**Transport Research Laboratory**
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# CLIENT PROJECT REPORT CPR1825

## Pedestrian legform test area assessment

Final report

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# Executive Summary

While the number of pedestrian injuries and fatalities continues to decline, year on year, within the European Union, this rate of decrease is no longer equivalent with the total traffic fatalities. This report documents the activities carried out for a project supporting the European Commission during Phase 2 of the development of the new United Nations (UN) Global Technical Regulation on "Pedestrian Safety". The tasks of the project have been set deliberately to align with the objectives of the Bumper Test Area Task Force reporting to the UN Informal Group on Pedestrian Safety Phase 2. As such, they offer the evidence base from which recommendations can be made regarding the way forward for the Task Force.

The pedestrian protection bumper test procedures within UN GTR No. 9, UN Regulation 127 and Commission Regulation (EC) No. 631/2009 all use a plane at 60 degrees to the vehicle longitudinal plane to define the bumper corners for vehicles. The area tested is within the limits of the bumper corners (66 mm inside on both sides).

The three main work items completed within the project were to:

- Understand the history of the 60 degree plane definition and any implications for changing it
- Assess the pedestrian protection performance of current vehicles
- Assess the likely effectiveness and potential benefit associated with a change to the bumper test area

This 60 degree definition seems to have been prompted through discussions surrounding the efforts of EEVC WG 10 in drafting pedestrian test procedures early in the 1990s. The motivation is likely to have come from an intention to harmonise definitions with the low-speed bumper test procedure within UN Regulation 42. In earlier versions of draft test procedures, a 45 degree definition had been used for the bumper corners.

Using the 60 degree bumper corner definition, a trend for decreasing bumper test areas in newer car designs was observed through a survey of modern vehicles. Some new models of car can have a testable area which represents as little as 40 percent of the vehicle width.

An analysis of pedestrian casualty data from the UK and Germany showed that vehicle-pedestrian contacts were distributed across the width of the vehicle. Pedestrians were struck by and could receive leg injuries from all regions of the vehicle front. It was not obvious that any one region was particularly safe or injurious.

Three vehicles were selected for testing and underwent a series of tests with the EEVC legform impactor and then the Flex-PLI. This testing demonstrated that:

- Outside of the current bumper test area there are hard structures which give results indicating their potentially injurious nature
- The legform impactors rotate substantially in oblique impacts with the bumper
- If it was desired to test at wide positions of the bumper, a practical solution to reduce the rotation of the legform might be to rotate the vehicle with respect to the impactor launching direction. However, this solution may not be feasible for all test houses without substantial changes to accommodate such a setup.

Based on the test results and accident analysis the level of benefit was estimated for extending the area of the bumper tested. It was anticipated that 35 to 207 moderate injuries could be mitigated in Europe each year. This would equate to a benefit of about € 20 million.

Along with a ‘do nothing’ option, four different options have been proposed for ways of extending the test area to encompass the hard points around the end of the bumper beam. These are described in the report and the main changes to the regulations that would be required to implement them are suggested. This includes the potential accompanying solution of turning the vehicle with respect to the direction in which the legform is launched to reduce the incident angle with the bumper. This extra change is only necessary if the rotation of the legform during the impact is considered too problematic to allow longitudinal tests outside of the current test area.

## Contents

# 1 Introduction

This report documents work carried out for a project undertaken to support the European Commission during Phase 2 of the development of the new United Nations (UN) Global Technical Regulation Number 9 on "Pedestrian Safety". In particular, the tasks of the project were set deliberately to align with the objectives of the Bumper Test Area Task Force reporting to the UN Informal Group on Pedestrian Safety Phase 2. Where appropriate, the project was intended to generate the evidence base from which to make recommendations for the way forward within that Task Force.

## 1.1 Background

Throughout the world each year, thousands of pedestrians and cyclists are struck by motor vehicles. In most countries, including those of the European Union (EU), pedestrians and other vulnerable road users form a significant proportion of all road user casualties. Measures to improve car design, to mitigate pedestrian injuries in collisions, are effective in reducing injury risk measures in physical testing and are assumed to be effective in reducing the number of fatalities and serious injuries (Zander and Pastor, 2012). Therefore, the European Commission (EC) and a number of national governments supported the development of test methods and test tools suitable for requiring certain standards of pedestrian protection. It is the intention of these Contracting Parties that the Global Technical Regulation (GTR) No. 9 will contribute towards a significant reduction in the levels of injury sustained by pedestrians involved in frontal impacts with motor vehicles.

The number of pedestrians killed or injured within Europe in recent years was determined after interrogation of the CARE accident database. These data are represented graphically in Figure 1-1. From this figure it can be observed that up to 2003, the pedestrian injuries tracked the total number of traffic fatalities closely. Since 2003 the reduction in pedestrian injuries has not been as steep as the reduction in total traffic fatalities. Road safety measures continue to be effective in preventing pedestrian and total traffic fatal accidents, but are perhaps less effective in preventing the occurrence of injuries from pedestrian accidents.

Eurostat was used as the source of information for the population numbers, providing estimates for the 1st January in each year. It should be noted that where data were missing for a country in EU-19 in a particular year, a value was estimated based on the next known value from a previous year.

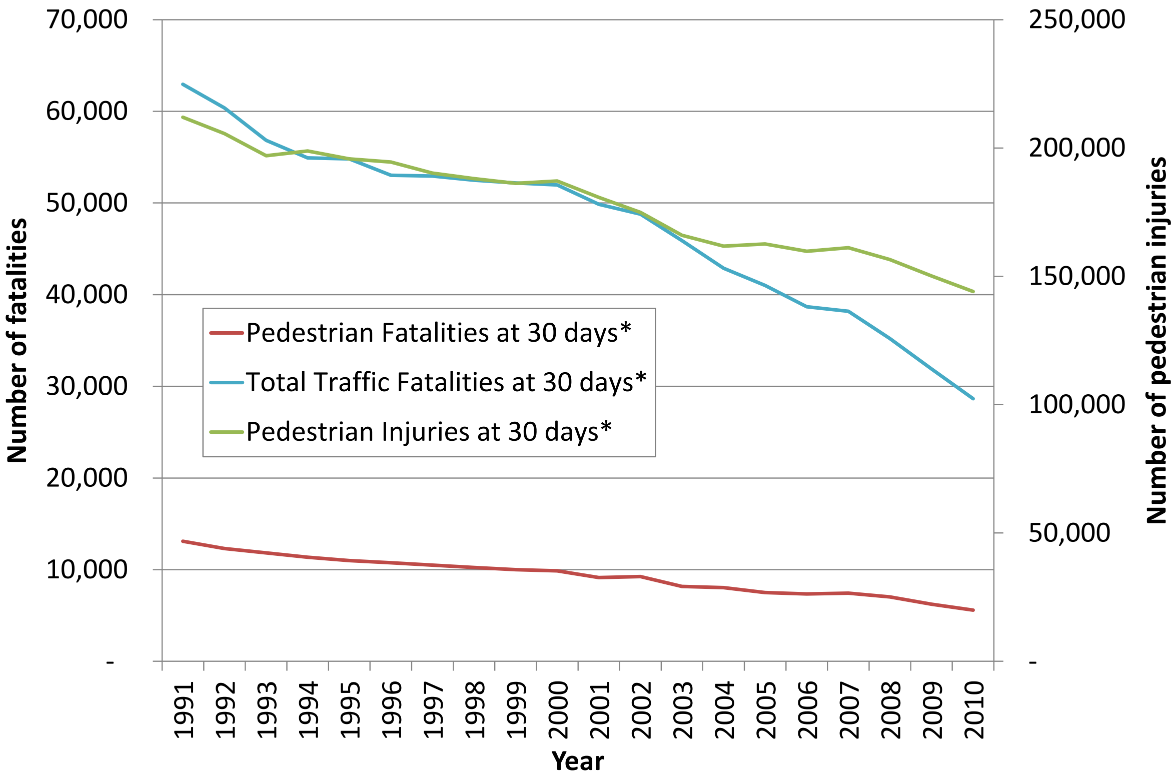


**Figure 1-1: Traffic fatalities and pedestrian injuries for twenty year period from 1991 to 2010** (*Where data are missing for a country in a particular year, its contribution to the total is estimated from the next known value)

In an effort to address the burden of pedestrian accident injuries around the world, efforts have been and continue to be made to implement and evolve legislative pedestrian protection requirements. At present there are three places where regulatory test procedures are available:

1. UN Global Technical Regulation Number 9

   Active through the Informal Group on GTR No.9 Phase 2, this is predominantly focussing on the use of the Flexible Pedestrian Legform Impactor and finalising the wording of the GTR.

2. UN Regulation Number 127
3. European Parliament and Council, Regulation EC Number 78/2009 and the implementing act Commission Regulation EC Number 631/2009

These legislative documents and test requirements are complemented by consumer information testing carried out in several regions throughout the world, for example in the Euro NCAP testing.

## 1.2 Pedestrian protection legislative testing

At present, the text for the GTR No. 9 and UN Regulation No. 127 tests for pedestrian protection of front bumper systems use the same bumper corner definition as Commission Regulation (EC) No. 631/2009 (laying down detailed rules for the implementation of Annex I to Regulation (EC) No 78/2009 of the European Parliament and of the Council on the type-approval of motor vehicles with regard to the protection of pedestrians and other vulnerable road users). However, the Terms of Reference of the Informal Group considering the pedestrian protection GTR No. 9 Phase 2 include the possibility of modifying the pedestrian test procedures, including the bumper test area. This item was included after the European Commission raised the possible trend for bumper test areas to be reducing in size with modern vehicle designs ("The informal group may also review further draft proposals to improve and / or clarify aspects of the legform test procedure.").

Annex I of the Commission Regulation specifies a series of tests, the requirements of which must be passed in order to grant the vehicle type-approval. The tests are based on three principal procedures each using different sub-system 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
- An upper legform impactor representing the adult upper leg and pelvis
- Child and adult headform impactors

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. For the legform impactor to bumper tests, a legform is propelled into the front of the vehicle at 40 km/h. The test results from the legform instrumentation are compared against performance criteria set out in the regulation to determine whether the vehicle has passed or failed to meet the test requirements. A minimum of three legform to bumper tests are required. One each is carried out to the middle and outer thirds of the bumper. The outer third test points have to be a minimum of 66 mm (the nominal radius of the EEVC legform) inside the defined corners of the bumper, so as to ensure that the full contact region is within the area defined between the bumper corners.

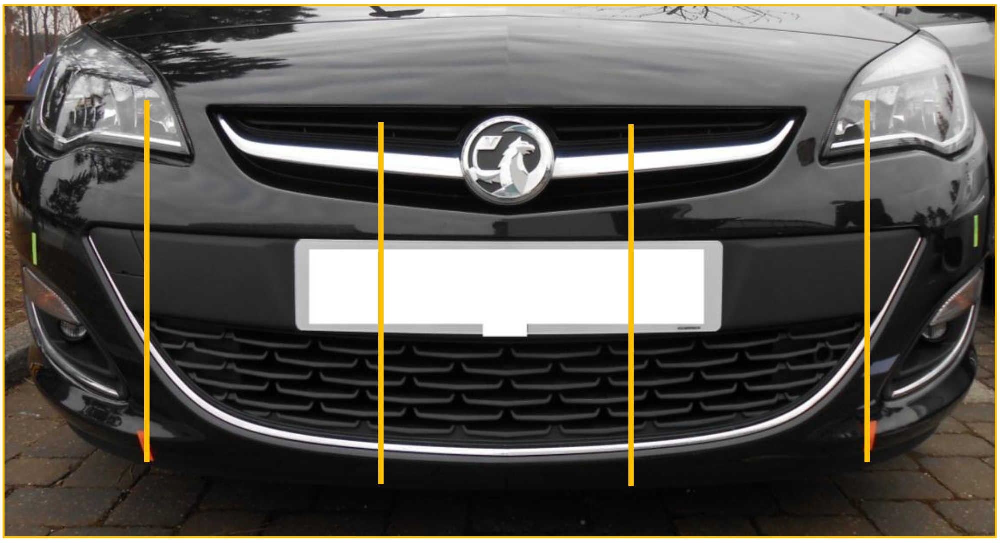


**Figure 1-2: Bumper test area divided into thirds for three tests**

The area to be assessed in the legform to bumper test is specified in Commission Regulation (EU) No. 631/2009. The corner of the bumper is determined through the following definition:

> "… the vehicle's point of contact with a vertical plane which makes an angle of 60° with the vertical longitudinal plane of the vehicle and is tangential to the outer surface of the bumper."

It has become a concern to the European Commission that pedestrian protection levels may be degraded from the original intent of the legislation if vehicle manufacturers produce vehicles where the defined corner of the bumper is a substantial distance from the side of the vehicle. In extreme cases, the area covered can be as little as 40 % of the full frontal width of a car. Assuming that pedestrians can be struck by any part of the vehicle front then there could be degradation in safety levels if the tested area is now smaller than it has been in the past.

The aim of this project is to investigate whether the 60° plane definition could be adjusted in a sensible and cost-effective way so that the bumper test area and pedestrian protection covers as much as possible of the vehicle's width.

## 1.3 Approach

The Informal Group on Pedestrian Safety Phase 2 was implemented to solve the pending issues for the incorporation of the Flex-PLI (Flexible Pedestrian Legform Impactor) in the UN GTR No. 9 and in the UN Regulation on pedestrian safety (Regulation No. 127). The Flex-PLI is the next generation legform impactor testing device which mimics the human lower leg more accurately than the EEVC WG17 (European Enhanced Vehicle-safety Committee, Working Group 17) legform, as used in current regulatory testing.

The aims of the Informal Group on Pedestrian Safety Phase 2 are to:

1. Address remaining items for introducing the Flex-PLI
2. Finalise wording of regulations
3. Submit a proposal on amending GTR No. 9 – Phase 2
4. Consider proposals to amend the UN Regulation on Pedestrian Safety (including recommendations for transitional provisions based on item 1)

The issue concerning the bumper corner definition should feed into activities 2, 3 and 4 of the Informal Group. To aid this, a new Task Force on the Bumper Test Area was set up to support the Informal Group on Pedestrian Safety.

This report documents the research undertaken supporting the European Commission during participation within the Informal Group. In particular, the tasks of the project have been set deliberately to align with the objectives of the Bumper Test Area Task Force.

The detailed work items required for completion of the project fall under the following four areas:

1. Understanding the history of the 60 degree plane and implications for change
    - Including a review of the reasons why this definition was adopted and information from other groups where alternative bumper corner definitions exist.
2. Current vehicle performance
    - With respect to the pedestrian protection in the bumper region
        i. How far the testable area extends for current vehicles
        ii. The level of protection both inside and outside of the current bumper test area.
3. Effectiveness and potential benefit
    - Considering an extension to the current bumper test area which might include areas of the bumper which would otherwise not be controlled with regard to their injurious potential in pedestrian accidents.
4. On-going validation of the Global Technical Regulation and assessment of certain specific issues identified by the Commission
    - Responding to specific issues as they arise throughout the period of the project.

The project tasks are described with respect to these specific issues in the following sections of the report.

# 2 Historical review of change to use of 60° plane to define bumper corner

Before the current project was commenced it was already known that the earliest known draft of the pedestrian test procedures (Department of Transport, 1985) used a plane at 45° to define the corner of the bumper. However, by the time of a 1991 version of the test procedures (Harris et al., 1991) this had been changed to a 60° plane, which remains the current definition method. As the current project is investigating the case for making changes to the bumper corner definition, or at least to the effective limits of the bumper test area, it is important to try to establish why the change was made, as the reasons for doing so may well still be relevant. TRL has therefore looked at some of the documents that it holds, particularly those from its past membership of European Enhanced Vehicle-safety Committee (EEVC) Working Groups. The following paragraphs describe briefly what is now known on the adoption of the 60° plane to define the bumper corners, based on that review.

## 2.1 Review of EEVC documents

From the early 1980s, the EEVC was active in pedestrian protection research. Initially, early proposals considered the use of a pedestrian dummy; however, throughout the 1980s component tests were developed through the European activities. This research considered the test methods, tools and performance criteria that would be needed for such tests. In 1987, the EEVC set up Working Group 10 (WG10) with the task to improve the proposal for an EC Directive with respect to pedestrian protection and to coordinate the necessary research. This Working Group finished its activities in 1994. Following this, the main task of EEVC WG17 Pedestrian Safety was to review the EEVC WG10 pedestrian protection test methods from 1994 and to propose possible adjustments taking into account new and existing data in the field of accident statistics, biomechanics and test results.

As mentioned above, it is known that the switch from a 45° plane to a 60° plane occurred somewhere between 1985 and 1991. TRL has reviewed documents that it holds in its archive, particularly those from our past membership of EEVC WG10. Whilst some documents have been found to be missing, TRL records of WG10 activities appear to be sufficiently complete for this purpose. The findings from this review are described in detail in Appendix A, where the information from each document is reported. The general finding with regard to the time and reason for the change is summarised briefly here.

### *2.1.1 Summary*

The review of the EEVC documents has shown how the original legform test procedure was drafted with the use of a 45° plane to define the bumper corner. This definition was changed around October 1990, switching to the 60 degree plane definition we have now. The exact reason for the change is not clear from the documents reviewed. However, it seems to be associated with a desire to be consistent with UN Regulation 42 and other bumper test procedures from North America.

Concerns about the capability of the lower legform were unlikely to be the reason for the change to a 60° plane, as the decision predated the availability of a working lower legform.

## 2.2 Other regulations and tests using a bumper definition

As was noted in Section 2.1, the justification or explanation for using the 60° plane found in the historical review of European Enhanced Vehicle-safety Committee (EEVC) documents was consistency with other regulations, particularly UN Regulation 42, 49 CFR (Code 49 of the U.S. Federal Regulations) Part 581 and CMVSS (Canada Motor Vehicle Safety Standard) 215. (Note that some of the document references within quotes in Section 2.1 are not strictly correct.) These regulations or standards involve testing to ensure the effectiveness of the bumpers in protecting the vehicle from damage in minor impacts. The following sections show the extent to which the different uses of a corner definition are consistent between the different regulatory applications.

### *2.2.1 UN Regulation 42*

UN Regulation 42 (front and rear protective devices; bumpers, etc.) is perhaps the most relevant to this review as it is part of the same framework of international regulations as the pedestrian protection regulation, Regulation No. 127. This regulation essentially requires that the bumpers provide a certain minimum level of protection to the vehicle in low-speed impacts. It defines impact tests that simulate low-speed impacts with another vehicle. After the impact tests the vehicle has to meet a series of functionality tests: working lights (bulb replacement and adjustment permitted), doors, bonnet, boot, fuel, cooling, exhaust, propulsion, suspension, steering and braking. There is a definition of the vehicle corner: "'Vehicle corner' means the vehicle's point of contact with a tangent vertical plane which makes an angle of 60° with the longitudinal median plane of the vehicle". Though the wording is a little different this is essentially the same as the definition used in the pedestrian test procedures. Two types of impact test are required: longitudinal tests at 4 km/h and corner tests at 2.5 km/h. Both use the same impactor, which is 610 mm wide (but with rounded corners) with a front face that is 114 mm high. In the longitudinal tests, the full width of the impactor has to be within the defined vehicle corners; this is somewhat similar to how the pedestrian tests are carried out with the 66 mm (EEVC legform radius) adjustment. However, in the corner tests the impact is angled at 60 ±5° and centred on the point of first contact, so the impact is nominally and presumably normally centred on the defined vehicle corners. The vehicle width that is directly impacted in the corner tests will therefore extend well beyond the defined vehicle corner, towards the side of the vehicle. So, comparing Reg. 42 with the pedestrian test procedures, while both use effectively the same corner definition, the effective test width is much wider with Reg. 42 than with the pedestrian test procedures.

### *2.2.2 49 CFR Part 581*

The USA's bumper regulation is 49 CFR Part 581, normally referred to simply as Part 581. This was formerly Federal Motor Vehicle Standard (FMVSS) No. 215. The vehicle is tested with a pendulum-type device in corner tests at 1.5 mph (2.4 km/h) and longitudinal tests at 2.5 mph (4.0 km/h) and is propelled into a fixed barrier at 2.5 mph (4.0 km/h). The protective requirements are similar to UN Reg. 42, but there are additional requirements limiting the load on the vehicle above and below the main impact face and on the degree of permitted damage. The vehicle corner is defined with the impact device rotated to an angle of 60 degrees with a vertical longitudinal plane, so it will contact and define the corner on the impact face of the test device (which is the same shape as the UN Reg. 42 test device). This means that the position of the corner may vary slightly between the two front corner tests, as one is centred at a height of

20 inches (508 mm) and the other at any height from 16 to 20 inches (406 – 508 mm). As the impact face is 4.5 inches (114 mm) high, this means that contact could occur roughly between heights of 349 and 565 mm from the ground. Therefore, any features below or above this range, such as the features seen in Figure 2-3, would be unlikely to influence the position of the vehicle corner. The vehicle shown in that figure would also certainly have the bumper corners for Part 581 further apart than the bumper corners for pedestrian protection. In summary, though there are some differences, Part 581 is quite similar to UN Reg. 42, and the same comment applies about the effective test width being much wider for Part 581 than for the pedestrian test procedures.

### 2.2.3 CMVSS 215

The Canadian bumper standard is CMVSS 215. This was amended a few years ago to replace the separate Canadian test procedure with the option of meeting either UN Reg. 42 or Part 581. However, earlier versions of CMVSS 215 are available online back to 2006. The earliest available version still contained the separate Canadian tests. This differs from the USA Part 581 principally in that the impact speeds are much higher, at 8 km/h for longitudinal tests and 4.8 km/h for corner tests. Otherwise it seems very similar to Part 581, including the way the vehicle corners are obtained using the impact face with the test device at an angle of 60°. The version of this standard that was in force at the time that EEVC WG10 switched to the 60° plane was probably very similar to the 2006 version in the way that the vehicle corners were defined.

### 2.2.4 RCAR

In addition to the above regulatory bumper tests, the Research Council for Automobile Repairs (RCAR), an organisation supporting the vehicle insurance industry, has developed a bumper test procedure (Research Council for Automobile Repairs, 2010). This includes a corner test, but this is a longitudinal test with a 15% overlap, rather than an angled test like the regulatory tests above. It does not define the bumper corner.

While the current study is concerned with how the corner definition is used in the pedestrian test procedures, and whether it should be changed, it can be noted that the vehicle corner as defined in the regulatory bumper test procedures may also have migrated nearer to the centre of the vehicle in recent years. This may not be so critical with the bumper tests, as the effective test zone extends beyond the vehicle corners. Nevertheless there may be untested bumper width at the extremities where there is potential for the protection provided to the vehicle to be compromised. It may therefore be prudent in the future to review whether the bumper regulations are still providing the desired level of performance for current vehicle designs.

### 2.2.5 Summary

UN Regulation 42 defines the vehicle corner using a plane at 60° to the longitudinal plane of the vehicle. Part 581 similarly defines the vehicle corner, instead using the impact face of the test device at 60° to the longitudinal plane of the vehicle. Making use of these definitions, two types of test are required:

- A longitudinal impact test, with the extremities of the impactor to be between the vehicle corners

- A corner impact test, with the impactor aligned at 60° to the vehicle longitudinal plane and with the impact centred on the corner.

