecting against low severity injuries with the current 40 km/h range.

One countermeasure where angular accelerations may need to be considered is the use of airbags. Though not currently used to provide pedestrian protection, they would probably be the technology of choice for proving protection from the A-pillars and the windscreen frame generally. It seems possible that an angled impact into an airbag might result in the airbag 'grabbing' the headform, to provide a high friction interaction that spins the headform rapidly.

2.6 Pedal cyclist headform test

2.6.1 Details of proposed pedal cyclist headform test

Watson and Hardy (2009) are proposing a pedal cyclist headform test, in addition to the pedal cyclist lower legform test discussed in Section 2.2. In summary, they propose that the test area should reflect pedal cyclist head impact zones and that the test impact angle should reflect pedal cyclist kinematics. In common with the pedestrian headform test proposals (Section 2.3) they are proposing that the test zone be allowed to extend onto the windscreen frame and windscreen, rather than being limited to the base of the windscreen as in the current test procedures. They propose a headform test speed of 32 km/h.

2.6.2 Assessment of proposed pedal cyclist headform test

Probably the greatest benefit would be obtained by extending the test area to accommodate the greater wrap around distances of pedal cyclists' head impacts. This would also benefit some pedestrians that would impact beyond the proposed pedestrian zone.

The cost of extending the head impact zone for pedal cyclists would vary according to where the pedestrian test zone ends. Perhaps the most common scenario would be that the test area is extended further up the windscreen, in which case larger airbags may be required to cover more of the A-pillar areas. More costly would be cases where the test area is extended onto the windscreen area, where airbags would be needed that would not have been for the pedestrian test, or cases where the header rail at the top of the windscreen is in the extended area, where an additional airbag might be required.

The proposed pedal cyclist headform impact angles give generally lower impact angles (more horizontal) than those proposed for the pedestrian tests. However, comparisons are currently hampered by gaps in the current proposals. For the same impact velocity, a normal impact is more demanding, in terms of crush depth, than an inclined impact. Ignoring the impact velocity for the moment, the pedal cyclist proposals would generally be less demanding and so wouldn't provide additional benefits. One exception might be for MPVs where a steeper bonnet could mean that the shallower angle impact is closer to a normal impact. However, the proposals for the pedestrian test for the MPV classes are not yet available.

Watson and Hardy (2009) are proposing a head impact speed of 32 km/h. However, this could be revised after further work on the remaining car classes, and on additional rider statures and bicycle geometries. The 32 km/h (8.9 m/s) impact speed would mean that the pedal cyclist impact speed is slightly less than the proposed pedestrian impact speed for the family car class, slightly more for the roadster class and significantly more for the SUV class (proposed pedestrian test speeds are 10.0, 8.0 and 5.0 m/s respectively, Brüll *et al*. (2009)). However, this comparison is complicated by differences of headform impactor and impact angle.

2.7 Bonnet rear edge test

2.7.1 Details of proposal for a bonnet rear edge test

A number of car manufacturers and first tier suppliers have developed ‘pop-up’ bonnets as a means of providing pedestrian protection in the bonnet area while minimising the normal packaging restraints on providing crush depth. These pop-up bonnets lift at the rear of the bonnet, leaving the rear bonnet edge exposed. Bovenkerk *et al*. (2008a) reported computer simulations of impacts involving pop-up bonnets. Rotational movements of the head and neck were obtained that could lead to contact with the rear edge of the bonnet. 5th percentile females, 50th percentile males and 95th percentile males could all contact the bonnet rear of most common car types. Therefore, a new test method to assess head impacts to the rear edges of pop-up bonnets, with a skull fracture based criterion, was recommended, by Brüll *et al*. (2009). This uses a new headform impactor, consisting of a headform mounted on a pendulum, with a load cell that can be used to estimate contact pressure. This pressure estimate can then be compared with proposed acceptance criteria.