Comparing Regulation 42 and Part 581 with GTR 9 and Regulation 127 (pedestrian safety performance), both use a plane / impact face at 60° to the vehicle longitudinal plane to define the bumper corner. However, for pedestrian safety the corner is used as the limit of the testable area: with impact centres at least a legform radius inside the corner; whereas, for Regulation 42 the corner becomes the centre for an angled impact test. Therefore, the front and rear protective devices regulation ensures performance extends significantly beyond the defined corner.

## 2.3 Review of Euro NCAP documents

Euro NCAP has already investigated alternatives to the 60° angle for use in its pedestrian testing to generate consumer information. This process resulted in Euro NCAP adopting a new method for defining the edge of the area that can be tested with a legform impactor. This task had the objective to review information offered by Euro NCAP to provide information about protection levels around the bumper corner to support later tasks in this project.

### *2.3.1 Information made available by Euro NCAP*

A presentation of historical information was given by James Ellway at the 1st session of the Task Force – Bumper Test Area. This has been reviewed along with additional material volunteered by Euro NCAP. A summary was given by TRL during the 3rd session of the Task Force and is described in more detail below.

In 2006/7 the Euro NCAP Technical Working Group (TWG) became aware of modern car design becoming increasingly "pointy/curved" at the front bumper. As a result, the defined test zones of the front bumper for pedestrian legform testing were becoming narrower relative to the actual width of the car. It was the opinion of the Euro NCAP group that this trend is in contrast with the original intention of the bumper corner definition, where the front bumper would ideally offer pedestrian impact protection across as much of the vehicle front as was reasonably practical. In certain cases where the car model has seen a substantial change in bumper design this has been accompanied by an improved Euro NCAP pedestrian rating. For example, the Vauxhall/Opel Corsa (front profile shown in Figure 2-1) improved its pedestrian safety rating from 1 star in 2002 to 3 stars in its 2006 model and the VW Polo (front profile shown in Figure 2-2) improved from 1 star (about 17%) in 2002 to 41% in 2009.

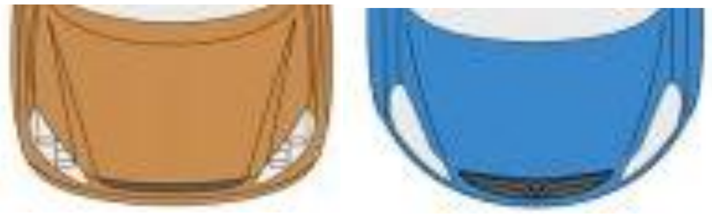


**Figure 2-1: Front Bumper profiles of Vauxhall/Opel Corsa C (2000-2006) on the left and Corsa D (2006-Present) on the right.**

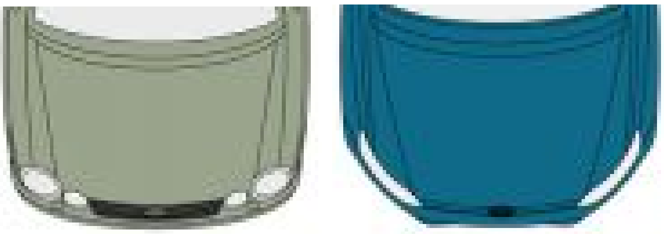


**Figure 2-2: Front bumper profiles of VW Polo Mk IV (2002-2009) on the left and Mk V (2009-Present) on the right.**

While Euro NCAP pedestrian ratings include all aspects of the pedestrian testing (including upper legform-to-bumper, headform-to-bonnet and headform-to-windscreen area testing), the legform test allows areas to be excluded that may be difficult to protect. Consequently, these untested areas may be more injurious than the rest of the vehicle's front which would not have been represented in the vehicle's Euro NCAP rating. Furthermore, there is a current trend toward front spoilers with pointed features that exaggerate this effect beyond the curved design of the front bumper (see Figure 2-3). These design changes drastically reduce the testable area of the front bumper to the width between the points of the spoiler.

**Figure 2-3: Example of a popular supermini car (Alfa Romeo MiTo) displaying additional front bumper designs that affect the definition of the bumper corners.**

In response to this, Euro NCAP began to monitor privately the cars suspected of taking advantage of the legislation at that time and began to test outside of the standard 60° plane defined test zones. Extension of the test zone was based on the identification of particularly injurious areas and components beneath the bumper skin. These tests revealed that certain vehicles were performing substantially worse in the previously un-tested areas and even within the bumper corners, e.g. inside the 66 mm margin on the corners. As mentioned briefly in the Pedestrian protection legislative testing section (Section 1.2), the 66 mm margin on the bumper corners (legform radius = 66 mm) means that the most outboard contact area should still be within the bumper corners.

In the case of the Volvo S60 and V60, when testing inside of the bumper corners but within the conventionally excluded 66 mm margin, the tibial acceleration was found to increase by a factor of 1.8 compared with the regular outer test point (L1A - 66mm inboard from the bumper corner). Testing outside of the bumper corner revealed an increase in tibial acceleration of 3.98 times that of the L1A test point and an increase in knee bending angle of 2.6 times L1A. The increased severity of this test point may be explained by its proximity to the towing-eye, which is a particularly stiff structure. This was identified during the Euro NCAP review as a potentially injurious structure that was identified for testing by all Euro NCAP laboratories since Version 6.2 of the Pedestrian Testing Protocol (December, 2012).

Similarly, testing of the Honda Insight revealed increased tibial acceleration, knee shear displacement and knee bending angle, each by a factor of 3, just outside of the normal test zone. This was linked to the presence of stiff structures under the bumper panel that were outboard of the protection offered by the bumper bar and any foam padding. Areas under the bumper panel that do not offer foam padded protection have also been highlighted for additional test points since Version 6.2 of the Pedestrian Testing Protocol (December, 2012).

During the course of this monitoring, Euro NCAP revised the legform testing protocol. Firstly by abolishing the 66 mm margin for test points at the end of the bumper corners in Version 4.3 Pedestrian Testing Protocol (February, 2009) and then to address the effect of underlying structures under the bumper panel in Version 5.0 Pedestrian Testing Protocol (October, 2009). Version 5.0 of the protocol stated that test laboratories should remove the front bumper panel to inspect for potentially injurious structures with additional tests on those points (such as towing-eyes and unpadded areas).

However, experimental difficulties arose when testing the oblique surfaces outside of the test zones. As an example, BASt performed separate tests with the Flex-PLI GTR legform and identified the asymmetry of early knee joint designs as the primary contributor to poor repeatability when testing on oblique surfaces. BASt made minor structural modifications to the legform impactor and reported that the discrepancies had been eliminated or at least reduced to an acceptable level. However, when BASt readdressed this issue they still observed unexplained z-axis rotation discrepancies when testing opposite sides of the same bumper. Furthermore, this investigation only tested oblique surfaces up to an impact angle of ±10° and not ±30° as used in the initial investigation. Ultimately BASt concluded that further experimentation was required to elucidate factors influencing repeatability when testing oblique surfaces. Therefore, to allow testing of potentially injurious points along the bumper beam without requiring oblique impacts which may cause issues with repeatability of the test tool, Euro NCAP limited the test sites to between the ends of the bumper beam.

While this often increased the available testing areas on cars with particularly narrow bumpers (e.g. 25% increase on VW Polo and 15% increase on Skoda Yeti) there are often large sections of the vehicle's front that still lie outside of the test zones. Since the implementation of this testing approach in Version 5.0 (October, 2009), it has remained unchanged and is still present in the current Version 7.1.1 (Jan 2014).

Some manufacturers have openly addressed the concerns raised by Euro NCAP's monitoring period. While Audi bumper designs across almost all of their models substantially reduce the testable area, they demonstrated that their pedestrian leg protection area extends beyond the testable area in the new A6 (Freyburger, 2012). They claim that the new A6 fulfils all legislative requirements (EC 78/2009) even outside of the test area. Two nominal points outside of the standard test area were tested on either side of the bumper and both provided acceptable legform results. However, the additional protection measures do not extend far beyond the testable zone, approximately only 66 mm beyond the bumper corner (the two nominal test sites were 29 mm beyond the corners). Further towards the outside of the vehicle it may be that the angle of the initial contact between the legform and vehicle front is sufficient to deflect the legform rather than requiring additional protective (energy absorbing) features to reduce the injury metrics. BMW have also responded to the issue by stating that their bumper designs do not considerably affect the testable zone in either the 3' series or 1' series with the bumper corners 690mm and 651mm from the vehicle midline respectively.

### *2.3.2 Other material from Task Force – Bumper Test Area meetings*

As described in the previous section, the discussions regarding the Euro NCAP change in test procedure to increase the testable bumper area were documented by Euro NCAP for consideration by the Task Force. Additionally, NASVA (National agency for Automotive Safety and Victim's Aid) / J-MLIT (Ministry of Land, Infrastructure and Transport of Japan) have also started testing outside of the 60 degree bumper corners for J-NCAP vehicle assessments. As with Euro NCAP, "… tests will be limited to locations between the two outermost ends of the bumper beam/lower rails/cross beam structures" (extract from J-NCAP Protocol provided by JASIC, 2012).

As reported to the Task Force, only the Suzuki Splash has been tested for J-NCAP outside of the 60 degree bumper corners (JASIC, 2012). The results from this vehicle showed that at the end of the bumper beam the Flex-PLI medial-collateral ligament (MCL) extension would have been close to (18.6 mm on the right and 21.0 mm on the left) the proposed injury assessment threshold of 22 mm and twice that measured in the central region of the bumper (9.3 to 10.6 mm). However, JASIC also demonstrated that the rotation of the leg about its z-axis (yaw) had reached 20 to 30 degrees by the time of maximum MCL extension in the tests towards the edges of the bumper beam.

The concern over rotation of the Flex-PLI in oblique impacts was also shared by the Pedestrians Task Force of the European Automobile Manufacturers' Association (ACEA). Based on simulations by Audi, Roth (2013) commented on "strong lateral rotation of Flex-PLI even at 25° [incident angle with the vehicle] as from 11 ms" into the event. This behaviour was compared with pedestrian impact simulations using the THUMS human body model at the same impact points. The THUMS model didn't show the same tendency towards yaw rotation of the impacted leg as the Flex-PLI model. This resistance to rotation seemed to be a function of the pelvis and upper body which constrain the top of the upper leg when the full body is present, a feature that cannot be replicated with the legform (leg-only) test tools. Roth proposed that the lateral rotation of the impactor relative to the car front artificially enables more bending and an increase in MCL elongation compared with that which would be expected for a whole pedestrian. At the 3rd meeting of the Task Force – Bumper Test Area, OICA noted that at more outboard locations, as well as increasing impactor rotation, the rebound of the legform was transformed to a sideways sliding or deflecting motion (OICA, 2013). At that meeting Renault, on behalf of ACEA (European Automobile Manufacturers' Association), confirmed the rotation of the legform impactors at impact points outside of the 60 degree plane bumper corners with both legforms impacting a third example vehicle. However, they also noted that whilst the behaviour of the legforms may not have been an appropriate replication of the kinematics in a pedestrian impact, due to the rotation, the injury criteria were acceptable. Audi also mentioned that both the Audi A3 and the Volkswagen Golf (mk VII) had been tested outside of the bumper testing zone for Euro NCAP and had achieved green results in those tests (Audi, 2013). The lower legform protection area for those vehicles had been designed to extend beyond the bumper corners as defined with a 60 degree plane. Therefore it seems that whilst it may not be biofidelic, any increase in knee bending brought on by the rotation of the legform is not of a sufficient magnitude to prevent existing protection levels from being achieved in modern vehicle construction.

# 3 Current vehicle performance

The level of pedestrian protection offered by the bumpers of the vehicles in the European fleet will be a combination of two aspects; the width of the bumper area offering particular pedestrian safety measures and the level of safety given by those measures. is The following two sections describe those two aspects for a small sample of vehicles. Despite its limitations, this information is used in the benefit calculations described in Section 4.5.

## 3.1 Review of vehicle geometry

The geometry of a variety of vehicles was considered to assess the proportion of the front of cars in the European fleet which falls outside of the current test area. The most common new models of vehicles in the UK and Europe were selected based on their sales figures. This was based on the top 10 highest selling vehicle models in each segment for 2012, according to DfT (2012) and JATO (JATO, 2012). The blueprints of these vehicles were used to view where the bumper corners are in relation to their full width using the 60° plane. In addition, the preceding versions of the vehicle models were compared to demonstrate how modern vehicle design affects the bumper corner definition and how the testable area is affected. An example of this information is shown in Figure 3-1 for a current vehicle.

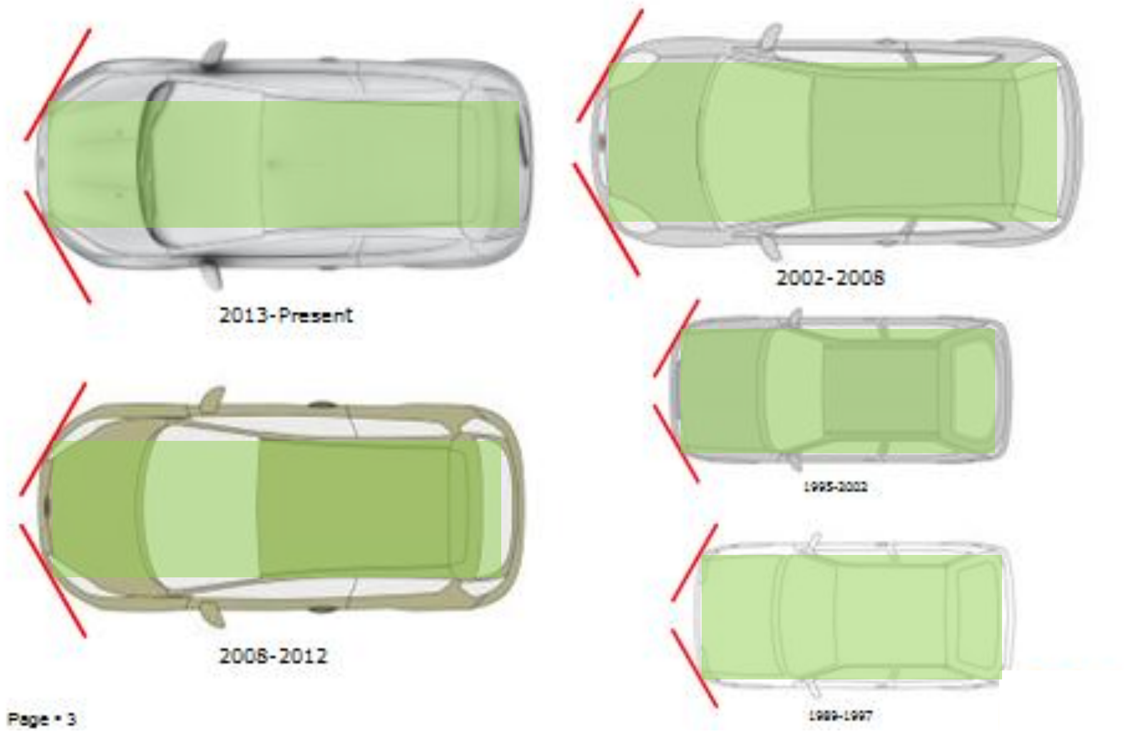


**Figure 3-1: Blueprints of a current vehicle and all of its preceding versions with the 60° plane applied to the front of the vehicles to define the bumper corners as per regulation.**

This provided a list of current vehicles that demonstrate a significant change in front bumper design in recent versions that result in a substantially reduced test area relative to the full width of the vehicle. It gave assurance that the trend for the testable areas of cars which had been observed, anecdotally, to be decreasing with time was evident and demonstrable.

From the review of vehicle shapes it was observed that older vehicle styles had more of a flat-fronted design which meant that the bumper corners were closer to the sides of the vehicle than in newer styles of vehicles. Another implication of this progression in design is that at the time of the change from a 45° to 60° plane for defining the bumper corners, that change would have had less of an effect on the tested area than now. The rounded or angular profiles of modern vehicles have increased the sensitivity of the test area to the plane used to define the corners.

To establish the extent of the problem, a collapsible frame with was manufactured at TRL to measure the length of the testable area in relation to the full width of the vehicle when using a 60° and 45° degree plane to define the bumper. The frame consisted of two steel planes that lock into a 120° or 90° position and have a milled gauge that allows the precise distance between the two contact points with the vehicle to be measured on the planes (see below).

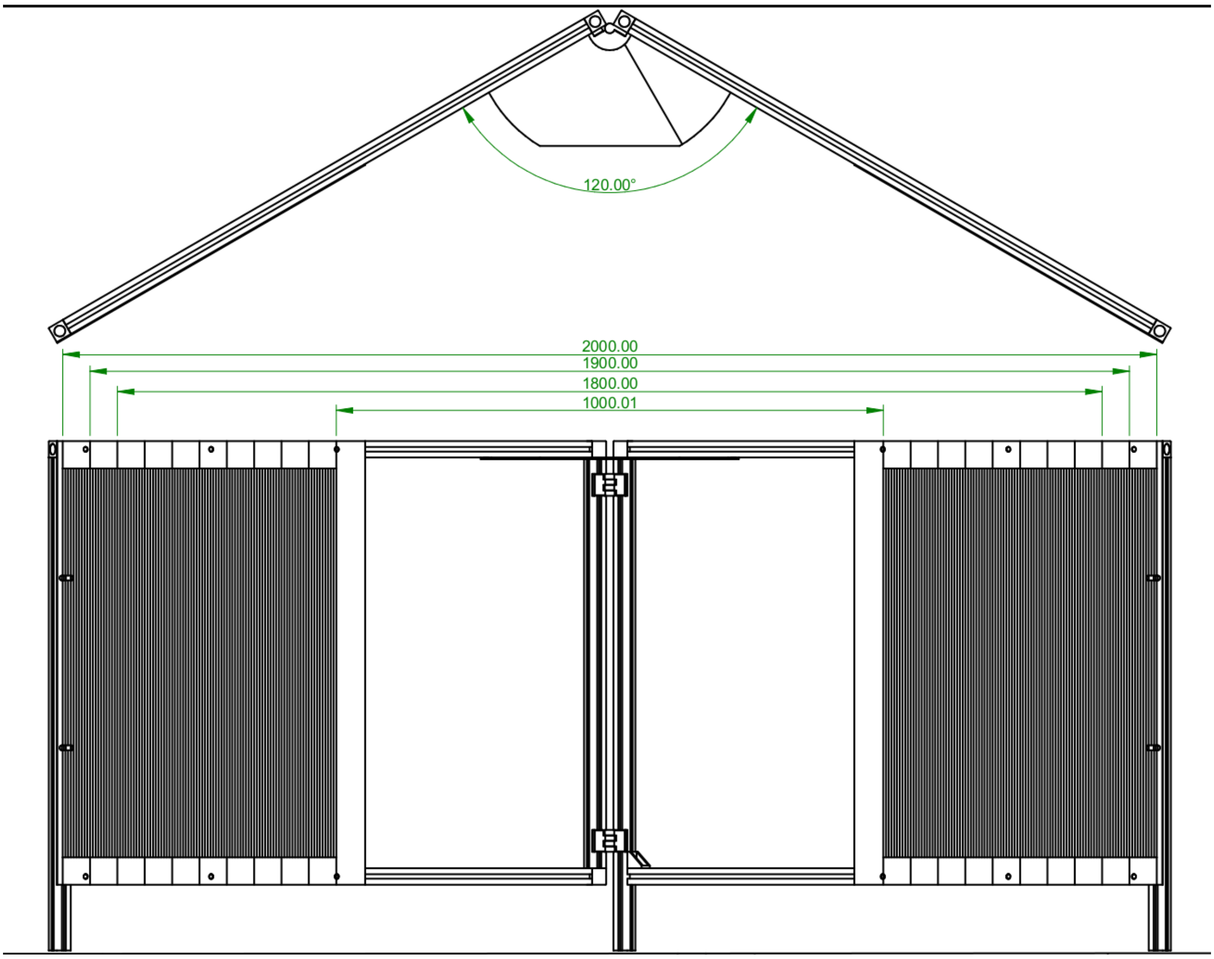


**Figure 3-2: Diagram of the collapsible frame with the milled gauge used to measure the distance between the bumper corners. The grey rectangles indicate the position of the gauge.**

The frame was set to 120° and aligned with the centre of the vehicle before being moved forwards until contact was made between the bumper corners and planes of the frame. The distance between the two contact points was then measured using the milled intervals on the gauge. The process was then repeated on the vehicle with the gauge locked at 90° and the distance between the new corners measured. These two bumper corner measurements were then compared to the full width of the vehicle to provide some understanding of how the testable area is influenced by the bumper design.

**Figure 3-3: Collapsible frame being used to measure the length of the testable area between bumper corners on a Volvo V70.**

Where possible, the same measurements were also performed on previous versions of the same vehicle models to observe how the testable area has changed over time. A broad range of car owners was then approached in order to obtain vehicle measurements for the best-selling vehicles from across Europe. Some vehicles were also available at TRL, being there for other reasons but still available for measuring.

The Alfa Romeo MiTo clearly has fangs which fix the position of the 60° plane bumper corners (Figure 3-4). The effect of these fangs is to limit the bumper test area to about 54 percent of the total vehicle width.

The initial findings of this task have shown that some new models of vehicle can have a testable area as little as 40% of the full vehicle width when defining the bumper corners with a 60° plane. The Ford Fiesta in Figure 3-5 has a testable area of 46% with corners defined by a 60° plane compared with 75% with corners from a 45° plane.

**Figure 3-4: Alfa Romeo MiTo after having been measured for this task, showing the location of the 60° bumper corners as marked with green tabs.**

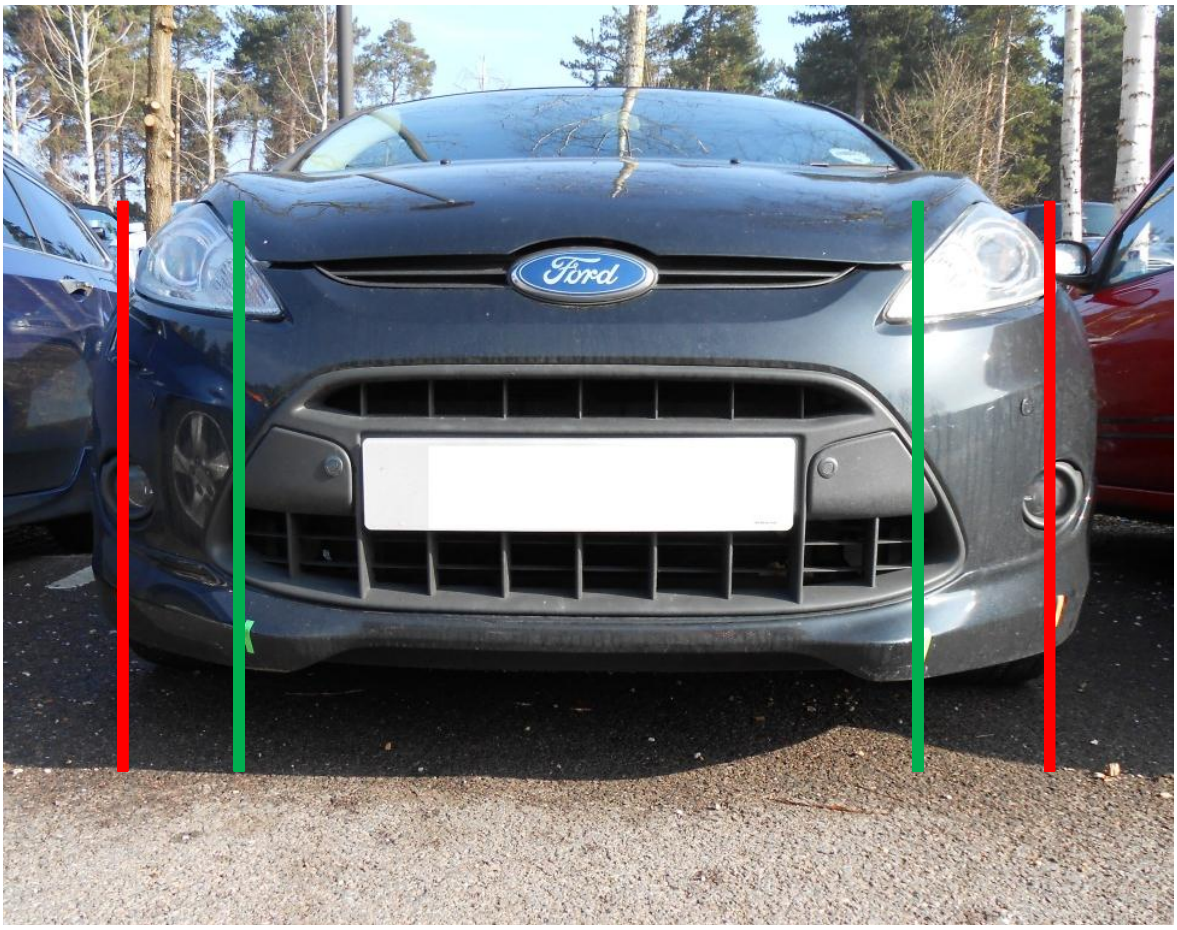


**Figure 3-5**: **Ford Fiesta with the bumper corners shown as determined with a 60˚ plane (green) and a 45˚ plane (red).**

## 3.2 Level of protection

As mentioned above, the second part of determining the current bumper performance for modern vehicles was associated with the levels of pedestrian protection available across the bumper width (both within and outside of the currently defined bumper test area). Based on the available resource in combination with the sales figures for vehicles in Europe and the UK, three vehicles were selected for testing. These three vehicles were a VW Polo, Vauxhall Corsa and Ford Focus. Their positions within the lists of top ten vehicle sellers for the UK and Europe are indicated in Table 3–1.

**Table 3–1: Vehicles selected for testing evaluation and their corresponding UK and European sales figures for 2011**

| Rank | Top UK sellers | Sales figures | Top European sellers | Sales figures |
|---|---|---|---|---|
| **1** | Ford Fiesta | 96,112 | VW Golf | 408,412 |
| **2** | Ford Focus | 81,832 | Ford Fiesta | 389,553 |
| **3** | Vauxhall Corsa | 77,751 | VW Polo | 269,000 |
| **4** | VW Golf | 63,368 | Vauxhall Corsa | 249,596 |
| **5** | Vauxhall Astra | 62,575 | Ford Focus | 226,378 |
| **6** | Vauxhall Insignia | 46,324 | Renault Clio | 225,287 |
| **7** | VW Polo | 45,992 | Vauxhall Astra | 216,802 |
| **8** | BMW 3’series | 42,471 | Nissan Qashqai | 193,695 |
| **9** | Nissan Qashqai | 39,406 | Renault Megane | 184,633 |
| **10** | Mini Mini | 35,845 | VW Passat | 182,194 |

### *3.2.1 Estimates of protection*

Fitting within the constraints of the project, three vehicles were selected from the list above for testing. Two phases of testing were then undertaken with the three cars, the first using the EEVC legform and the second using the Flex-PLI.

*EEVC legform testing*

In the first phase, seven EEVC legform tests were carried out with each of the vehicles. The impact sites were:

1. Centre of the bumper
2. Limit of conventional regulatory bumper test area (60 degree plane, minus the 66 mm legform radius allowance)
3. Limit of the conventional regulatory test area without the 66 mm legform radius allowance
4. The end of the bumper beam (i.e. limit of Euro NCAP bumper test zone – when based on the underlying structure)
5. Limit of bumper test area defined with 45 degree plane (instead of 60 degrees)

6. Limit of bumper test area defined with 45 degree plane (instead of 60 degrees) – but with the vehicle rotated through 15 degrees
    a. The test velocity was reduced to maintain the same normal speed as in test 5. For 15 degrees of vehicle rotation the desired test speed was reduced to 9.1 m/s.
        i. Speed normal to the bumper in Test 5 = 11.1 m/s x cos(45°) = 7.8 m/s
        ii. Speed normal to the bumper at 15° of vehicle rotation (30° incident angle) = 11.1 m/s x cos(30°) = 9.6 m/s
        iii. *Pro rata* speed for Test 6 = 11.1 x 7.8 / 9.6 = 9.1 m/s
7. Limit of bumper test area defined with 45 degree plane (instead of 60 degrees) – but with the vehicle rotated through 30 degrees
    a. Note the need to reduce the test velocity to maintain the same normal speed as in test 5. For 30 degrees of vehicle rotation the desired test speed was reduced to 8.1 m/s.
        i. Normal speed in Test 5 = 11.1 m/s x cos(45°) = 7.8 m/s
        ii. Normal speed at 30° of vehicle rotation (15° incident angle) = 11.1 m/s x cos(15°) = 10.7 m/s
        iii. *Pro rata* speed for Test 6 = 11.1 x 7.8 / 10.7 = 8.1 m/s

A brief description of the process used to test the vehicles with the EEVC legform is described in the following section.

- Each vehicle was marked out specifically for the testing that was to be undertaken.
- To ensure that this testing could be compared with previous testing, measured ride heights were matched to those that were recorded as the manufacturer specified ride heights from Euro NCAP testing.
- The centre of the vehicle was measured and marked, this was typically taken from the centre of the badge and cross checked with a laser measurement from the outer edge of each vehicle. The centre line of the vehicle was then considered as the origin for all additional measurements.
- The 60 and 45° bumper corner lines were measured.
- Once the vehicles had been marked up, the front end of the vehicles were then stripped down to ensure there was no existing damage and any worn parts were replaced to ensure that the testing was consistent.
- Each vehicle was then tested.

Testing:

- Each vehicle was then tested according to the regulatory test specification and the impact points identified above; however, the order of the testing was adjusted to maximise the number of tests completed with the number of spare parts available. The five impacts that were not at an offset angle were tested first to ensure that the method was similar for each vehicle.
- Between each test, the vehicle was assessed to ascertain whether there was any damage that would affect the performance of the vehicle and any worn or damaged parts considered to be of significance for the test results were replaced.
- Once the straight impacts had been completed, the vehicle was then rotated to sit at 15 degrees and 30 degrees for additional impacts at the 45 degree mark out line. This was completed by measuring the length of the vehicle and calculating the required offset for the rear of the vehicle.
- The rotation of the legform for the EEVC impactor tests was determined through the use of an angular rate sensor mounted to the footplate. The angular rate was integrated to provide the rotation throughout the impact event.

**Figure 3-6: Volkswagen Polo post mark-out and aligned with the test rig prior to testing.**

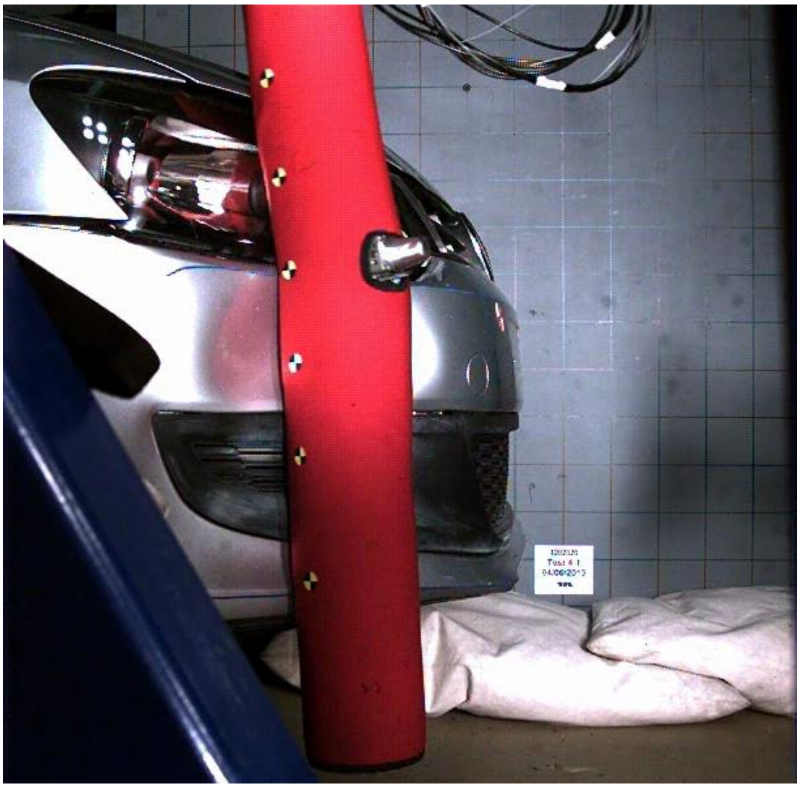


**Figure 3-7: Volkswagen Polo during testing of the bumper corner defined by the 45˚ plane.**

The following tables (Tables 3–2 to 3–4) show the peak value results (acceleration, shear and bending angle) for the three vehicles tested at each of the seven test positions. Underneath each of the measurement values is an angle which indicates the rotation of the legform about its 'z' (vertical)-axis at the time the peak value occurred. It should be remembered that the threshold limits for the injury criteria are:

- Knee bending angle ≤ 19.0°
- Knee shearing displacement ≤ 6.0 mm
- Acceleration ≤ 170 *g*
    - (apart from 264 mm width where the limit is ≤ 250 *g*)

It was expected that the vehicles would meet these performance limits when tested within the current bumper test area as they would have been designed anticipating EEVC legform tests being carried out in that zone.

**Table 3–2: Vehicle 1 – EEVC legform peak values and angle of impactor rotation**

| Description | | Acceleration | Shear | Bending |
|---|---|---|---|---|
| Centre | Value | 127.3 *g* | 2.8 mm | 11.8º |
| | Angle | - | - | - |
| 60 degrees – 66 mm | Value | 128.3 *g* | -2.6 mm | 8.6º |
| | Angle | 1.3º | 1.1º | 0.6º |
| 60 degrees | Value | 174.1 *g* | -4.4 mm | 13.6º |
| | Angle | 1.5º | 4.8º | 18.8º |
| End of bumper beam | Value | 338.3 *g* | -6.8 mm | 18.1º |
| | Angle | 5.0º | 9.6º | 30.3º |
| 45 degrees – straight car | Value | 83.7 *g* | 3.1 mm | 6.6º |
| | Angle | 5.0º | 7.8º | 41.0º |
| 45 degrees – 15 deg car | Value | 79.1 *g* | 2.4 mm | 5.8º |
| | Angle | 3.3º | 5.1º | 29.0º |
| 45 degrees – 30 deg car | Value | 91.1 *g* | 2.8 mm | 7.8º |
| | Angle | 6.3º | 9.2º | 23.4º |

**Table 3–3: Vehicle 2 – EEVC legform peak values and angle of impactor rotation**

| Description | | Acceleration | Shear | Bending |
|---|---|---|---|---|
| Centre | Value | 99.1 *g* | -1.8 mm | 5.3º |
| | Angle | 3.7º | 3.4º | 5.0º |
| 60 degrees – 66 mm | Value | 172.0 *g* | -3.0 mm | 13.5º |
| | Angle | 4.4º | 5.7º | 10.1º |
| 60 degrees | Value | 237.9 *g* | -2.8 mm | 17.1º |
| | Angle | 10.8º | 15.3º | 43.7º |
| End of bumper beam | Value | 394.4 *g* | -7.8 mm | 27.0º |
| | Angle | 2.5º | 6.9º | 27.9º |
| 45 degrees – straight car | Value | 74.3 *g* | 2.7 mm | 6.9º |
| | Angle | 7.5º | 37.4º | 36.6º |
| 45 degrees – 15 deg car | Value | 97.6 *g* | 1.7 mm | 8.5º |
| | Angle | 5.2º | 49.3º | 37.0º |
| 45 degrees – 30 deg car | Value | 74.3 *g* | 4.8 mm | 6.1º |
| | Angle | 10.2º | 11.7º | 21.1º |

**Table 3–4: Vehicle 3 – EEVC legform peak values and angle of impactor rotation**

| Description | | Acceleration | Shear | Bending |
|---|---|---|---|---|
| Centre | Value | 100.8 *g* | 3.3 mm | 2.9º |
| | Angle | 2.3º | 3.4º | 3.5º |
| 60 degrees – 66 mm | Value | 93.5 *g* | 3.8 mm | 2.8º |
| | Angle | 4.4º | 5.7º | 10.1º |
| 60 degrees | Value | 126.4 *g* | 2.5 mm | 13.7º |
| | Angle | 5.1º | 26.7º | 34.4º |
| End of bumper beam | Value | 181.8 *g* | 6.1 mm | 19.6º |
| | Angle | 7.4º | 10.8º | 45.2º |
| 45 degrees – straight car | Value | 67.0 *g* | 3.3 mm | 5.7º |
| | Angle | 11.0º | 28.7º | 61.5º |
| 45 degrees – 15 deg car | Value | 92.8 *g* | 4.2 mm | 9.0º |
| | Angle | 12.3º | 21.3º | 48.2º |
| 45 degrees – 30 deg car | Value | 93.0 *g* | 4.6 mm | 6.8º |
| | Angle | 6.3º | 9.2º | 23.4º |

The results demonstrated that where the impactor did not strike the vehicle perpendicularly to the surface (i.e. the impact to the centre of the bumper), the incident angle allowed the legform to slide and rotate after contact. As would be expected with this behaviour, the tests at the 45 degree (to the vehicle centreline) positions produced the lowest legform acceleration values. The knee shear and bending angle were also well within the thresholds for these measures at that position.

If the sliding behaviour had dominated the response from the legform, then for each vehicle the expected result would have been for the highest peak acceleration to have been recorded in the test to the centre of the bumper. However, this was not the case. For all three vehicles the centre of the bumper also provided acceleration, shear and bending results which were well within the thresholds. Peak values from the centre of the bumper tests were also lower than the values from the 60 degree bumper corner positions and the end of the bumper beam position. This demonstrates that at positions in the bumper where there is no need to position hard features, vehicle manufacturers are providing bumper designs which are compliant and 'safe'. The bumpers at this position managed the impact conditions of the legform test well, keeping the test tool measurements to a minimum, and providing contact surfaces which, are predicted to have a low risk of causing leg injuries for a pedestrian.

On moving to the edge of the existing test area, as defined with the 60 degree plane, then the peak values from the legform varied depending on the vehicle being tested. In the tests with one of the three vehicles, the peak values remained well within the thresholds. Whereas for another vehicle, the position 66 mm inside of the corner was above the 170 *g* limit required for the majority of the bumper in GTR9. At the 60 degree plane, excluding the 66 mm legform radius, then the test of this vehicle gave a peak acceleration value of almost 240 *g*. When tested at the end of the bumper beam, none of the cars produced a peak acceleration value that was within the GTR9 acceleration requirement of 170 *g*.

The results from the test positions at the 60 degree plane without the legform radius allowance and at the end of the bumper beam, based on these three vehicles only, show that the provision of pedestrian safety measures on current vehicles may not extend across the whole of the vehicle width. The testing identifies that where the current assessments don't require conformance, peak values can exceed the thresholds. Whilst this may be expected, it highlights two important aspects for this research programme.

1. There are hard features which in current vehicle designs are located around the existing bumper corners. These would need a dedicated focus from vehicle manufacturers for them to be as 'safe' for pedestrian leg strikes as other regions of the bumper – if that is even feasible.
2. Despite the rotation of the legform impactor testing beyond the existing bumper corner, it is still possible to detect potentially injurious structures.

When testing with a legform impactor at incident angles, where the direction in which the legform is fired is not perpendicular to the vehicle surface, then there is some concern as to whether rotation will occur in a manner that is unrealistic of a pedestrian accident (e.g. Roth and Coulongeat (2013)). The propensity for a legform impactor to rotate about its vertical axis is greater than for a full body because there is no constraining connection with the pelvis and upper body. Where incident angles are small, then it can be assumed that rotation of the legform will affect the measured parameters in a negligible way. However, the use of an angular rate sensor for the testing with the EEVC legform provided the opportunity to determine the rotation of the legform throughout the impact event. In particular the rotation of the legform at the time peak values occurred was investigated.

In the specification of the legform impactor test, it is required that, "At the time of first contact the impactor shall have the intended orientation about its vertical axis, for the correct operation of its knee joint, with a yaw angle tolerance of ± 5°." It is assumed that this specification comes from an assumption that within 5 degrees any rotation is unlikely to cause substantial error in linear measurements. Based purely on kinetics, and not considering the biomechanics, we would expect linear measurements to be underestimated by five percent once the angle of rotation reaches 18.2 degrees.

Typically in a legform impact, it is possible to observe that the peak in acceleration occurs before the peak in shear displacement which occurs before the peak in bending angle. With a progressive increase in the legform rotation throughout an impact this means that the highest rotation at the time of the peak value should be associated with the bending angle. In agreement with this progression, the rotation values from this testing showed that beyond the current bumper test area, large rotations of the legform could be observed, particularly at the time of the peak bending angle. The acceleration values were associated with smaller angles of rotation up to 10 or 11 degrees at most.

The implications of the large legform rotation with such incident conditions are that the injury criteria measurements obtained may have been taken when the impactor was behaving in a manner unlike that of a whole body. The peak values could be over or under-estimated with respect to a perpendicular impact. Either way it is possible that they cannot be robustly related to the injury risk predictions used to set the performance thresholds.

The tests at 45 degrees with the car rotated by 15 or 30 degrees offer a potential means for assessing positions outside of the current test area without large incident angles between the longitudinal line of the vehicle and the direction in which the legform is fired. They demonstrate how the rotation of the legform at the time of peak injury metric value can be decreased without vastly altering the peak value. This is important because it seems to support this practical method of reducing rotation; but also because it indicates that even with large rotations, the legform impactor didn't produce a large discrepancy, under or over-estimating the severity of the impact.

It should be noted that the rotation of the vehicle to reduce the incident angle with the legform is not an attempt to imitate an oblique impact between the car and pedestrian. Instead it is a practical approach to simulating a longitudinal vehicle-pedestrian collision to the sides of the vehicle front without incurring problems of legform robustness, legform rotation, invalid injury metrics and poorer repeatability and reproducibility. The rotation of the vehicle provides a reduction of the legform rotation during the impact event and therefore, it is hoped, reduced issues when using the legform tools compared with the corresponding longitudinal impact condition.

### *EEVC legform testing summary*

In summary of the tests with the EEVC legform three points seem to be particularly pertinent:

1. Outside of the bumper test area currently assessed there are hard structures which give results indicating their potentially injurious nature
2. The legform rotates substantially in oblique impacts with the bumper
    a. Though this doesn't seem to produce vastly erroneous instrumentation measurements.
3. If it was desired to test at wide positions of the bumper, one practical solution might be to rotate the vehicle with respect to the impactor firing direction
    a. In this case the test speed needs to be reduced in order to match the equivalent severity of the 'straight ahead' condition
    b. It is not clear to what extent Test Services can accommodate the need to rotate vehicles. Some frames used for determining the correct vehicle orientation and test points have fixed posts close to the sides of the vehicle to be tested. Other test facilities may have been built (or allocated to that purpose) with the assumption that the vehicle will always be straight and may not have the space available to accommodate much rotation.

Based on these findings a second phase of test work was undertaken to determine if the Flex-PLI showed similar behaviour. This second phase of test work is summarised in the following section.

### *Flex-PLI testing*

In the second phase, five Flex-PLI tests were carried out on each of the vehicles. The test details for this phase of testing were agreed at the 4th meeting of the Task Force – Bumper Test Area (TF-BTA), after consideration of the results of the first phase with the EEVC legform and in order to build on the results obtained from that phase. The impact sites and target test parameters for the second phase of testing were:

1. Centre of the bumper, with a longitudinal impact (i.e. standard test)
2. The end of the bumper beam (i.e. limit of Euro NCAP bumper test zone), with a longitudinal impact
3. The end of the bumper beam (i.e. limit of Euro NCAP bumper test zone), with a normal (i.e. perpendicular) impact
    a. Note the need to reduce the test velocity to maintain the same normal velocity component as in Test 2. This depends on the angle of the vehicle surface at the test location, relative to the lateral plane.
        i. Test velocity = 11.1 * cos (rotation angle) m/s
        ii. Vehicle 1: 35° rotation angle gives 9.09 m/s test velocity
        iii. Vehicle 2: 36° rotation angle gives 8.98 m/s test velocity
        iv. Vehicle 3: 45° rotation angle gives 7.85 m/s test velocity
    b. Note that this was to the same test point as for Test 2, as marked on the *exterior* of the car. As with all tests, the centreline of the impactor was lined up on the marked test point. Therefore, given that the bumper beam was a small distance behind the exterior of the car, this impact would not have been exactly in-line with the end of the bumper beam.
4. Limit of bumper test area defined with 45 degree plane (instead of 60 degrees and without 66 mm inwards adjustments) – but with the vehicle rotated through 15 degrees
    a. Note the need to reduce the test velocity to maintain the same normal velocity component as in a longitudinal test. For 15 degrees of vehicle rotation the desired test velocity was reduced to 9.06 m/s.
        i. Velocity component normal to the bumper in a longitudinal test = 11.1 m/s x cos(45°) = 7.85 m/s
        ii. Velocity component normal to the bumper at 15° of vehicle rotation (30° incident angle) at standard test velocity = 11.1 m/s x cos(30°) = 9.61 m/s
        iii. *Pro rata* velocity for Test 4 = 11.1 x 7.85 / 9.61 = 9.06 m/s
5. Centre of the bumper, but with the vehicle rotated through 30 degrees
    a. This test was included primarily for comparison with Test 4, therefore the same test velocity of 9.06 m/s was used.

In contrast to the EEVC legform testing, the Flex-PLI was not used to assess the region at the end of the bumper test area as defined using the 60 degree plane. Also, only one test was conducted at the bumper corner based on a 45 degree plane. Instead, a tangential impact at the end of the underlying bumper beam was added as well as a test to the centre of the bumper with the vehicle rotated.

A brief description of the process used to test the vehicles with the Flex-PLI is described in the following section.

- The vehicles tested were the same as those tested in the first phase, so no further marking out was required, other than to transfer the target points onto replacement parts. However, at the end of the bumper beam test points it was necessary to determine the angle of the vehicle surface to a lateral plane; this was then the angle by which the car was rotated in order to achieve a normal (i.e. perpendicular) impact in Test 3 above.
- The front end of each vehicle was stripped down and parts damaged in the first test series were replaced to ensure that the testing was consistent.