2.7.2 Assessment of proposal for a bonnet rear edge test

This test is only proposed currently for vehicles with pop-up bonnets, though it would be possible to extend it to test other features, such as wiper spindles. Pop-up bonnets are only fitted to a small proportion of cars. There are known to be at least three such systems on the road, and there may be many more, but they still form a small proportion of the total. If this proportion remains low then both the potential benefits and the potential costs will remain low, in comparison with proposals affecting a wider scope of vehicles. However, given the range of statures that

Bovenkerk *et al*. (2008a) reported as potentially impacting the rear edge of the bonnet, the potential benefit per vehicle model could be significant.

Because pop-up bonnets are so new, it is unlikely that this theoretical injury mode has been proven as yet in the real world. However, with new technologies, the onus is perhaps more on those developing the technology to prove the safety of the systems than on others to prove the injury risk.

The cost of designing the pop-up bonnet to avoid this injury mode is likely to be small, particularly in relation to the relatively high cost of any pop-up system. One solution might be to fold down the rear edge of the bonnet. Another might be to fit a plastic or rubber strip over the edge.

2.8 Hybrid test procedure

2.8.1 Details of proposed hybrid test procedure

It has already been mentioned that pedestrian head impact velocities and angles vary by the shape of the vehicles involved. A proposal to vary headform test velocity and angle by testing different vehicle classes at different velocities and angles was discussed in Section 2.4; this was part of a package of proposals for the headform test.

However, the logical conclusion of this principle would be to test every car according to its individual shape. Meijer *et al*. (2008) are proposing a hybrid test procedure that does this. The key features of this would be:

- The impact test parameters for the upper legform to bonnet leading edge test and the child and adult headforms to bonnet top test are obtained from a computer model. The headform test area is also adjusted according to the simulations.
- The locations of a series of defined points on the vehicle are measured and used to set the shape of the vehicle in the computer model.
- Transducer outputs from impact tests representing earlier impact phases are used to estimate the stiffness of the test vehicle. These stiffnesses are then entered into the corresponding parts of the computer model of the car.
- A number of different pedestrian statures and stances are modelled.

2.8.2 Assessment of proposed hybrid test procedure

Most of the comments made about the vehicle class concept, in Section 2.4.2, apply here also. In some cases VRU would benefit from increased injury protection, in others the manufacturers would benefit from being able to reduce costs while still providing the required safety level.

Again, it would be useful to have reviews and checks of the computer model that would be used.

Again, one of the main advantages would be that it rewards good vehicle designs that reduce upper leg and head impact speeds. This can create a ‘win-win’ situation where the pedestrian gains greater protection and the manufacturer reduces their costs.

Once varying test parameters for different vehicle shapes is accepted, it seems more logical to make the parameters vary for every car. Using vehicle classes will either test the vehicles at the extremes of the class with the wrong parameters, or require such a fine sub-division of the classes that it becomes unmanageable.

3 Discussion

The work of APROSYS SP3 has led to a number of proposals to improve the VRU test procedures. Although these proposals are varying, some themes emerge:

- Extending test area to protect a higher proportion of impacted VRU.
- Taking account of differences between cars when setting test parameters.
- Considering the needs of pedal cyclists.

At this time it would be extremely difficult to carry out a formal cost benefit study. Some of the issues are:

- Very little accident data to date relating to vehicles that pass the current European phase one legislation. Moreover, the revised phase two, and equivalent UNECE GTR, which are effectively the baseline for the APROSYS proposals, are not yet in force.
- The improvements do not necessarily provide greater safety. In some cases the required level of protection could be provided at lower cost.
- Most of the proposals are necessarily more complex than what they would replace, making quantifying the benefits and costs difficult.
- Some of the proposals are not yet complete, making full assessment difficult.
- Little has been done to work out how the proposed requirements could be met by manufacturers, making it difficult to estimate the likely costs.

4 Conclusions

1. A qualitative assessment of the APROSYS proposals for improved test procedures for vulnerable road users (VRU) has been carried out.
2. In many cases the proposals could prevent further VRU casualties beyond those prevented by current legislation. In some cases the proposals could allow the intended protection level to be achieved at lower cost.
3. At this time it would be difficult to carry out a full cost benefit for reasons including lack of baseline accident data, remaining gaps in the proposals and there being no studies to date on how compliance could be achieved.

5 References

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