Testing:

- Each vehicle was then tested according to the Flex-PLI test specification, except that as described above the impact velocity was reduced for some tests.
    - The Flex-PLI was certified using the pendulum certification test before and during the test series.
    - Tests were carried out with the legform’s foot end the specified 75 mm above the ground reference plane at impact rather than the 25 mm used for the EEVC legform.
    - When testing at lower speeds the launch height was adjusted to allow for the greater influence of gravity on impact height, and it was ensured that velocity at impact remained within ±2° of horizontal.
    - Due to a faulty sensor, femur bending moments were not available for determining the Assessment Interval (AI), beyond which higher peaks should be ignored. Nevertheless, by using the available tibia and knee channels, and using the available video clips, appropriate Assessment Intervals are believed to have been selected.
- The order of the testing, the side of the car tested and in the case of Test 5 the direction of impact were adjusted to maximise the number of tests completed with the number of spare parts available and to minimise testing effort associated with rotating the car.
- Between each test, the vehicle was assessed to ascertain whether there was any damage that would affect the performance of the vehicle and any worn or damaged parts considered to be of significance for the test results were replaced.
- For this test series there were practical reasons why it was considered preferable to obtain impactor rotation by video analysis. A second video camera was installed to provide an overhead view. Once the recorded test data were analysed and the times of the peak values obtained, this view was then analysed to measure the rotation of the hip end at those times. It should be noted that as the legform rotated forwards it was no longer perpendicular to the camera view. No

correction was made for viewing angle effects, so the angles measured may have small errors. However, they should be adequate for the current purpose. In a few cases rotation angles were not available from the overhead view and had to be roughly estimated from the side view; these are indicated in the relevant table following.

The following tables (Tables 3–5 to 3–7) show the peak value results (Anterior Cruciate Ligament (ACL) elongation, Posterior Cruciate Ligament (PCL) elongation, Medial Collateral Ligament (MCL) elongation and Tibia Bending Moment (highest peak value from the four gauge positions) for the three vehicles tested for each of the five tests. Underneath each of the measurement values is an angle which indicates the rotation of the legform about its 'z' (vertical)-axis at the time the peak value occurred (clockwise rotation as seen from above is a positive angle). It should be remembered that the proposed threshold limits for the injury criteria are:

- Anterior Cruciate Ligament (ACL) elongation ≤ 13 mm
- Posterior Cruciate Ligament (PCL) elongation ≤ 13 mm
- Medial Collateral Ligament (MCL) elongation ≤ 22 mm
- Tibia Bending Moment ≤ 340 Nm
    - (apart from 264 mm width where the limit is ≤ 380 Nm)

It should be noted that age of the vehicles tested means that they could have been designed before the widespread use of the Flex-PLI for assessing pedestrian leg protection. Therefore, unlike the EEVC legform tests, there was no firm expectation that the thresholds would be met, even in the central test area.

**Table 3–5: Vehicle 1 – Flex-PLI peak values and angle of impactor rotation**

| Description | | ACL | PCL | MCL | Tibia Bending Moment |
|---|---|---|---|---|---|
| Centre – longitudinal impact | Value | 5.6 mm | 5.6 mm | 18.2 mm | 225 Nm |
| | Angle | 0º | 1º | 1º | 1º |
| End of bumper beam – longitudinal impact | Value | 10.0 mm | 6.3 mm | 18.8 mm | 314 Nm |
| | Angle | -1º | -20º | -20º | -3º |
| End of bumper beam – 35 deg car (normal impact) | Value | 9.5 mm | 5.2 mm | 15.8 mm | 286 Nm |
| | Angle | -1º | -3º | -4º | -2º |
| 45 degrees – 15 deg car | Value | 5.4 mm | 4.9 mm | 14.7 mm | 151 Nm |
| | Angle | 6º | 36º | 38º | 48º |
| Centre – 30 deg car | Value | 4.3 mm | 5.4 mm | 12.1 mm | 175 Nm |
| | Angle | 18º | 33º | 35º | 2º |

**Table 3–6: Vehicle 2 – Flex-PLI peak values and angle of impactor rotation**

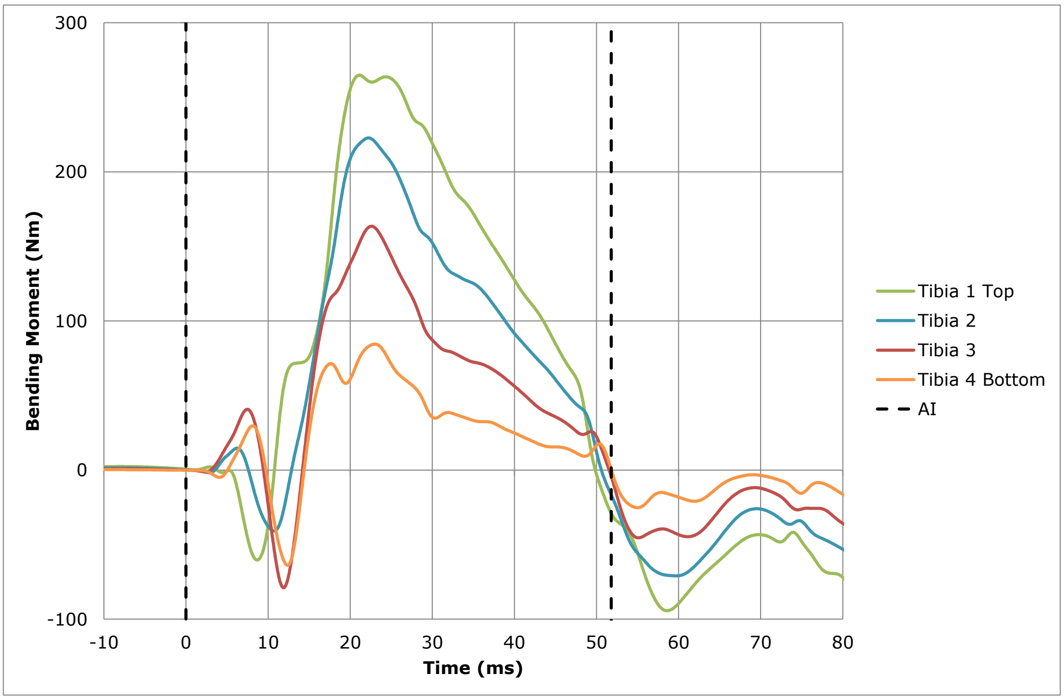
| Description | | ACL | PCL | MCL | Tibia Bending Moment |
|---|---|---|---|---|---|
| Centre – longitudinal impact | Value | 1.8 mm | 2.3 mm | 6.8 mm | 191 Nm |
| | Angle | (0°) | (0°) | (0°) | (0°) |
| End of bumper beam – longitudinal impact | Value | 12.9 mm | 7.4 mm | 23.7 mm | 395 Nm |
| | Angle | 2° | 26° | 27° | 15° |
| End of bumper beam – 36 deg car (normal impact) | Value | 9.3 mm | 6.0 mm | 20.3 mm | 332 Nm |
| | Angle | -1° | -10° | -11° | -5° |
| 45 degrees – 15 deg car | Value | 7.1 mm | 7.1 mm | 18.9 mm | 166 Nm |
| | Angle | 24° | 38° | 39° | 44° |
| Centre – 30 deg car | Value | 3.0 mm | 5.9 mm | 10.2 mm | 140 Nm |
| | Angle | (75°) | (60°) | (75°) | (75°) |

*Note: angle values in parentheses were estimated from the side view*

**Table 3–7: Vehicle 3 – Flex-PLI peak values and angle of impactor rotation**

| Description | | ACL | PCL | MCL | Tibia Bending Moment |
|---|---|---|---|---|---|
| Centre – longitudinal impact | Value | 3.7 mm | 3.7 mm | 12.1 mm | 230 Nm |
| | Angle | -4° | -1° | -4° | -1° |
| End of bumper beam – longitudinal impact | Value | 9.4 mm | 8.6 mm | 24.8 mm | 265 Nm |
| | Angle | 42° | 5° | 43° | 38° |
| End of bumper beam – 45 deg car (normal impact) | Value | 7.7 mm | 8.6 mm | 23.1 mm | 271 Nm |
| | Angle | -3° | -1° | -3° | -2° |
| 45 degrees – 15 deg car | Value | 4.5 mm | 5.9 mm | 14.6 mm | 195 Nm |
| | Angle | -46° | -36° | -46° | -46° |
| Centre – 30 deg car | Value | 2.3 mm | 3.2 mm | 9.0 mm | 144 Nm |
| | Angle | -52° | -40° | -52° | -4° |

As an example of the results obtained from this testing, time histories of the data are shown in Figure 3-8, for the longitudinal test to the end of the bumper beam (Test 2) of Vehicle 3. The lower graph includes the Lateral Collateral Ligament (LCL) elongation, for which no injury criterion is specified. As already noted, rotation angles were obtained only for the specific times at which peak values were obtained, so no time histories are available for Flex-PLI rotation. However, in order to show the rotation visually, frames have been extracted from the test videos for the two tests to the bumper beam (Tests 2 and 3) of the Vauxhall Corsa; see Figure 3-9.



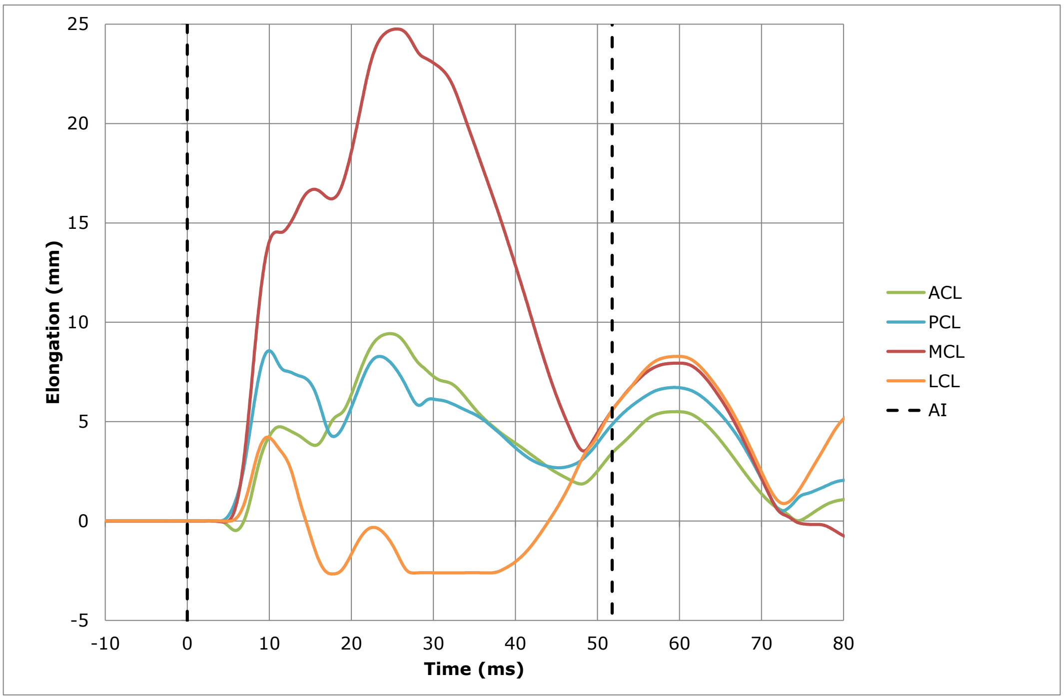
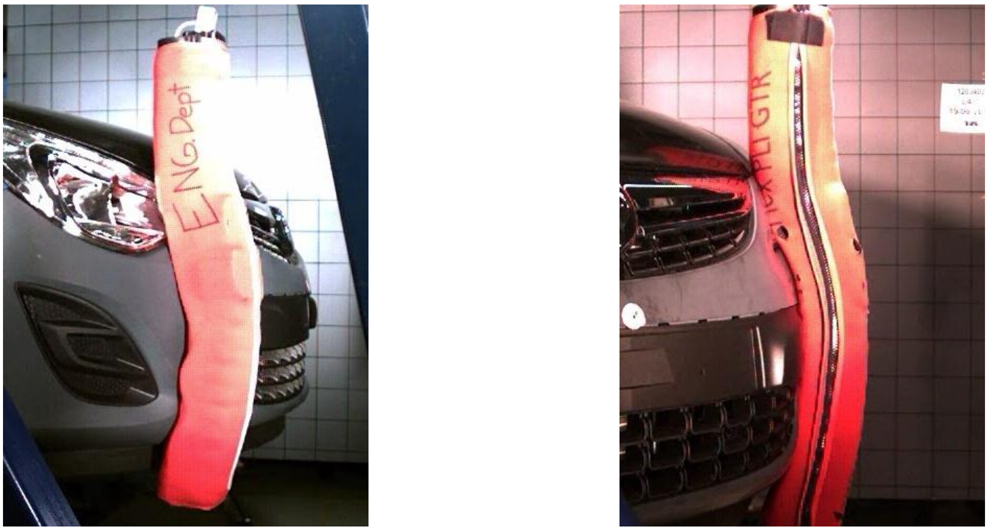
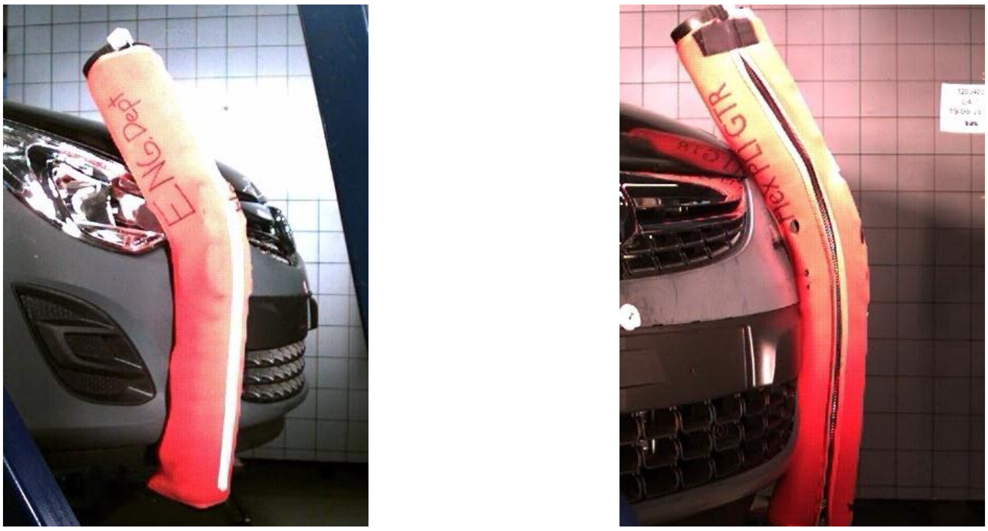


**Figure 3-8: Example tibia bending moment and knee ligament elongation time histories – Vehicle 3, longitudinal test to the end of the bumper beam (Test 2)**

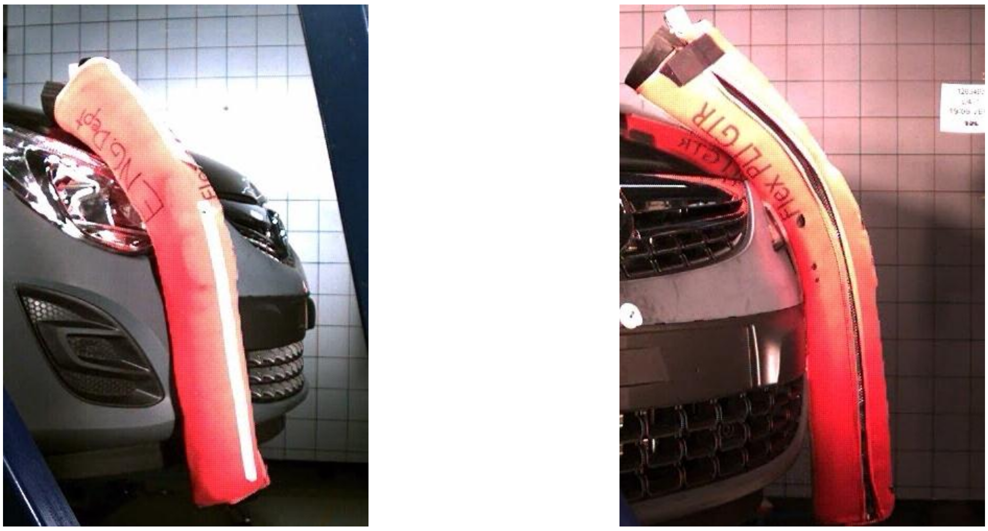
At impact time, t = 0 ms



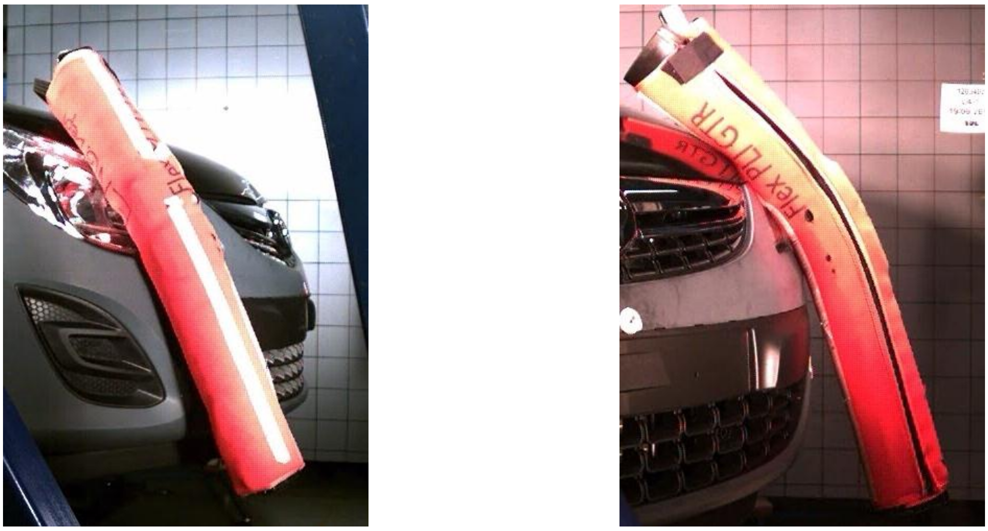
At time t = 10 ms



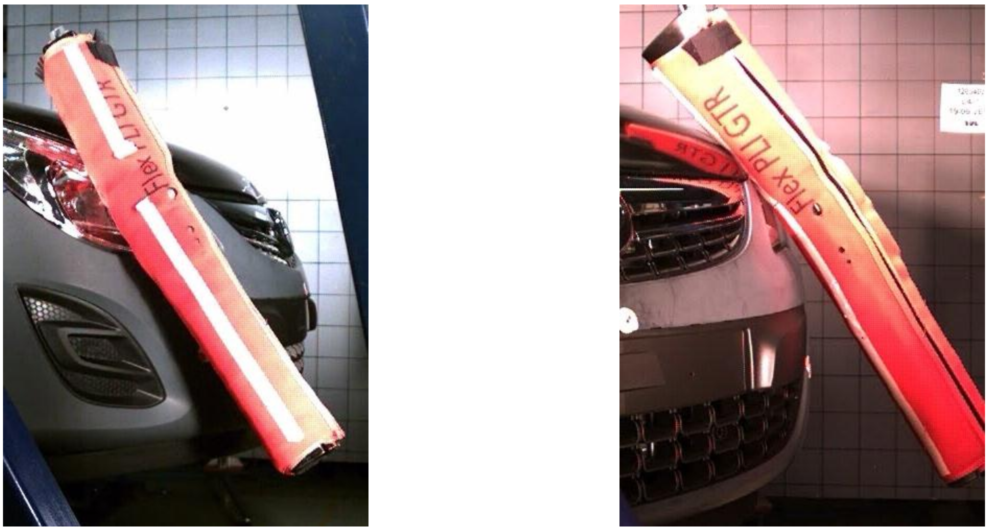
At time t = 20 ms



At time t = 30 ms



At time t = 40 ms



At time t = 50 ms

**Figure 3-9: Motion of Flex-PLI during tests to end of bumper beam of Vauxhall Corsa: longitudinal test (Test 2) on left, normal test (test 3) on right**

The high rotation angles experienced by the Flex-PLI in some tests did not appear to create significant problems in testing. No damage to the Flex-PLI was observed other than additional cuts to the outer skin. Greater care had to be taken to anticipate its likely post-impact trajectory and provide appropriate padding. The photographic lighting probably suffered more impact damage than it would have in more conventional tests.

The tests where the car was rotated took significantly longer to prepare, though it would be expected that this could be reduced to some degree if such tests became routine.

The end of the bumper beam test with a perpendicular impact required 45 degrees of vehicle rotation for Vehicle 3. This was at the limit of what was currently possible at this test facility due to the proximity of the fixed frames used to ensure correct alignment of the vehicle with respect to the launching device for the legforms.

As with the EEVC legform tests, with the Flex-PLI the highest peak values have been obtained in the (two Flex-PLI) tests to the end of the bumper beam, with all three cars.

- Vehicle 1 did not exceed any of the proposed injury criteria in either test at this position, though in some cases the values were quite close to the criteria, being within the 20% safety margin that manufacturers typically aim for.
- Vehicle 2 exceeded the MCL elongation and tibia bending moment criteria in the longitudinal test, and came very close with ACL elongation, but in the perpendicular test it met all the injury criteria, though MCL and tibia bending moment came close.
- Vehicle 3 exceeded the MCL elongation criterion in both tests at the end of the bumper beam position.

For Vehicle 1, the test with the next highest peak values was the longitudinal test to the centre of the bumper. For the other two vehicles this position had the next highest tibia bending moment, but the test at the 45° point had generally higher knee elongations. No injury criteria were exceeded in either of these tests with any car. MCL elongation was within 20% for the centre test to Vehicle 1 and the 45° point test to Vehicle 2.

As with the EEVC legform tests, the end of the bumper beam, outside the current bumper test area on these cars, did not provide the same level of protection that was provided at the centre of the bumper.

When comparing the two tests to the end of the bumper beam, the peaks values were higher in almost all cases in the longitudinal test. This test is oblique to the surface and generates high rotation angles, but the impact velocity was higher than in the perpendicular test. These results differ from the results with the EEVC legform at the 45° point, where the impact direction seemed to have little effect on the peak values. This will be further discussed later.

Significant rotations were observed in all tests with non-normal incident angles to the target surface. Note that because the times of the peak values can vary considerably within the defined Assessment Interval (AI), the rotation angles obtained also vary considerably. A higher rotation angle at a peak value in one test compared with another does not necessarily mean that the legform was rotating more; it may be due to the peak value being later, allowing greater rotation to occur by the time of the peak value.

### *Flex-PLI testing summary*

In summary of the Flex-PLI tests the following can be stated:

1. The results with the Flex-PLI are generally but not totally in agreement with results of the EEVC legform tests
2. Outside of the bumper test area currently assessed there are hard structures which give results indicating their potentially injurious nature
3. The legform rotates substantially in oblique impacts with the bumper
    a. This doesn’t seem to produce vastly erroneous instrumentation measurements
    b. Longitudinal impacts at high incident angles tend to produce higher peak values than perpendicular tests with the same perpendicular velocity component
4. If it was desired to test at wide positions of the bumper, one practical solution might be to rotate the vehicle with respect to the impactor firing direction (or the impactor firing direction with respect to the vehicle)
    a. In this case the test speed needs to be reduced in order to match the equivalent severity of the ‘straight ahead’ condition
    b. It is not clear to what extent Test Services can accommodate the need to rotate vehicles

## 3.3 Implications of protection levels

Whilst some of the findings from the tests with the EEVC legform and Flex-PLI were specific to the test tool, others were consistent and led to some general observations regarding the available pedestrian leg protection levels around the bumper corners.

### 3.3.1 *Injurious potential*

Due to the project constraints, not every possible bumper contact location could be tested. However, tests were carried out at the bumper corners (as currently defined), in line with the end of the underlying bumper beam structure and at bumper corner positions where a 45 degree plane was used instead of the current 60 degree plane. The tests outside of the currently defined corners at the end of the bumper beam showed high peak value results with both the EEVC legform and Flex-PLI. For instance Vehicles 2 and 3 failed to meet the injury criteria thresholds for mediocollateral ligament elongation and tibia bending moment in the end of the bumper beam tests. This indicates that there may be hard points located in this region which prevent the effective stiffness of the impact from being managed as it is in the centre of the bumper. This also suggests that there could be some merit in extending the tested area of the bumper to include these test points if vehicle design was then forced to improve the protection levels in these regions of the bumper.

By changing the defined width of the bumper test zone so that it covers more of the vehicle front, again, it is expected that one of two things could happen to the design of the vehicle front as a result. In the first case, and in the theoretical ideal scenario, any hard points would be recessed from the front surface of the bumper. This would allow improvements in the way in which the bumper skin and supporting energy absorbing material manage the impact, keeping the risk of injury within the thresholds for the test tools. Where this is not possible, it is expected that vehicle design would incorporate a combination of bumper shape and positioning of functional components and structures that means any hard points are moved outside of the wider test zone (or located in the small relaxation zone).

It is understood that there are functional (and perhaps safety-related) reasons why vehicle features are located in their respective positions. Some of these reasons may have an influence on how much pedestrian protection can be offered realistically around key components such as the joint of the bumper beam and longitudinal rails and also the headlights. It was beyond the scope of this project to determine to what extent vehicle design could be changed to improve pedestrian leg injury protection levels outside of the existing bumper corners. Whilst the test zone was wider for older designs of vehicle, at that time there may have been different compromises necessary with respect to aerodynamics and styling, etc. Therefore care should be taken when considering options for changes to the legislation to ensure that reasonable and feasible vehicle changes are encouraged. However, it should be noted that Vehicle 1 would have passed the performance criteria in all of the tests conducted with the Flex-PLI.

Within this project, testing did not extend beyond the point on the bumper which would be defined as the bumper corner defined using a 45 degree plane instead of the currently used 60 degree plane. As such no information was generated regarding the pedestrian protection levels available to the extremes of the vehicle width. However, there are two components to the protection levels beyond the tested sites which may lend support to extending the test area across the complete width of the vehicle. Firstly, beyond the stiff components at the end of the bumper beam and around the lights, there seems to be little functional reason why pedestrian protection cannot be offered, although subject to styling. This is supported by the 45° plane position usually giving lower injury criteria values than the end of the bumper beam test position. Secondly, without considering the full width of the vehicle, it may be that a new bumper corner definition creates only a small migration of hard components, rather than ensuring that they are positioned allowing for suitable protection in pedestrian contacts. In contrast to these suggestions, it is true that this project has not identified the very edges of the vehicle front to be particularly injurious (as a subset of the last 10 % of the width) and there is no supporting test data.

### 3.3.2 *Legform assessments*

When either the EEVC legform or Flex-PLI is fired into an oblique bumper surface, the test results have demonstrated a susceptibility of the test tool to rotate about its ‘z’ or long axis. A similar rotation was seen with both impactors in equivalent tests. When testing at the end of the bumper beam with the vehicle aligned with the direction in which the test tool was launched, 20 to 45 degrees of legform rotation could be seen by the time the impactor reached the peak values for all injury criteria.

The legform impactors are designed with a primary direction of loading having been considered, that is a lateral pedestrian contact with the vehicle. This is particularly true of the EEVC legform which has instrumentation sensitive in the medial-lateral axis only. The rotation of the legform implies that the intended sensitive axis (or axes) of the legform may not be aligned with the direction of loading throughout the entire impact event.

However, it should be noted that the legforms do not respond instantaneously to the applied loads. The early phase of the impact will load specific components of the legform, imparting energy and momentum to them. These will cause some components to commence moving and rotating in relation to other components. This relative motion and rotation will continue, even in the absence of further inputs, whether due to the legform rebounding away from the vehicle or to it rotating to present its insensitive axis. These relative motions and rotations, generated in the early impact, may therefore be the major contributory cause of peak legform outputs (for the Flex-PLI, knee ligament elongations and tibia bending moments) that occur later in the impact. This will be particularly the case for the Flex-PLI, because bending of the tibia is required to generate tibia bending moments, and because the Flex-PLI has low internal damping compared with the EEVC legform. Therefore, whilst the peak injury criteria results have been reported together with the legform rotation angle at that time, the main input leading to those results could have occurred at a much smaller legform rotation..

### 3.3.3 *Means of testing beyond existing bumper corners*

A solution was evaluated with the aim of enabling testing beyond the current bumper corners without encompassing large incident angles between the legform and bumper surface. This solution was to rotate the vehicle with respect to the direction in which the legform was fired, whilst still maintaining the target point on the surface of the bumper. As described above in Section 3.2.1, a mathematical method was used to keep the component of the impactor velocity vector perpendicular to the bumper surface the same even after the vehicle was rotated.

For the most part the injury criteria were similar in the tests with the vehicle aligned with the direction in which the test tool was fired and also in the tests where the vehicle was rotated. With the Flex-PLI for the small number of tests evaluated, the rotated vehicle tests seemed to give slightly smaller values, though this effect was not so evident with the EEVC legform. Generally, it appears that this solution could be used as a mechanism to allow testing further around the surface of the bumper than currently permitted with the 60 degree plane definition for the bumper corners.

It should be noted that some Technical Service laboratories may not be able to facilitate large rotations of a vehicle with respect to the firing mechanism for the legform impactors. This is due to practical constraints of fitting the rotated vehicle in small spaces between alignment frames, etc. This project did not include a survey of test laboratories to see to what extent this is a practical solution. However, it should be noted that whilst some laboratories cannot accommodate a rotated vehicle, there are other firing mechanisms which may allow equivalent rotation of the firing direction without the need to move the vehicle.

## 3.4 Options for amendments to the bumper corner definition

Based on the findings from the tests several options were considered for alternative definitions for the bumper corners. These are presented below:

1. No change – to the test area
    a. It might be that practicality, feasibility of changes in pedestrian protection and a small benefit make any change unreasonable
2. Extend the testable bumper width to include the hard points associated with the end of the bumper beam
    a. This would require the adoption of a test procedure similar to that already being used in Euro NCAP
3. Change the bumper corner definition to use a 45 degree rather than a 60 degree plane to the longitudinal plane of the vehicle
    a. Consideration might have to be given as to whether a 66 mm legform radius allowance still needs to be maintained, or not, within the defined corners
4. Removal of all bumper corner limits
    a. To allow testing across the complete width of the vehicle

These options were presented to the fifth meeting of the Task Force – Bumper Test Area (held in Brussels, 30 January 2014) for discussion amongst that group of experts.

Associated with these potential options it should be noted that changes to the test procedure would be needed in order to manage the potential rotation of the legform impactors in oblique impacts

A. No change – maintain longitudinal tests, throughout the test area

    a. This assumes that within the constraints of repeatability and reproducibility, the accuracy of the legform measurements is not substantially affected by the initial period of rotation in the contact event

B. Allow rotation of the vehicle to reduce the incident angle of the legform with the vehicle

    a. This would require writing the test speed calculation into the test procedure

    b. The results from the Flex-PLI tests suggest the lowest injury criteria outputs are obtained when the vehicle is rotated (as much as possible) hence this may be the most desirable condition if the test applicant (vehicle manufacturer) was given the option

    c. It is not yet certain that all Technical Service test houses could accommodate large angles of vehicle rotation due to possible limitations in the space available in the laboratory and/or in the equipment used

C. Force a set amount of vehicle rotation

    a. To keep the incident angle consistent regardless of the test position

    b. Again, it is not yet certain that all Technical Service test houses could accommodate large angles of vehicle rotation

## 3.5 Discussion

In the consideration of existing protection levels, testing was carried out with both the EEVC legform and Flex-PLI. During these tests measurements were taken to determine the angle of rotation of the leg about its vertical axis at the time when peak values occurred in the instrumentation data. These peak values are important as they are used as the injury metrics and compared with pass/fail thresholds in the test specifications. The purpose of assessing the rotation at the critical points in the data was to assess whether the rotation could have been adversely influencing the values obtained.

In the sequence of events (for the EEVC legform), the peak in tibia acceleration occurs first followed by the displacement of the knee and then the bending of the knee ligaments. Whilst the acceleration maximum will coincide with the legform interacting with the stiffest part of the bumper, the other peak values come after this. In the case of the knee bending, the legform may often be rebounding from the vehicle and no longer in contact with it. Therefore, whilst the reported rotations identify the legform angle at the time of the peak, this could be slightly misleading. For instance where a peak bending angle occurs during rebound the last moments of legform rotation during free-flight can have no significant influence on the value measured. Once the legform leaves contact with the bumper then the rotation will not affect the inertia of the upper and lower leg segments responsible for the bending. In this way the reported values of rotation are a slight overestimate of the rotation at the last significant moment of influence on the bending angle. However, this was chosen as the method of reporting because it is consistent with the acceleration assessment and is also consistent test to test, without substantial further, and subjective, analysis of the videos and data.

When testing at oblique angles to the surface of the vehicle bumper, it was expected that two types of behaviour could be generated for the legform impactors. The first is that the legform slides during the contact. The effect of this is that the interaction is not as severe as would be the case if the friction coefficient was infinite or in a perpendicular impact, where no sliding can occur. The other is that the legform rotates. Due to the arrangement of the contact, the side of the impactor closest to the centreline of the vehicle will be struck first and this will tend to cause the legform to rotate into the vehicle (leading edge of the impactor towards the centre of the car). Hypothetically, this behaviour might increase the tendency of the legform to bend over the vehicle front compared with a leg constrained so as to prevent such rotation. Visual examination of the test videos confirmed that both behaviours could be observed to some extent. The rotation of the legform was particularly clear from the angular rate sensor data and from overhead videos. However, it was not certain to what extent the legform might be over or under-reading in regard to the injury metrics with respect to an impact where these characteristics were not present. With the Flex-PLI in the tests at the end of the bumper beam, all peak values (for the ACL, PCL and MCL elongation and the peak tibia bending moment), with the one exception of the bending moment for Vehicle 3, were greater in the oblique test than the perpendicular test with the vehicle rotated. This would tend to suggest that the rotation of the legform does indeed allow a mechanism whereby the impact is more severe in terms of the injury metrics than is the case without rotation. In general this seems to dominate over the sliding motion and under-estimation of peak values that might be caused through that characteristic of the kinematics. Though this over reading could be seen in the EEVC legform tests with Vehicle 3, it wasn’t as pronounced or clear with the other two vehicles. This suggests that the additional knee bending could be greater with the more humanlike arrangement of the Flex-PLI knee than with the simplified construction and fewer degrees of bending freedom of the EEVC legform knee.

The solution of reducing the incident angle between the legform and bumper surface, through rotating the vehicle was considered. For these tests, the same contact point on the bumper surface was given as a target. The advantage of this process is that it is simple for a test engineer to manipulate the vehicle to keep the contact point the same. The disadvantage is that beyond the immediate surface contact, the straight ahead and rotated impacts could load slightly different underlying vehicle components. Also, the vertical profile may be slightly different between the two conditions. This is a limitation of keeping the same external contact point. An alternative would be to shift the contact point to try and maintain the same energy absorbing pathway underneath the bumper skin. It is not yet clear how this could be achieved consistently by a Technical Service. However, providing a more equivalent loading pathway for the two impact conditions does seem to merit further investigation to address the limitations of the simple solution.

This project has not considered frontal protection systems. It is possible that any change made to the regulations may need to be reflected in the frontal protection system testing sections of Commission Regulation (EC) No. 631/2009 as well.

# 4 Effectiveness and potential benefit

Fractures to the shaft of the tibia are the second most commonly observed primary injury for pedestrians recorded in the Hospital Episode Statistics (HES; Cookson et al., 2011). Also, whilst simple fractures of the long bones may generally be expected to have a good prognosis, fractures involving multiple regions of both lower limbs can have a very long duration of stay in hospital associated with them (mean of 33.9 days). The consequence of this is that whilst lower limb injuries sustained by pedestrians may not be the most costly on an individual basis, their high rate of incidence means that they are by far the most costly based on hospital admissions in England. Cookson et al. estimated an annual cost for lower limb injuries in England to be over £ 14.5 million.

In terms of injury causation, contact with the front bumper of a car is the most frequent cause of all leg injuries in car-pedestrian accidents, and is by far the most important cause of non-minor leg injuries (Cuerden et al., 2007). Contact with the ground is the second most frequent cause of leg injuries, although the vast majority of these are likely to be minor injuries.

Previous research regarding pedestrian contacts with vehicle bumpers has assumed an equal distribution of impact points across the width of the vehicle front. If, instead, there was an increased risk of contact towards the edge of the bumper then it may have important consequences for the effectiveness of a change to the corner definition. To investigate this assumption accident case data from the UK and Germany have been reviewed.

## 4.1 Pedestrian casualties

This section provides a brief overview of the number of pedestrian casualties in Great Britain and Germany. Pedestrian injury data for Great Britain only include pedestrian casualties struck by cars and cover the period 2000-2011. Data for Germany show the number of pedestrians in accidents involving a car and include all years from 2000 to 2010 (data for 2011 was not available from the CARE database).

### *4.1.1 Great Britain – STATS19 data*

STATS19 is the reported road injury accident database in Great Britain. The database comprises details of the accident circumstances, together with data on the vehicles and casualties involved in the collision.

Pedestrian casualties account for approximately 12-13% of all road accident casualties in Great Britain each year; pedestrians hit by cars[1] account for over 80% of these. Figure 4-1 displays the number of pedestrian casualties hit by cars by casualty severity and year of accident.

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[1] 'cars' includes both cars and taxis

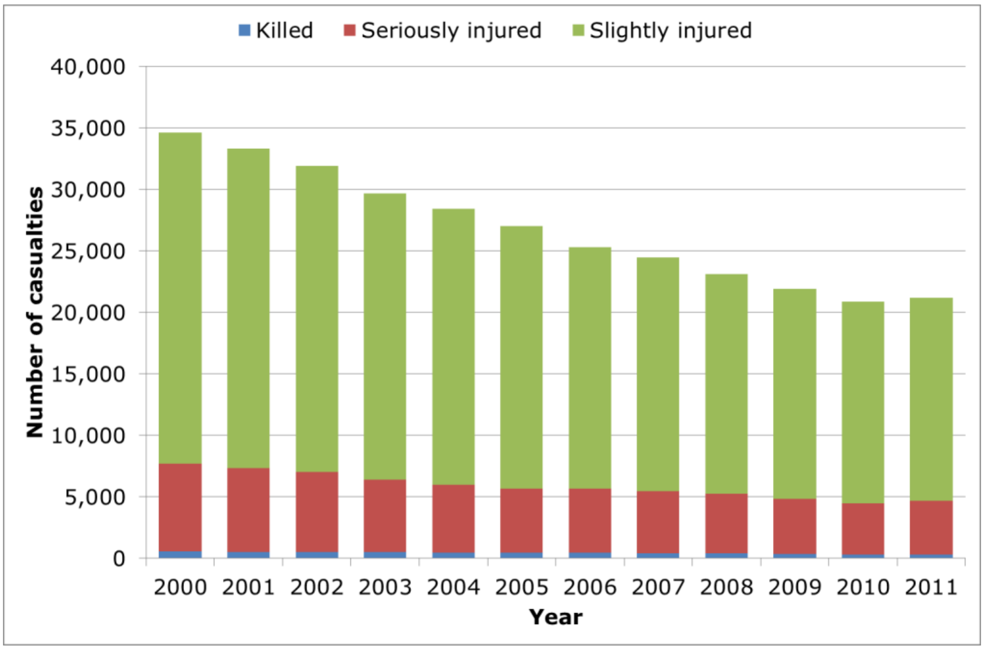

**Figure 4-1: Number of pedestrians hit by cars by casualty severity and year of accident (GB)**

Over the period, the number of pedestrian casualties hit by cars has declined with a slight increase across all three severities in 2011. Each year approximately 22% of the casualties hit by cars were killed or seriously injured.

Between 2000 and 2011 58% of pedestrians hit by cars were male. Table 4–1 shows the casualty numbers split by casualty age.

**Table 4–1: Number of pedestrians hit by cars by casualty severity and age of casualty (2000-2011)**

| Casualty age | Killed | Seriously injured | Slightly injured | Total | % killed or seriously injured |
|---|---|---|---|---|---|
| 0-15 | 578 | 22,810 | 95,248 | 118,636 | 20% |
| 16-24 | 789 | 10,757 | 44,868 | 56,414 | 20% |
| 25-39 | 841 | 9,792 | 40,544 | 51,177 | 21% |
| 40-59 | 988 | 9,005 | 33,540 | 43,533 | 23% |
| 60-79 | 1,158 | 7,851 | 20,707 | 29,716 | 30% |
| 80+ | 952 | 3,893 | 7,678 | 12,523 | 39% |
| Unknown | 24 | 1,149 | 8,683 | 9,856 | 12% |
| **Total** | **5,330** | **65,257** | **251,268** | **321,855** | **22%** |

The majority (37%) of pedestrians hit by cars were children aged 15 or less. There are relatively few elderly casualties aged 80+; however this group had the highest proportion of casualties which were killed or seriously injured.

Each pedestrian casualty is linked to the vehicle which hit them. The first point of impact (did not impact, front, back, offside, nearside, unknown) is recorded for each of the vehicles in an accident. Note that this first point of impact may not refer to the pedestrian casualty; it may refer to another vehicle in the accident or to a stationary object. However, if the assumption is made that all cars with the first point of impact recorded as 'front' hit the pedestrian first this will provide an (over)estimate of the number of pedestrian casualties in Great Britain which are of interest as part of this project.

Overall, 58% (187,887) of pedestrian casualties hit by cars between 2000 and 2011 were struck by a car with first point of impact 'front'; this proportion was higher for killed and seriously injured casualties (80% and 63% respectively).

## 4.2 Germany – CARE data

The CARE (Community Road Accident) database contains information on road accidents which result in death or serious injury across the European Union. Information on the number of pedestrian casualties in Germany was extracted from CARE and is summarised in this section. Data from 2000 to 2010 are included to demonstrate how the casualty trend has changed over time.

STATS19 contains information which allows us to select only those pedestrians struck by a car (or taxi); CARE does not allow this level of disaggregation. As such, pedestrian numbers quoted in this section are 'pedestrians in an accident involving at least one car or taxi' i.e. although a car was involved in the accident in which the pedestrian was injured, we cannot be certain that it was the car which struck the pedestrian, as a secondary vehicle may have also been involved. In addition, the CARE database does not contain information on the part of the vehicle which struck the pedestrian.

Pedestrian casualties account for approximately 8% of all road accident casualties in Germany each year; just under 80% of these are injured in accidents involving at least one car[2]. Figure 4-2 displays the number of pedestrian casualties in accidents involving at least one car by casualty severity and year of accident.

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[2] 'car' again refers to a car or taxi

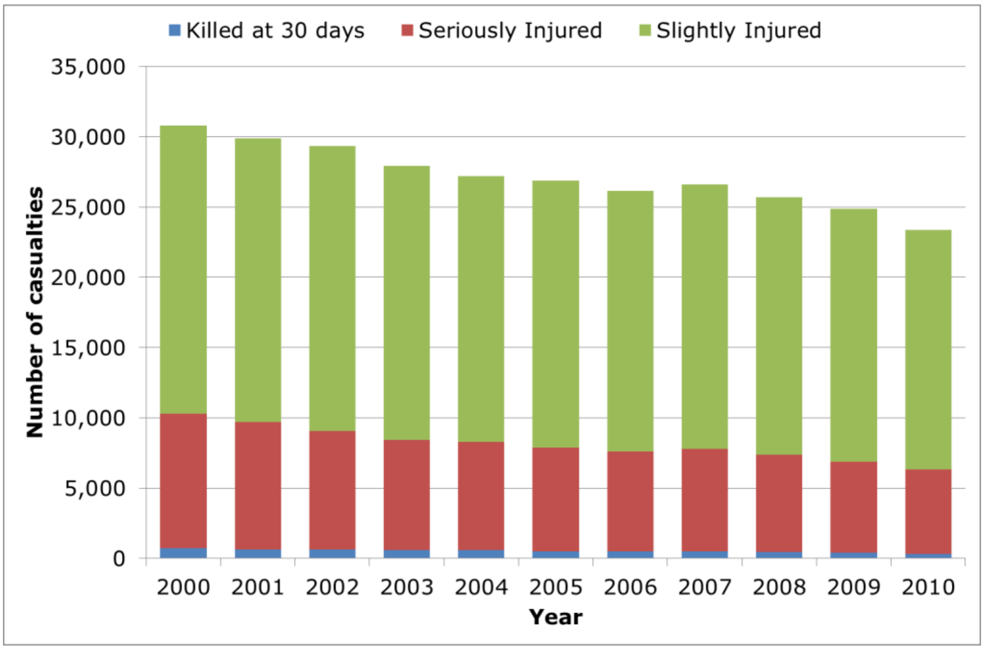


**Figure 4-2: Number of pedestrians in accidents involving a car by casualty severity and year of accident (Germany)**

In general, the number of pedestrian casualties in accidents involving cars has declined; however there was a slight increase in all three severities in 2007. Each year between 29% and 33% of the casualties in these accidents were killed or seriously injured.

In Germany, male casualties accounted for 52% of pedestrians in accidents involving at least one car between 2000 and 2010. Table 4–2 shows the casualty numbers split by casualty age.

**Table 4–2: Number of pedestrians in accidents involving a car by casualty severity and age of casualty (2000-2010)**

| Casualty age | Killed at 30 days | Seriously injured | Slightly injured | Total | % killed or seriously injured |
|---|---|---|---|---|---|
| 0-15 | 380 | 26,470 | 63,745 | 90,595 | 30% |
| 16-24 | 570 | 9,113 | 32,291 | 41,974 | 23% |
| 25-39 | 630 | 8,332 | 33,726 | 42,688 | 21% |
| 40-59 | 1,166 | 13,870 | 40,013 | 55,049 | 27% |
| 60-79 | 1,822 | 18,096 | 29,773 | 49,691 | 40% |
| 80+ | 1,255 | 7,758 | 8,311 | 17,324 | 52% |
| Unknown | 5 | 106 | 1,269 | 1,380 | 8% |
| **Total** | **5,828** | **83,745** | **209,128** | **298,701** | **30%** |

The CARE database does not contain information on which part of the vehicle the pedestrian was struck by and thus it cannot be used to quantify the size of the 'target population' of interest in this study i.e. pedestrians hit by the front bumper of cars.

Children aged 15 or less accounted for the largest proportion of pedestrians in accidents involving a car (30%). There were relatively few elderly casualties aged 80+; however over half of these casualties were killed or seriously injured.

## 4.3 In-depth accident analysis

Although the national accident datasets such as STATS19 can provide an indication of the target population (i.e. pedestrians hit by the front bumper of cars), information about the location on the bumper where the pedestrian struck the vehicle is not available. In depth accident studies such as On-The-Spot (OTS) in Great Britain and GIDAS in Germany provide detailed information on a small sample of the road accidents.

These data can be considered to help understand the accident situation in more detail – specifically where on the bumper are pedestrian casualties struck and if there is a difference in this distribution by age, sex or movement of the casualty, speed or registration year of the vehicle.

### *4.3.1 OTS*

The On-The-Spot accident data collection study gathered in-depth information on over 4,700 road traffic accidents from two distinct geographical areas between 2000 and 2010. The work was commissioned by the UK's Department for Transport (DfT) and Highways Agency (HA). The study was undertaken by two investigation teams, from the Vehicle Safety Research Centre (VSRC) at Loughborough University and the Transport Research Laboratory (TRL), working in close co-operation to produce a joint dataset. The teams worked in defined geographical sample areas in Nottinghamshire and Thames Valley Police Force regions respectively, and each investigated 250 crashes per year of the study.

The study areas were chosen to ensure a broadly representative sample of accidents involving different road users. However, there was a slightly higher proportion of pedestrian accidents in the VSRC area and a slightly higher proportion of car occupant injury accidents in the TRL area, compared with the national average. This is to be expected as the VSRC sampling area was relatively urban while TRL's was relatively rural. Additionally, OTS sampling is biased towards more severe accidents leading to over representation of killed and seriously injured (KSI) accidents in the final sample, 53% of the pedestrians were KSI, much higher than the national average. However, when broken down by MAIS score, 23% of pedestrians had MAIS 3+ injuries, which is very close to the national KSI proportion (22% of pedestrian casualties in STATS19 were KSI). The additional information on AIS from the in-depth OTS study suggests there are many seriously injured pedestrians with only MAIS 2 injuries. This may not be surprising given that examples of AIS 2 injuries are closed fractures of the lower leg and knee ligament tears or avulsions, some of which may result in long-term disability or impairment.

The final sample of pedestrian accidents resulted in a total of 232 pedestrian accidents out of 304 total pedestrian cases.

Further exclusion criteria were applied to this sample including:

- The pedestrian was struck by the side of the vehicle, side swiped or the pedestrian ran into side of vehicle;
- The vehicle was stationary and the pedestrian collided into vehicle;
- The vehicle reversed over the pedestrian;
- In cases where the pedestrians were not impacted by the front of the cars the cases were discarded from the sample.

This resulted in **116 relevant pedestrian** accident cases for analysis each with 1 pedestrian involved.

The point of contact where the pedestrian was struck on the vehicle's bumper was divided into five equal segments stretching across the full width of the bumper. These segments are displayed as percentage ranges of the vehicle width starting from 0% to 100% from right to left of the bumper as viewed from head-on (see Figure 4-3). This was determined using a combination of vehicle and pedestrian paths, case summary, recorded evidence and vehicle photos from the OTS database.

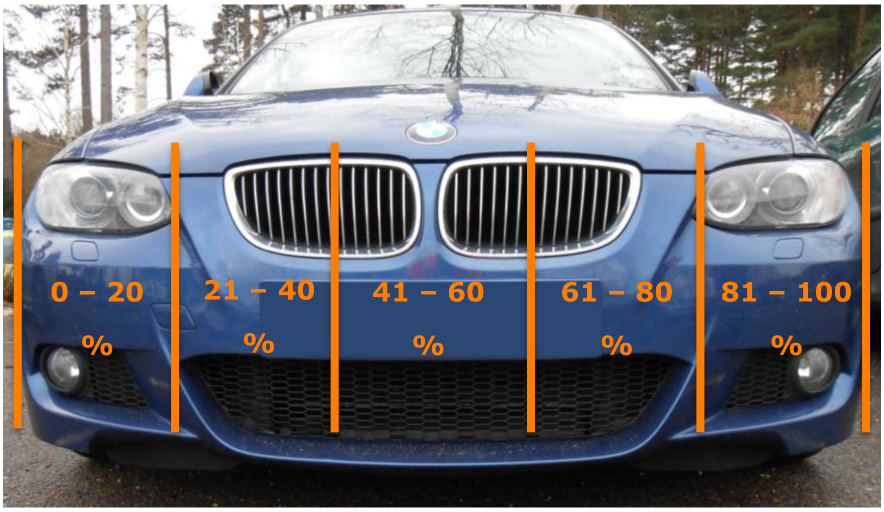


**Figure 4-3: Contact point is divided into five equal segments across the bumper displayed as percentages of the vehicle width.**

### *4.3.2 GIDAS*

GIDAS is a joint project of the Federal Highway Research Institute of Germany and the German Association for Research on Automobile Technique. It emerged in 1999 from a preceding project of the Medical School in Hanover and the University of Berlin and comprises data from the research areas Dresden and Hanover. In these two areas about 2,000 accidents are recorded each year. Each case is then encoded in the database with about 3,400 variables. Due to the facts that the research areas represent the average German topography very well, the investigation follows an exact statistical sampling plan and the number of cases is fairly high, the statistics are representative for Germany.

This study is based on the latest available GIDAS dataset from January 2013. Currently there are 23,444 reconstructed accidents from both investigation areas Dresden and

Hanover. 27,690 passenger cars were involved in these accidents. In 2,271 accidents a car hit a pedestrian. **758 pedestrians** had their first contact with the legs on the bumper (Figure 4-4). Pedestrians whose exact contact point location could not be determined were excluded from the dataset.

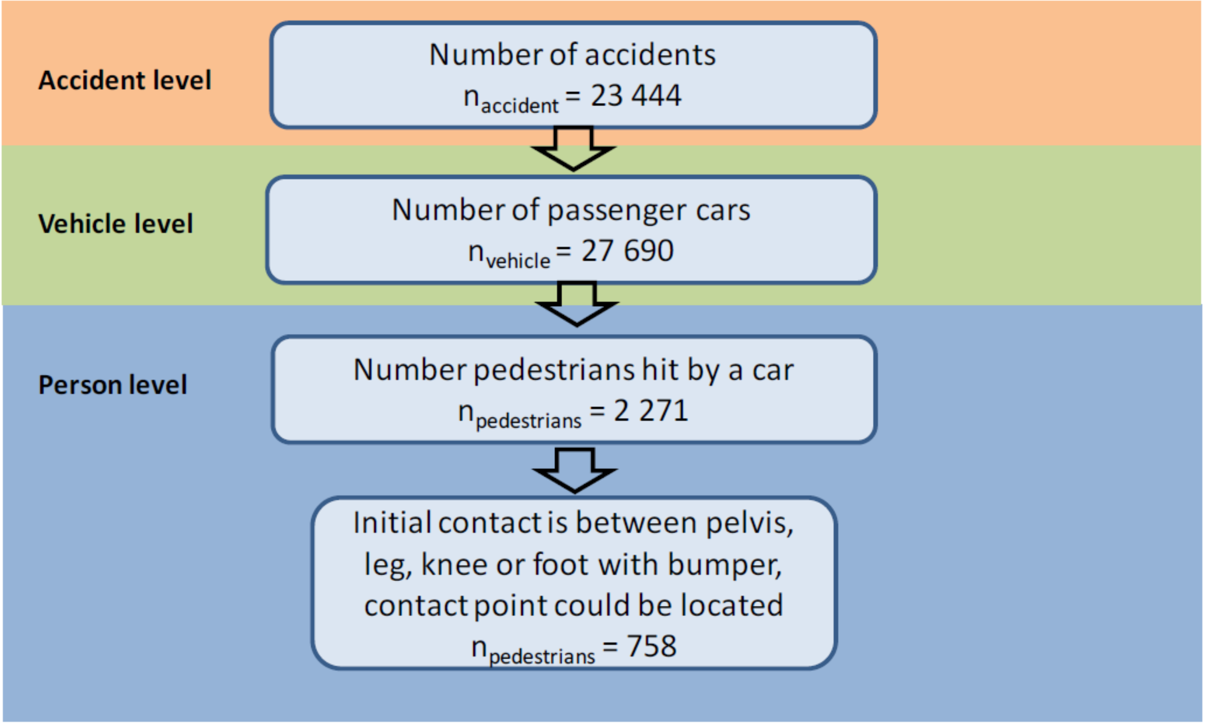


**Figure 4-4: Selection process for the GIDAS dataset**

The information recorded in the GIDAS database allowed a higher degree of precision in determining the pedestrian contact point on the bumper and so the bumper was divided into 10 segments of the vehicle width. The segments are also labelled 0% to 100% from the right to the left of the vehicle front as viewed head-on (Figure 4-3).

## 4.4 Analysis of OTS and GIDAS

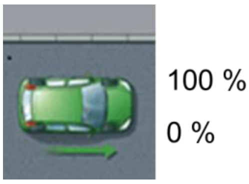
### *4.4.1 Overview of cases by contact position*

The initial hypothesis was that there was equal probability of a pedestrian being struck across the length of the bumper. To assess this a chi-squared goodness-of-fit test was used; this tests for a difference between the number of casualties struck in each of the contact positions and the theoretical number if the distribution of contact positions was uniform across the bumper.

This test generates a p-value which represents the probability of observing these data given that the hypothesis we are testing is true. Hence, a low p-value (typically $p<0.05$) indicates that the hypothesis is false. Statistical significance is classified in two categories within this report. A p-value<0.05 indicates 95% confidence that the observed numbers are significantly different from the hypothesised values. A p-value<0.10 indicates 90% confidence (there is less confidence) that the observed numbers are significantly different from the hypothesised values.

Table 4–3 and Table 4–4 show the number of OTS and GIDAS cases by contact position across the bumper. The chi-squared test (excluding those with unknown contact position) shows that the distribution of casualties across contact position groups is not significantly different from that of a uniform distribution for the OTS sample. The test has a p-value of 0.11, i.e. the test is close to being significant at the 10% level.

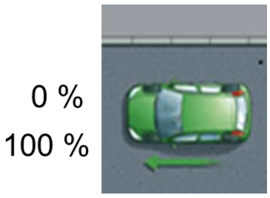
**Table 4–3: Number of OTS cases by contact position across the bumper**



| Contact position | Number of casualties |
|---|---|
| 0-20 | 18 |
| 20-40 | 14 |
| 40-60 | 23 |
| 60-80 | 22 |
| 80-100 | 31 |
| Unknown | 8 |
| **Total** | **116** |

The chi-squared test for the GIDAS sample shows that the distribution of casualties across categories of contact position is significantly different (at the 5% level) from that of a uniform distribution. The test has a p-value<0.05.

**Table 4–4: Number of GIDAS cases by contact position across the bumper**



| Contact position | Number of casualties |
|---|---|
| 0-10 | 65 |
| 10-20 | 116 |
| 20-30 | 101 |
| 30-40 | 65 |
| 40-50 | 85 |
| 50-60 | 83 |
| 60-70 | 54 |
| 70-80 | 76 |
| 80-90 | 62 |
| 90-100 | 51 |
| **Total** | **758** |

A second hypothesis is that if the distribution of contact points across the bumper is not uniform then the relationship between number of casualties and contact points is linear. This hypothesis arises from the fact that pedestrians are more likely to be hit by a vehicle when crossing from the nearside of the vehicle as the car driver has less time to see the pedestrian before the point of impact.

Figure 4-5 shows the distribution of casualties across contact points of the bumper in the OTS sample; a line of best fit is included. Figure 4-6 shows the equivalent data from the GIDAS sample. The $R^2$ value (a measure of the variance explained by the model) is also shown.

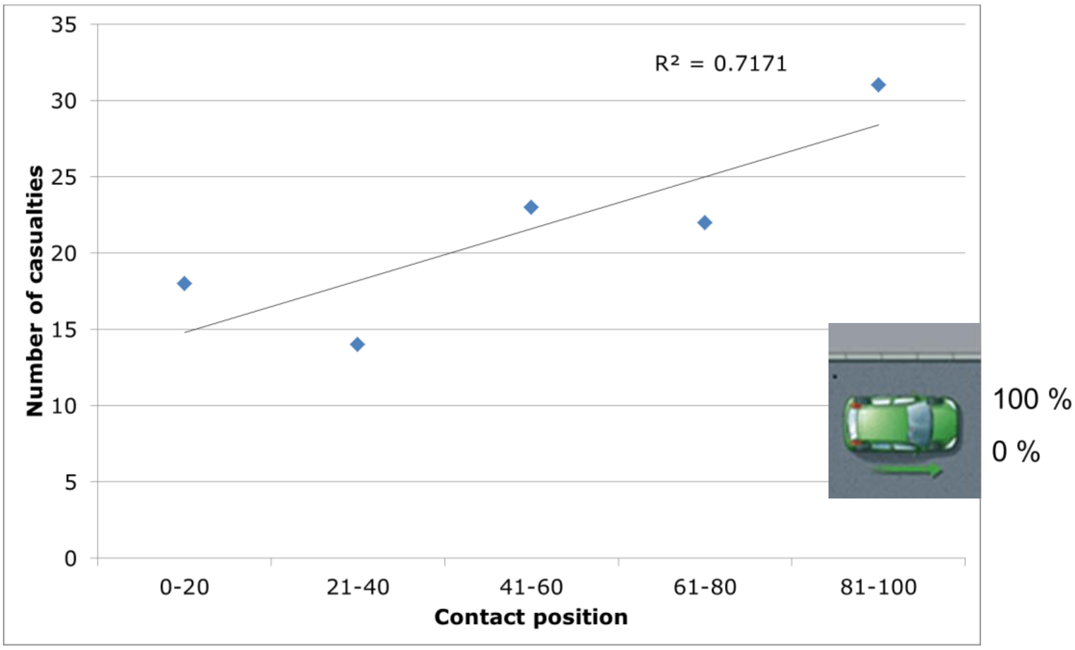


**Figure 4-5: Distribution of casualties across contact points of the bumper (OTS)**

Figure 4-5 shows that more pedestrian casualties were struck between contact positions 81-100 (i.e. the nearside of the vehicle in GB) than those struck by the offside. The regression line shows that the contact position explains 71% of the variability in the number of casualties. The linear trend between number of casualties and contact position seems a reasonable approximation in this instance.

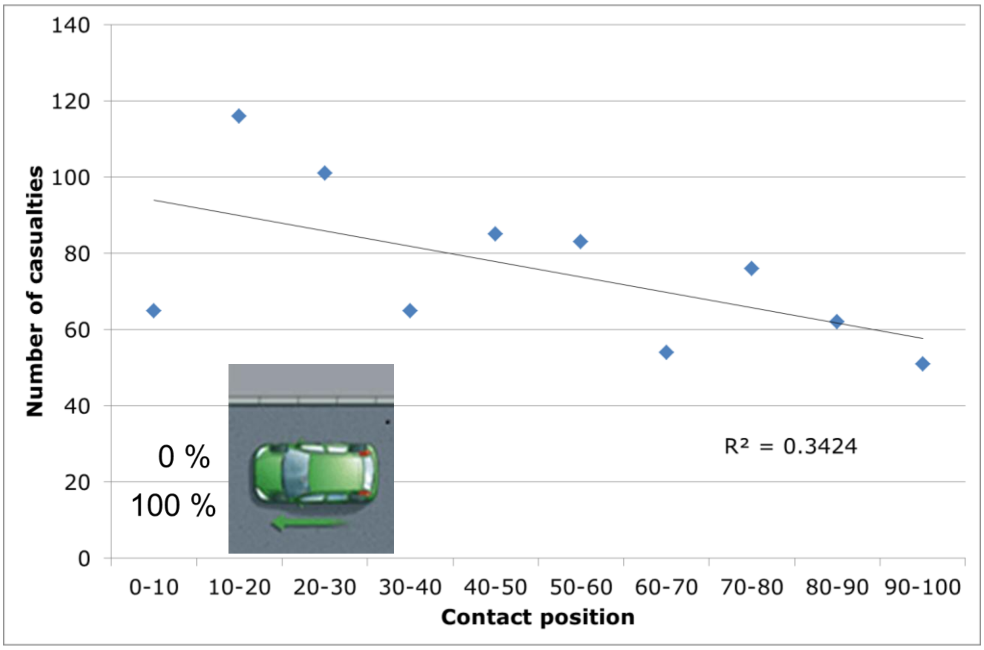


**Figure 4-6: Distribution of casualties across contact points of the bumper (GIDAS)**

Figure 4-6 shows that more pedestrian casualties were struck by the nearside of the vehicle than those struck by the offside. The regression line shows that the contact position only explains 34% of the variability in the number of casualties.

However, if the data are grouped into five contact positions equivalent to the OTS groups the contact position explains approximately 90% of the variability in the number of casualties. Hence, within the GIDAS data we conclude that the relationship between contact position and number of casualties can also be approximated as being linear.

### *4.4.2 Cases by pedestrian and vehicle factors*

The OTS and GIDAS data provide information on the age, sex and movement of the pedestrian, the vehicle registration year and the speed of the collision. Each of these variables has been examined to determine if it causes bias in the distribution across categories of contact position. This is potentially important if, for instance, a group of casualties was more likely to be hit by the extremities of the vehicle and that group was more or less susceptible to injury than the rest of the pedestrian population. The results from this analysis are reproduced in Appendix C.

### *4.4.3 Datasets Summary*

Both datasets display a linear relationship of contact point distribution skewed towards the nearside of the vehicle.

- Although the contact distribution is skewed, the linear relationship means that the risk of contact across the bumper is actually equal assuming symmetrical design of the vehicle's bumper and substructures. The increased risk to the nearside is cancelled out exactly by the reduced risk mirrored on the offside in both datasets. This assumes that either the vehicles are symmetrical in design or that any asymmetry doesn't affect the risk of injury from the impact. It also takes a broad approximation of the contact point data, where a larger dataset could show small deviations from this approximation to be more important.
- However, bumper design can vary with certain vehicles that have offset licence plates such as the Alfa Romeo MiTo and most vehicles will have a tow-eye present on one side underneath the bumper.

In addition, both datasets show that males are more likely to be impacted by vehicles than females and that the distribution of contact points is different for males and females.

- It could be important for investigating injury risk across the bumper width if certain regions are associated with more males or females than another. In general terms, female leg bones tend to be narrower and have thinner cortical walls than males (e.g. Beck et al., 2000). Therefore one could speculate that female pedestrians may be more susceptible to some types of leg injury than male pedestrians.
- Whilst the distribution of males and female contact points was different, no obvious dominating trends were evident which would suggest one part of the vehicle front should be designed with a specific attention to protecting female pedestrians more than any other part.

The age of the pedestrian and the vehicle appear to have no influence on the contact point distribution.

### *4.4.4 Injury risk*

The next part of the analysis aims to determine if there is a greater risk of injury at the outskirts of the bumper compared with the centre or if injury risk is also linear across the bumper.

In the first instance, the whole-body MAIS score for each pedestrian was considered. This gives an overall indication of the severity of the accident for the pedestrian. The results from the OTS sample and GIDAS are shown in Tables 4–5 and 4–6.

These data seem to support the assertion that, whilst relatively uncommon, MAIS 4, 5 or 6 casualty severities can be caused by contacts from any fifth of the vehicle front. Unfortunately, on the sample size is not large enough to determine whether a particular region of the vehicle width is more likely to cause these injuries than other regions.

MAIS 1, 2 or 3 pedestrian injuries seem to follow the same trend as the overall number of casualties, with a greater proportion occurring from contacts to the near-side than to the off-side. There doesn't appear to be any one region which causes such injuries much more than would be expected based on an equal risk of injury across the whole vehicle width. Any MAIS severity of casualty injury can seemingly be caused by any fifth of the vehicle front.

**Table 4–5: Number of OTS cases by whole-body MAIS and contact position**

| | Contact position not determined | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|---|
| MAIS 0 | 3 | 2 | 2 | 2 | 4 | 4 | 17 |
| MAIS 1 | 3 | 8 | 7 | 9 | 6 | 8 | 41 |
| MAIS 2 | 1 | 5 | 2 | 8 | 2 | 6 | 24 |
| MAIS 3 | 1 | 2 | 0 | 2 | 3 | 8 | 16 |
| MAIS 4 | 0 | 0 | 1 | 1 | 4 | 1 | 7 |
| MAIS 5 | 0 | 0 | 0 | 1 | 2 | 1 | 4 |
| MAIS 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MAIS 9 | 0 | 1 | 2 | 0 | 1 | 3 | 7 |
| Total | 8 | 18 | 14 | 23 | 22 | 31 | 116 |

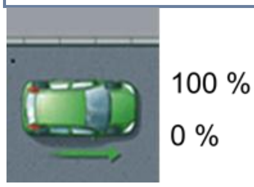
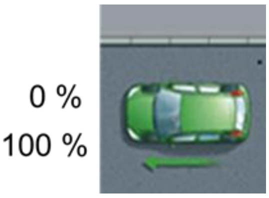


**Table 4–6: Number of GIDAS cases by whole-body MAIS and contact position**



| | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|
| MAIS 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MAIS 1 | 21 | 24 | 26 | 19 | 15 | 105 |
| MAIS 2 | 25 | 20 | 11 | 12 | 20 | 88 |
| MAIS 3 | 5 | 2 | 1 | 3 | 2 | 13 |
| MAIS 4 | 3 | 1 | 2 | 3 | 2 | 11 |
| MAIS 5 | 1 | 4 | 1 | 1 | 1 | 8 |
| MAIS 6 | 3 | 0 | 0 | 2 | 0 | 5 |
| MAIS 9 | 5 | 0 | 4 | 3 | 2 | 14 |
| Total | 63 | 51 | 45 | 43 | 42 | 244 |

It should be noted that the GIDAS MAIS is based on AIS 1998 edition, whereas the OTS MAIS was a mixture of AIS 1990 and 2005, but for simplicity is presented here based on the 1990 coding. This is not expected to alter the general impressions provided by the data in Tables 4–5 and 4–6, substantially.

**The GIDAS database allows injuries to be assigned to an injury causing vehicle part. Therefore it is possible to look at the maximum AIS of the lower extremity injuries caused by the bumper (**

Table 4–8). An equivalent analysis of the OTS sample was not possible, therefore all lower extremity injuries are considered regardless of the contact causing the injury (Table 4–7). The advantage of doing this with the GIDAS data is that injuries caused as the pedestrian was thrown to the ground are excluded. The injuries reported are thought by the investigators to have been caused by the primary interaction with the vehicle bumper. This exclusion of alternative injury sources is therefore not available for the OTS data.

Tables 4–7 and 4–8, show the numbers of injuries in the OTS and GIDAS samples, grouped according to the contact position as well as the part of the lower extremity which sustained the injury. By considering the data in this way it gives an indication as to whether any region of the vehicle offers a substantially more injurious contact for the pedestrian lower extremity than another.

Based on these results it can be observed that upper leg, knee, lower leg, ankle and foot injuries can be caused by a contact in any of the five fifths of the vehicle front.

**Table 4–7: Number of OTS injuries by body region and contact position for all injury severities**

| | Unknown | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|---|
| whole leg | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| upper leg | 0 | 1 | 0 | 1 | 3 | 4 | 9 |
| knee | 0 | 3 | 0 | 1 | 2 | 2 | 8 |
| lower leg | 1 | 3 | 7 | 11 | 4 | 7 | 33 |
| ankle | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| foot | 0 | 0 | 0 | 0 | 1 | 4 | 5 |
| unknown or unclassifiable | 5 | 14 | 15 | 23 | 29 | 35 | 121 |
| Total | 6 | 21 | 22 | 37 | 39 | 52 | 177 |

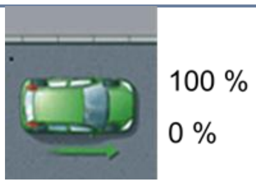
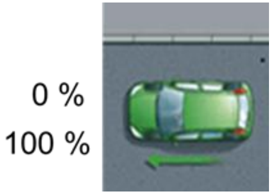


**Table 4–8: Number of GIDAS injuries (caused by bumper contacts only) by body region and contact position for all injury severities**

| | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|
| whole leg | 1 | 0 | 0 | 0 | 0 | 1 |
| upper leg | 3 | 2 | 3 | 4 | 2 | 14 |
| knee | 15 | 15 | 11 | 17 | 8 | 66 |
| lower leg | 35 | 34 | 23 | 25 | 16 | 133 |
| ankle | 2 | 2 | 0 | 1 | 1 | 6 |
| foot | 5 | 2 | 1 | 4 | 0 | 12 |
| unknown or unclassifiable | 2 | 0 | 3 | 2 | 1 | 8 |
| excluded (hip or pelvis) | 0 | 0 | 0 | 1 | 1 | 2 |
| Total | 63 | 55 | 41 | 54 | 29 | 242 |



The previous two tables included injuries of all severities to each of the various parts of the lower extremity. However, it is known that the injuries occurring most frequently in hospital admissions and likely to lead to the greatest burden of disability and cost will come from AIS 2 injuries to the knee and lower leg. To investigate these injuries specifically the breakdown of number of injuries by contact point and region of the lower extremity injured was limited to AIS 2 injuries only. These results are shown in Tables 4–9 and 4–10. Equivalent tables showing the AIS 1 and AIS 3 injuries only are provided in Appendix D.

Again it is evident that these injuries can be caused through contacts with any fifth of the vehicle front. In the context of a bias in injury occurrence towards the near-side of the vehicle, it is not obvious that any region is particularly injurious. Equally it does not appear as though there is a substantial decrease in injury risk towards the extremity of the bumper (based on the division into five portions). Using the more detailed breakdown of the vehicle front from the GIDAS data, into ten parts, there is some suggestion that fewer AIS 2 injuries are caused by the outer 10 percent of the vehicle front either side, although the numbers are small for all regions.

**Table 4–9: Number of OTS injuries by body region and contact position for AIS 2 injuries**

| | Unknown | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|---|
| whole leg | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| upper leg | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| knee | 0 | 3 | 0 | 1 | 1 | 2 | 7 |
| lower leg | 1 | 2 | 5 | 11 | 4 | 7 | 30 |
| ankle | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| foot | 0 | 0 | 0 | 0 | 0 | 4 | 4 |
| unknown or unclassifiable | 0 | 0 | 0 | 3 | 0 | 1 | 4 |
| Total | 1 | 5 | 5 | 16 | 5 | 14 | 46 |

**Table 4–10: Number of GIDAS injuries by body region and contact position for AIS 2 injuries**

| | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|
| whole leg | 1 | 0 | 0 | 0 | 0 | 1 |
| upper leg | 0 | 0 | 0 | 0 | 0 | 0 |
| knee | 3 | 2 | 2 | 3 | 3 | 13 |
| lower leg | 16 | 21 | 10 | 10 | 7 | 64 |
| ankle | 0 | 0 | 0 | 0 | 0 | 0 |
| foot | 0 | 0 | 0 | 1 | 0 | 1 |
| unknown or unclassifiable | 0 | 0 | 0 | 0 | 1 | 1 |
| excluded (hip or pelvis) | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 20 | 23 | 12 | 14 | 11 | 80 |

The accident data described above is used again in the following section to generate a target population for consideration of the potential benefit of any change to the corner definition used in the pedestrian safety regulation. The following section describes the extent of that target population for Europe and also the analysis of potential benefit.

## 4.5 Benefit analysis

This Chapter combines analyses of the On-The-Spot (OTS) and German In-Depth Accident Study (GIDAS) databases with crash test data and published information on European Union (EU) accident numbers and injury risks to estimate the likely range of EU-wide benefits for an improved regulatory test procedure, both in terms of casualty numbers and as Euro values (€).

To perform such calculations, and to reflect the inevitable uncertainties arising from limited and imperfect data, a series of assumptions have had to be made, as follows.

Major assumptions:

- That the OTS and GIDAS databases are broadly representative of car-pedestrian accidents across the EU;
    - The GIDAS study is set to represent accidents in Germany and OTS is known to have a bias towards severe crashes in Great Britain.
    - The assumption will be correct only if pedestrian accidents around Europe are the same as those occurring in Germany and GB.
- That an improved test procedure can only, at best, reduce serious injuries to slight injuries. The conservative assumption was taken that improved leg injury protection cannot prevent fatalities directly nor can it convert slight injuries into non-injuries;
    - This assumption is based on the belief that contacts with the bumper were not directly responsible for the death of any pedestrian and that changes to the bumper design would not be dramatic enough to prevent the risk of a slight injury being caused.
    - It may be that improved management of the leg contact phase of a pedestrian accident could influence the outcome in some fatal accidents.
- That any injuries sustained from parts of the car other than the bumper would not be prevented by an improved test procedure, so only those pedestrians seriously injured by contact with the bumper, and not by any other contact, can be affected;
    - Note that there may be a benefit to an individual and a reduced cost to society if a serious leg injury is reduced to slight injury, even if that individual still has a serious injury to another body region; however, the conservative estimate of zero benefit has been used in this study.
- That only a certain proportion of the cars’ bumper width can be improved by a new test procedure – the performance of the central and extreme outer portions would not be altered;

  - The performance of the bumper in the central region is already controlled via the legislation.
  - The performance of the vehicle corners may not need revision as pedestrian impacts there are likely to be glancing rather than perpendicular and very few hard components need to be placed there which would create injurious contacts

- That the numbers of reported road casualties in the EU under-estimate the true situation and that, therefore, some reasonable allowance has to be made for under-reporting;

These and other (less significant) assumptions are described and explained more fully in the following sections, along with an account of the various steps taken to derive the overall benefit estimates. The two major process steps were, first, to define the target population and, second, to estimate the effectiveness of the new test procedure. The 'target population' here is defined as all those seriously injured pedestrians who could be only slightly injured if the new test procedure was 100% effective in all the target situations. 'Effectiveness' is the proportion of that target population that would be likely to have their injury level reduced to slight in the real world.

### 4.5.1 Estimating the target population

The first step in estimating the overall numbers of casualties that could potentially be prevented is to relate the numbers of pedestrian to front-of-car collisions in the GIDAS and OTS databases to the number of (reported) accidents in the EU.

The corresponding proportions from GIDAS and OTS are shown in Table 4–11.

**Table 4–11: Pedestrian to front-of-car cases in GIDAS and OTS**

| Collision type | GIDAS | OTS |
|---|---:|---:|
| Pedestrians struck by front of car | 758 | 116 |
| All accidents investigated | 23,444 | 4.700 |
| **Proportion** | **3.2%** | **2.5%** |

The GIDAS figure, however, of 758 cases, excludes an unknown number where the pedestrian was struck by the front of a car but the exact point of impact was unknown, so the true proportion may be a little higher than the 3.2% figure. To account for this uncertainty, an upper estimate of 3.5% was used in the analysis process.

The OTS database is known to be biased towards higher severity cases, which could potentially affect the proportion of pedestrian to front-of-car cases in comparison to all reported accidents. Further analysis of the OTS data, however, suggests that its coverage of car to pedestrian impacts is broadly in line with GB's national statistics (as reported by STATS19) – 50% of such cases involve the front of the car in OTS whereas this proportion is 58% in STATS19. This suggests that the OTS proportion of 2.5% is probably a reasonable representation of the overall situation in GB.

For the purposes of making EU-wide estimates, therefore, the above analyses indicate that the number of pedestrian casualties arising from impacts with car fronts lies somewhere between 2.5% and 3.5% of all reported accidents.

The latest EU Transport Pocketbook (European Commission, 2012) reports that between 2009 and 2011 there were, on average, 1,140,494 reported injury accidents in the EU27 per annum. Using the 2.5% to 3.5% range, the numbers of (reported) pedestrian casualties arising from impacts with car fronts are estimated to be between 28,512 and 39,917 per annum.

The next step is to estimate what proportion of these casualties is likely to be seriously injured, as opposed to fatally or only slightly injured. The OTS and GIDAS databases again provide data on which to base such an estimate. In OTS, 53% of the pedestrians hurt in collisions with the fronts of cars were recorded as being seriously injured. In GIDAS, however, the overall casualty severities are classified by MAIS level. For the purposes of converting these into equivalent slight, serious and fatal casualties, it is assumed that MAIS 1 are all slight injuries, that MAIS 2, 3 and 4 are serious injuries and that MAIS 5 and 6 are fatal injuries. With these assumptions, the proportion of GIDAS casualties who are seriously injured in impacts with car fronts is 49% (for cars manufactured after 2000, Table 4–12).

**Table 4–12: GIDAS data – whole-body MAIS in frontal impacts with cars manufactured post-2000**

| Whole-body MAIS level | Equivalent severity level | Casualties | Proportion |
|---|---|---|---|
| MAIS 6 | Fatal | 5 | 6% |
| MAIS 5 | | 8 | |
| MAIS 4 | Serious | 11 | 49% |
| MAIS 3 | | 13 | |
| MAIS 2 | | 88 | |
| MAIS 1 | Slight | 105 | 46% |
| **All** | | **230** | **100%** |

The two databases are thus in very close agreement, and for the purposes of estimating EU-wide benefits it is assumed that 50% of all reported pedestrian casualties from front-of-car impacts are seriously injured as a result. This suggests that there are somewhere between 14,256 and 19,959 such casualties in the EU per annum.

The third step in estimating the target population is to make an allowance for under-reporting. This is the well-recognised propensity for some injury-causing road accidents (or injuries) to go unreported to the police or other authorities, and thus not be included in the official reported accident/casualty statistics at the country or European level. The most recent and comprehensive assessment of under-reporting in the EU formed part of the HEATCO project (HEATCO, 2006). This recommended that official seriously injured pedestrian casualty statistics should be multiplied by 1.35 to allow for under-reporting.

The overall correction factor for all accidents ("average injury") was recommended to be 2.25.

Since the HEATCO project, further work in the UK has indicated that estimates at that time were likely to be too conservative – the current recommendation in the UK is to factor official pedestrian casualty figures (all non-fatal severities) by between 1.6 and 3.7 (95% confidence limits), with a central estimate of 2.6 (Department for Transport, 2013). The HEATCO project further suggested that correction factors (expressed as a percentage) for slight injuries should be about four times those for serious cases, so an upper confidence limit of 3.7 implies a correction factor for serious injuries could be as high as 2.1, if serious and slight injuries are split fairly evenly in the overall reported figures (as suggested by OTS and GIDAS).

For the purposes of estimating the true numbers of seriously injured pedestrians resulting from impacts with car fronts in the EU per annum, a range of correction factors of between 1.35 and 2.1 is used. This takes the likely numbers of casualties to between 19,246 and 41,913 per annum.

The fourth step is to exclude all those casualties whose impact with the car front is with parts of that front unlikely to be affected by the proposed changes to the test procedure. This involves combining OTS and GIDAS data to calculate the likely distribution of impacts across the car front, and excluding those that fall within the central or extreme outer edge regions.

The analyses of the GIDAS and OTS databases reported earlier in this report found that there was, approximately, a linear relationship between contact position and number of casualties, with approximately 71% (OTS) – 90 % (GIDAS) of the variability in number of casualties being explained by the variability in contact position. These data (for post-2000 cars) are combined in Figure 4-7, for the five contact position ranges common to both databases (0-20, 21-40, 41-60, 61-80 and 81-100) and swapping the OTS distribution around to allow for GB cars driving on the other side of the road to their German counterparts.

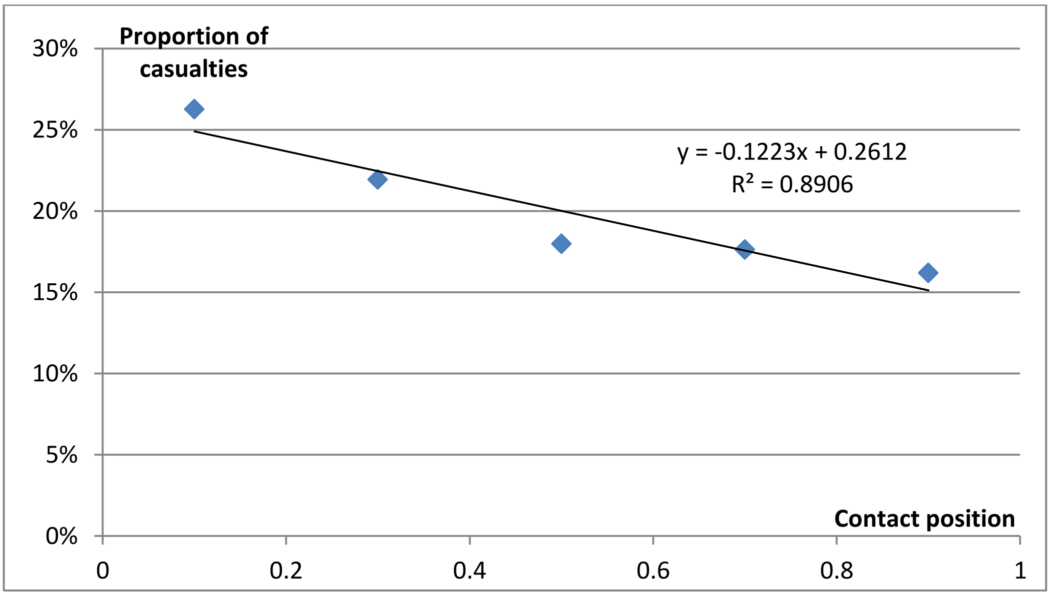


**Figure 4-7: Combined GIDAS and OTS data – distribution of frontal impacts for post-2000 cars.**

The line of best fit equation (shown in the figure) can then be used to calculate the distributions for various different ranges of contact position (as long as they are each 20% wide). Because the distribution is linear, and the test procedure will not differentiate between one side of the car and the other, it is also possible to deduce that any combination of two 20%-wide ranges either side of the centre line must always sum to 40% of the casualties, and any two 10%-wide ranges similarly equally spaced from the centre line must sum to 20% of the overall casualties. It is impossible to know with any great certainty exactly how car designs will change as a result of any new test procedure, and exactly how much of the frontal width of the bumper would be changed (improved). It seems reasonable, however, to suppose that the central portion and the extreme outer edges would not be affected, but exactly how much of the intermediate areas would be improved is very difficult to predict.

An optimistic, but probably still reasonable, estimate is that the two 10%-wide bands between 21-30% and 71-80% contact positions would be improved (i.e. the central 31-70% region and the two outer 20% bands would be unaffected). A more pessimistic, but no less reasonable, estimate is that only two 5%-wide bands in these regions would be affected. This scenario would mean that only 10% of the cars’ width is potentially improvable.

These pessimistic and optimistic scenarios combined gives estimates of the likely proportions of casualties that could potentially be ‘saved’ of between 10% and 20%. The EU-wide estimates of the numbers of seriously injured pedestrians in frontal impacts with cars, struck by those parts of the car front that could potentially be improved by a new test procedure are thus between 3,850 and 16,769.

The final step in the calculation of the target population is to exclude all seriously injured casualties who sustain serious injuries from parts of the car or road infrastructure other than the car bumper. Changes to the bumper design are assumed not to affect the overall severity of any such casualty – i.e. they would still get the serious injury from the other contact and thus still be classified as seriously injured overall. However, whilst not included in the benefit calculation, it should be noted that there would be a real benefit to the casualty and to society of mitigating serious injuries even when occurring alongside another serious injury.

Only the GIDAS database could be analysed to this level of detail. Out of an original sample of 244 cases (involved in frontal impacts with post-2000 cars), 32 (13%) definitely had a bumper-caused AIS 2 or AIS 3 injury (i.e. serious) and no other injury above AIS 1 (slight). However, due to a change in the categorisation of cerebral concussion injuries, an unknown number of further cases were excluded, because for consistency the old categorisation of such injuries as AIS 2 was applied (on the basis that the reported loss of consciousness could have been correct). Current practice defines cerebral concussion as AIS 1 if it cannot be validated by a physician or medic. It is possible that up to 11 further cases should thus not have been excluded (because the bumper caused injury was AIS 2 and the concussion could have been classed as AIS 1 using the latest scoring codes). As a consequence, the target population cases could have been as high as 43, 18% of the original sample of 244 cases.

The overall range of estimates is thus 13% – 18%, and the final estimates for the EU-wide target populations are **between 252 and 1,478 casualties per annum**. This represents the likely range of estimates for the numbers of seriously injured pedestrians in front-of-car impacts who could potentially be amenable to conversion to slight injuries only, if the new test procedure is effective in all relevant cases.

### *4.5.2 Summary of target population calculations*

The preceding section gives the full details, but in outline the target population estimate has been derived as summarised in Table 4–13.

**Table 4–13: Summary of calculation steps to derive EU target population estimate**

| Step | Lower value | Upper value | Lower EU estimate | Upper EU estimate |
|---|---|---|---|---|
| Step 1.<br>Apply proportions of accidents in GIDAS and OTS involving pedestrians struck by car fronts to overall EU reported figures | 2.5% | 3.5% | 28,512 | 39,917 |
| Step 2.<br>Estimate proportion likely to be seriously injured, based on OTS and GIDAS data | 50% | 50% | 14,256 | 19,959 |
| Step 3.<br>Make allowance for under-reporting to estimate true numbers of casualties | 1.35 | 2.10 | 19,246 | 41,913 |
| Step 4.<br>Exclude cases where point of impact with car front is unlikely to be affected by changes to test procedure | 10% | 20% | 1,925 | 8,385 |
| Step 5.<br>Exclude cases where serious injuries also caused by parts other than the bumper | 13% | 18% | 252 | 1,478 |
| **Target population estimate** | | | **252** | **1,478** |

### *4.5.3 Target population valuation*

The HEATCO project, described earlier, also reviewed the various approaches across the EU to putting a financial value on casualties. It suggested that a willingness-to-pay approach should be used. Amongst those countries where such an approach was followed, data reproduced by the project indicates that the UK valuation at the time was broadly in line with most other countries. In the absence of an official EU-wide figure, therefore, it is reasonable to apply the current UK valuations as a proxy for an EU-wide average.

The current (2012) UK valuations for serious and slight road accident casualties are £191,462 and £14,760 respectively (Department for Transport, 2013). Converting a serious injury into a slight injury, therefore, will save, on average, £176,702. The average exchange rate over the last two years between the GBP and Euro has been 1.20. At the time of writing, the rate is currently 1.19. Applying the rate of 1.2 Euros to the pound gives an overall valuation for converting one serious injury into a slight injury of €212,042.

If all the above target population casualties are reduced from serious to slight as a result of changes to the test procedure, the financial savings at current prices and based on a willingness-to-pay approach would thus be **between €54 million and €313 million**.

### *4.5.4 Effectiveness estimates*

The primary route by which the potential effectiveness of a new test procedure has been estimated is through use of the crash test results, and specifically converting legform peak injury measures into (AIS 2+) injury risks.

Modelled AIS 2+ injury risk data for two of the measured parameters is available from Takahashi et al. (2012), for the Medial Collateral Ligament (MCL) elongation and the tibial bending moment. Each car tested produced a peak measure of each of these parameters, and the data in Takahashi et al. allows each of those values to be used to estimate the average risk/probability of a serious injury arising. These can then be compared against the equivalent probabilities for a car that just meets the proposed test limit values to estimate how much of a reduction in serious injury probability there might be if the cars tested that exceeded those limits were redesigned in such a way as to produce the limit values (i.e. to just pass the new test).

The overall risk of a serious injury is needed to make these calculations, so the individual risks from the MCL and Tibia need to be combined. This is achieved via the following calculation:

For two independent events with probabilities a and b, four scenarios are possible:

i. Event a only occurs - probability = a x (1 – b)
ii. Event b only occurs - probability = b x (1 – a)
iii. Both events occur – probability = a x b
iv. Neither event occurs - probability = (1 - a) x (1 - b)

Only the fourth of these results in no serious injury overall, so the overall probability of a serious injury being sustained (i.e. a, b or both occur) is given by the sum of the first three occurrences (or 1 minus the probability of the fourth occurrence which is mathematically equivalent).

The probability of a serious injury, $P_S$, arising is thus:

$$P_S = a - ab + b - ab + ab = a + b - ab$$

Table 4–14 shows the results of these calculations for the crash test results and the limit values.

### Table 4–14: Test data and limit values – calculated probabilities of serious injury (using risk probability curves in Takahashi et al, 2012)

| Test | Peak MCL Elongation (mm) | MCL AIS2+ probability (a) | Peak Tibia Bending Moment (Nm) | Tibia AIS 2+ probability (b) | Overall AIS 2+ probability (a+b-ab) |
|---|---|---|---|---|---|
| **Limit values** | 22.0 | 0.64 | 340 | 0.29 | 0.74 |
| **Vehicle 1** | 18.8 | 0.21 | 314 | 0.21 | 0.38 |
| **Vehicle 2** | 23.7 | 0.84 | 395 | 0.51 | 0.92 |
| **Vehicle 3** | 24.8 | 0.93 | 265 | 0.10 | 0.94 |

It is worth noting that meeting the limit values exactly for the peak MCL elongation and tibia bending moment would still be associated with a 74 percent risk of an AIS2+ lower extremity injury. This value is dominated by the MCL injury risk which is 64 percent at the proposed regulatory limit of 22 mm according to the risk curves reported by Takahashi et al. (2012).

For Vehicle 1, it can be seen from the values in Table 4–14 that the test parameters were both comfortably within the limit values. This was also true for this vehicle on the third parameter (posterior cruciate ligament elongation) – as indeed it was for all the cars tested. For the designers/manufacturers of this vehicle, therefore, there would be no need to alter the design to comply with the new test procedure and thus it can be assumed that there would be no change in injury risk. For vehicles 2 and 3, however, changes would need to be made around the end of the bumper beam to ensure compliance with the proposed test limits. Assuming these changes would be just sufficient to pass the test, the resulting decreases in serious injury risk would be from 0.92 (Vehicle 2) and 0.94 (Vehicle 3) down to 0.74 (limit values). For Vehicle 2, this would entail a 20% reduction in overall serious injury risk, and for Vehicle 3 it would be equivalent to a 21% reduction.

As stated, it is assumed that protection levels would be brought down to exactly the threshold limit. However it is expected that, to account for production tolerances so that every vehicle produced will meet the requirements, manufacturers would allow an additional margin bringing the mean vehicle response below the threshold. The precise magnitude of this allowance could vary from one manufacturer to another and is not known. Hence the conservative assumption of zero margin below the threshold.

Across the three vehicles tested, therefore, **the average reduction in risk arising from introducing the new test procedure would be (rounding to the nearest whole number) 14%**. This is therefore the best estimate of the overall effectiveness of the new procedure, assuming of course that the three cars tested are all equally representative of all cars in use in the EU. This assumption is somewhat supported on the basis of the sales figures for Europe (as were reproduced in Table 3–1), which indicated that there were some of the best-selling models in recent years. A further assumption is that the new test procedure is representative of all pedestrian leg impacts with car bumpers in the regions of the car front estimated to be relevant in the above target population calculations. In particular, the end of the bumper beam may be the worst case in terms of injury risk. Therefore this level of improvement would be an overestimate for the rest of the vehicle front. However, the size of the area used in determining the target group has been set conservatively to account for this.

In summary, the crash test data analyses suggest the new procedure might have an overall effectiveness of 14%. Using this figure, **the overall estimated casualty savings from revision of the legform test procedure, along with their valuations, are shown in Table 4–15**.

**Table 4–15: Overall estimates of casualty and financial benefits of the revised legform test procedure**

| Estimate | Casualties (lower) | Casualties (upper) | Valuation (lower) €million | Valuation (upper) €million |
|---|---|---|---|---|
| **Target population** | 252 | 1,478 | 54 | 313 |
| **Overall effectiveness**<br>(14 % of the target population) | **35** | **207** | **7** | **43** |

The central estimates are thus that the new procedure would prevent 96 serious injuries in the EU per annum (+111/-61), and save €20 million per annum (+€23m/-€13m).

# 5 Potential regulatory changes

Following the result that indicated extension of the test area ought to provide some non-zero benefit, consideration was given to how the potential options (identified in Section 3.4) for a change in the bumper test area could be written into the regulatory text. The initial and most profound changes that would be required are described in the following paragraphs.

It should be noted that these potential amendments are based initially on the original GTR No. 9 and Regulation 127 (Revision 2, 2013). Before implementing any changes it needs to be confirmed that amendments published from this point onwards don’t influence or alter the changes described below. For instance, there are other draft amendments which may require changes: e.g. GRSP-54-07-Rev.1 (for GTR) and ECE/TRANS/WP.29/GRSP/54/Add.1 (for Regulation 127) include a proposed change to the 66 mm legform radius adjustment.

Also, depending on transition timescales, it may be desirable to consider modifying both the current test procedures that use the EEVC legform and the amended versions that use the Flex-PLI, as the former may remain in use for some time after the latter are published.

Based on the order of the Options and the arbitrary numbering given to them, the following points describe changes that may implement each option. Initially, the definitions of the test area are considered.

1. **No change to the test area**

2. **Extend bumper test area to end of bumper beam**

   In GTR 9 replace Paragraph 3.13 with the following two paragraphs and delete Figure 5:

   > "Corner of bumper" means the outer surface of the bumper directly in front of the outermost ends of the bumper beam/lower rails/cross beam structures.
   >
   > The corner is to be defined by the manufacturer and confirmed by the test laboratory based on information provided in the communication accompanying the application for approval of a vehicle type.

   In Regulation 127, change Paragraph 2.14 in the same way.

   As it is not necessarily the case that the bumper beam will always extend beyond the current corners a qualifying statement may be needed instead, where the furthest point from the centreline is taken either from the 60 degree plane definition or from the underlying structure.

## 3. Extend to 45 degrees

In GTR 9 Paragraph 3.13 replace “60°” with “45°”.

In GTR 9 replace Figure 5 with Figure 5-1.

In Reg. 127 paragraph 2.14 replace “60°” by “45°”.

In Reg. 127 replace Figure 5 with Figure 5-1.

In draft Reg. 127 amendment (ECE/TRANS/WP.29/GRSP/54/Add.1) similarly amend Paragraph 2.16 and Figure 5.

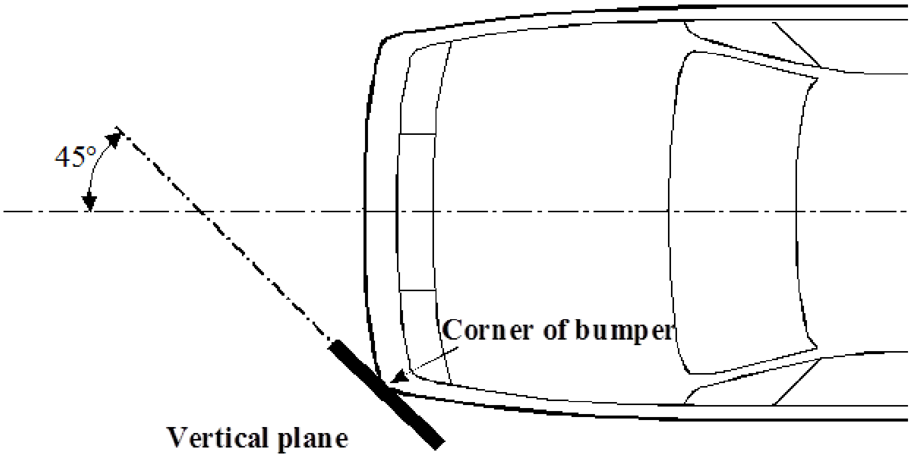


Figure 5-1: Corner of bumper

## 4. Remove bumper corner limits

The minimum change here is to define points on the vehicle that set the whole width as the corners of the bumper.

> 3.13. "Corner of bumper" means the vehicle's point of contact with a vertical plane which is parallel to the vertical longitudinal plane of the vehicle and is tangential to the outer surface of the bumper (see Figure 5 {to be amended}). The rear edge of the plane shall be in-line with the centre of the front axle. The plane shall not contact wing mirrors or other external projections.

However, it may be better to amend paragraphs 3.8 and 3.10 so the corner definition in 3.13 can be deleted.

> 3.8. "Bumper" means the front, lower, outer structure of a vehicle. It includes all structures that are intended to give protection to a vehicle when involved in a low speed frontal collision and also any attachments to this structure. Structures at the side of the vehicle that protrude laterally beyond the front structure may also be considered as part of the “bumper”. The reference height is identified by the bumper reference lines.

> 3.10. "Bumper test area" means the frontal surface of the bumper limited by two longitudinal vertical planes intersecting the corners of the bumper {or new definition of vehicle width} and moved 66 mm parallel and inboard of the corners of the bumpers.

Also change Paragraphs 2.9 and 2.11 of Reg. 127.

In addition, the bumper thirds also need to be considered, as using a flexible tape may no longer be appropriate.

> 2.32. "Third of the bumper" means the width of the vehicle between the bumper corners, divided into three equal parts and transposed to the outer contour of the bumper.

In Annex 5, Paragraph 1.5.

> 1.5. A minimum of three lower legform to bumper tests shall be carried out, one each to the middle and the outer thirds of the bumper at positions judged to be the most likely to cause injury. Tests shall be to different types of structure, where they vary throughout the area to be assessed. The selected test points shall be a minimum of 132 mm apart~~, and a minimum of 66 mm inside the defined corners of the bumper~~. These minimum distances are to be set with a flexible tape held tautly along the outer surface of the vehicle. The positions tested by the laboratories shall be indicated in the test report.

With regard to the options for changes to the alignment and impact conditions:

### A. No change to the impact conditions

### B. Allow vehicle rotation

In GTR 9 replace Paragraph 7.1.1.2., 7.1.1.4., 7.1.2.2. and 7.1.2.3. with the following paragraphs and replace Figure 16 with Figure 5-2. In Regulation 127 make similar changes to Annex 5, Figure 1 and paragraphs 1.6, 1.12, 2.6 and 2.7:

> 7.1.1.2. The direction of the impact velocity vector shall be in the horizontal plane. To reduce the incident angle between the direction of the impact velocity vector and the outer surface of the bumper, the vehicle can be rotated with respect to the impact velocity vector.
>
> The intended incident angle for each test position can be specified by the manufacturer, to be in the range from 0 degrees where the vehicle is rotated so that the impact velocity vector is perpendicular to the outer bumper surface at that point and a maximum where the vehicle longitudinal vertical plane is coincident with the impact velocity vector.

The tolerance for the direction of the velocity vector in the horizontal plane and in the specified vertical plane shall be ± 2° at the time of first contact. The axis of the impactor shall be perpendicular to the horizontal plane with a tolerance of ± 2° in planes lateral and longitudinal to the specified velocity vector. The horizontal plane and planes longitudinal and lateral to the specified velocity vector are orthogonal to each other (see Figure 16).

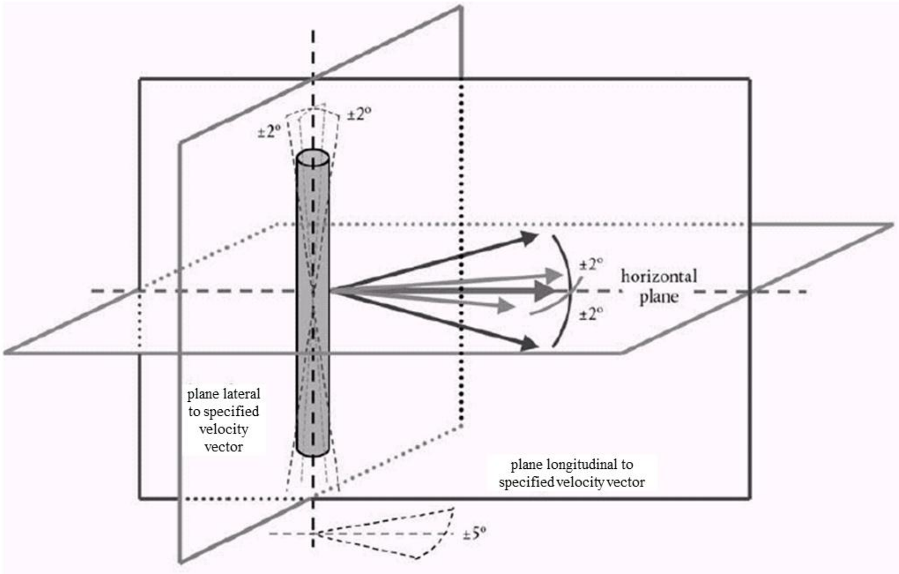


**Figure 5-2: Tolerances of angles for the lower legform impactor at the time of the first impact (see paragraphs 7.1.1.2. and 7.1.1.3.2.)**

7.1.2.2. The direction of the impact velocity vector shall be in the horizontal plane. To reduce the incident angle between the direction of the impact velocity vector and the outer surface of the bumper, the vehicle can be rotated with respect to the impact velocity vector.

The intended incident angle for each test position can be specified by the manufacturer, to be in the range from 0 degrees where the vehicle is rotated so that the impact velocity vector is perpendicular to the outer bumper surface at that point and a maximum where the vehicle longitudinal vertical plane is coincident with the impact velocity vector.

The direction of impact shall be along the specified axis, with the axis of the upper legform vertical at the time of first contact. The tolerance to this direction is ± 2°.

The impact velocity of the impactor when striking the bumper shall be 11.1 ± 0.2 m/s unless the vehicle is rotated.

Where the vehicle is rotated with respect to the impact velocity vector, the test speed shall be reduced to keep the perpendicular component of the impact consistent regardless of the chosen alignment. The reduced test speed is calculated using the following relationships.

With the vehicle longitudinal vertical plane aligned with the impact velocity vector, determine the incident angle between the impact vector and the outer surface (θ1)

With the vehicle rotated to the nominated manufacturer angle, determine the incident angle between the impact velocity vector and the outer surface (θ2)

Using θ1 calculate the perpendicular velocity in the longitudinally aligned test:

$$11.1 * \cos(\theta 1) = v1 \ (m/s)$$

Using θ2 calculate the perpendicular velocity in the rotated test:

$$11.1 * \cos(\theta 2) = v2 \ (m/s)$$

The impact velocity is reduced from the nominal 11.1 m/s by the ratio of v1:v2:

$$11.1 * (v1/v2) = \text{impact velocity for the test}$$

Ensure that the final sentence of Paragraph 7.1.1.4. (pertaining to the effect of gravity) is maintained.

Also change Paragraph 7.1.2.3. of the GTR in a similar way noting that for the upper legform impactor there is no requirement on the effect of gravity.

### C. Mandated rotation of the impact direction

The direction of the impact velocity vector shall be in the horizontal plane.

At test positions where the incident angle between the direction of the impact velocity vector and the outer surface of the bumper would be greater than [15] degrees, the vehicle must be rotated to maintain this angle as a maximum.

All other changes would follow Option B.

Note that the 15 degree angle is to be confirmed, as denoted by the square brackets.

Furthermore, as definitions of bumper corners and bumper test are apply equally to the high bumper test using the upper legform, it will be important to address those tests as well as the legform to bumper tests. The influence of large incident angles for the upper legform was beyond the remit of the test programme within this project. However, it is expected that the following issues might occur for the upper legform:

- Issues with the load transducers – inaccurate readings or even damage, due to shear loading
- Issues with guidance system – damage or high friction, due to lateral loading

- Issues with launching – firing system may not have sufficient stroke for some oblique set-ups

## 5.1 Additional option

After presenting these options at the fifth meeting of the Task Force – Bumper Test Area, an additional idea was put forward for consideration (Insel et al., 2014). This is described in the following section.

It should be noted that a second option was also presented by Insel et al. However, this was to measure the bumper corners at the 60° planes and measuring the overall width of the bumper structural parts and defining the test area using the wider of the two. This seems to be a sensible interpretation of Option 2, as described above.

The other new option was described as:

> “Applying the existing bumper corners in the height where today structural interaction is required by bumper regulations (445 mm for UN R42, 16 –20 inches (406–508 mm) for CFR part 581).” (Insel et al., 2014)

The supporting reasoning for this proposal is that, pedestrian injuries are assumed to be caused mainly by the structural parts of the underlying surface. These structural parts are configured in response to various functional requirements, but importantly are already designed so as to meet the requirements of the bumper tests in UN Regulation 42 and the US Code of Federal Regulations, Part 581.

The existing bumper test procedures include a corner impact test which, as discussed in Section 2.2, uses a plane at 60° to the longitudinal plane of the vehicle in its definition. The reason for the mention of the measurements in the Insel et al. presentation is because these are the reference line heights used in those procedures. For instance in UN Regulation 42, the corner impact is aligned with the centre of the impactor at the height of 445 mm; whereas, in Part 581, the reference line can be between the heights of 16.1” and 20”. The 60 degree alignment (± 5 degrees, Reg. 42; ± 2 degrees, Part 581) is checked at the height used for the test. In both cases, the impact face has an initial contact surface with a 4.5” height (114 mm).

If something similar to the Part 581 definition was adopted for pedestrian testing, it could be imagined that the bumper corners would be defined as the points with greatest separation where a 60 degree plane to the vehicle longitudinal plane contacts the surface of the vehicle within the height range of 406 to 508 mm. The only change from the current test area definition is then the limited height range, rather than considering the vehicle profile throughout its full height.

At the meeting where this proposal was presented, ACEA accepted an action to draft text based on this idea in preparation for the next meeting of the Task Force – Bumper Test Area. This next meeting is scheduled to take place on 15 May 2014 in Paris.

It is suggested that evidence would be needed to ensure that this option would ensure that the tested area definitely included the bumper beam and therefore could give the benefit identified in Section 4.5.

With all of these options, there may still need to be a decision as to whether the 66 mm impactor radius allowance would remain or be removed.

# 6 Discussion

Within the ACEA presentation by Insel et al. (2014) there are some comments related to the accident analysis task conducted within this project. One of these relates to an ambition to consider the relative injurious nature of cars which have a pronounced tapered or angular bumper design and other vehicles (perhaps older models) without those design features. This additional investigation was not carried out within this project because the case numbers from the OTS study would not allow such detailed investigation and because it was outside of the scope of work provided by VUFO in analysis of the GIDAS data. In principle there may be enough cases in the GIDAS data to make such an investigation possible and this is therefore recommended for further study. However, care should be taken when defining the study for the following reasons:

- As mentioned in Section 3.1, there has been a trend for newer vehicle designs to have smaller bumper test areas. There are examples of car designs in the modern vehicle fleet where the bumper corners are still wider apart than is normal for most high-selling models. However, there may be other design reasons to explain such differences. Therefore the comparison between cars with angled or curved bumpers and those with larger test areas could be compromised by other vehicle design changes between those two groups.
- Case numbers are limited even in the GIDAS groups. Features of the crash conditions that will have to be taken into account when considering the injurious nature of vehicle designs are: the severity of the collision, the fragility of the pedestrian and the contact position on the vehicle. In the GIDAS sample prepared for this study there were 242 leg injuries of all severities (133 to the lower leg and 66 to the knee), of which 80 were AIS 2. This number would allow statistical treatment of the crash conditions and then investigation of the relationship of vehicle age and vehicle design. However, there were only 51 lower leg injuries from contacts to the two ends (outer 20% each side) of the width of the vehicle. This number would preclude such an analysis. Therefore, it is still marginal as to whether meaningful results can be obtained from the investigation of whether front-end shape affects injury risk for pedestrian accidents.

The presentation by Insel et al. (2014) rejected the idea of rotating the vehicle with respect to the direction in which the legform test tool is fired. The reasons cited were:

> 1. "The vehicle and/or the launcher unit has to be turned and adjusted several times during each single test series
> 2. In several cases, test facilities are not spacious enough to turn vehicles for an angular impact and/or launcher units are not able to be turned
> 3. Testing in an angle to the driving direction as applied by TRL creates artificial loadings that do not occur in real accidents"

As such, the ACEA Members' Proposal seems to suggest using straight tests (where the direction in which the legform is fired is parallel to the vertical longitudinal plane) even at the end of the bumper beam. During the Flex-PLI tests conducted for this project the end of the bumper beam was one of the target points used. In those tests substantial rotation of the legform was observed at the time of peak values in the injury metrics.

It may be that Insel et al. are correct in that rotation of the vehicle or legform firing system is not a feasible solution to reducing the potential incident angle with the bumper surface. However, if the bumper test area is extended without this measure to reduce legform rotation then it can be inferred that the behaviour of the rotating legform is accepted.

During the 5th meeting of the Task Force – Bumper Test Area, there was some discussion surrounding the options presented. It was reiterated that any change to the bumper corner definition would have the aim of returning the test procedure to its intended coverage of the vehicle front. The concept to extend the test area to include the bumper beam was generally accepted as this seems relevant with respect to the potentially injury causing elements within the bumper area. However, Option 2, which extends the test area to the end of the bumper beam has the potential problem of defining the 'bumper beam' in a way that is acceptable for easy adoption of the legislation. To address this problem, the definition used in the RCAR bumper test procedure could be used. This definition has already been accepted by U.S. parties such as the Insurance Institute for Highway Safety (IIHS). It may also be possible to clarify the definition further by adding additional statements such as, "any attachment supports or brackets intended to hold other components such as a horn or fluid tanks are not considered".

> "Bumper Beam: Structural cross member under the bumper fascia protecting the front or rear of the vehicle (Note: The beam does not include foam, cover support or pedestrian protection devices)." (Research Council for Automobile Repairs, 2010).

One of the issues raised with regard to Option 5, but which also relates to Option 3, is that the use of a new 60 degree (or 45 degree) definition is its unchanged sensitivity towards vehicle design features. By selecting one of these options, there may be many modern vehicles for which their bumper test area would be extended ompared with the existing 60 degree definition. However, it is entirely reasonable to expect that vehicle front-end designs react to the new definition and in the future the bumper test area return to something similar to todays. Thus, it can be imagined that the same issue may occur again in several months or years.

As an example of vehicle front designs responding to new stimuli, The Insurance Institute for Highway Safety (IIHS) in the U.S. recently implemented a small overlap frontal crash test. Already, vehicle designs are having components added to them in order to control the frontal deformation during this test. The counter-measure seen on face-lifted, rather than new model, vehicles often includes an extension of the bumper beam. In this way the width of the bumper beam hard components can be seen to be independent of the profile of the bumper skin. As such, the options based on bumper surface geometry offer no guarantee of including all of the underlying hard structural parts within the test area.

Indeed an example was readily found for a European current high-volume vehicle which has a bumper beam which extends beyond the corners, as would be defined with Option 5. In this case (Figures 6-1 and 6-2) the difference between the bumper beam width and the proposed impact zone was approximately 140 mm. This shows how this change in definition for the bumper corner will not include the hard structures around the end of the bumper beam for all vehicles. As such it may not offer a means of obtaining the full benefit identified within this report (in Section 4.5).

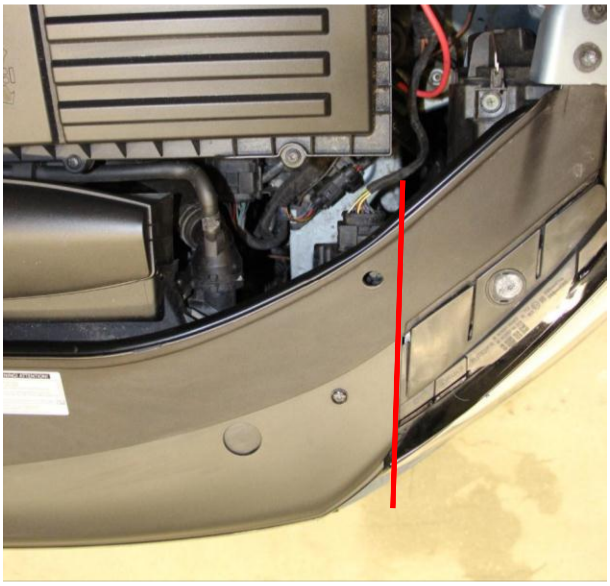


**Figure 6-1: End of the bumper beam (end of longitudinal member) indicated with the red line**

**Figure 6-2: Bumper corner according to Option 5**

30 degree plate at bumper height
(in the range 350 to 550 mm)

As mentioned in Section 2.2, the current study has been concerned with how the corner definition is used in the pedestrian test procedures, and whether it should be changed. This project has identified links between pedestrian and low-speed bumper protection standards such as UN Regulation 42. Therefore, the issue that the vehicle corner (as defined in the regulations) has migrated towards the centre of the vehicle in recent years may affect the bumper tests as well as the pedestrian tests. It is suggested that it may be prudent to review whether the bumper regulations are still adequate for current vehicle designs.

# 7 Summary and Conclusions

While the number of pedestrian injuries and fatalities continues to decline, year on year, within the European Union, this rate of decrease is no longer equivalent with the total traffic fatalities.

The pedestrian protection bumper test procedures within UN GTR No. 9, UN Regulation 127 and Commission Regulation (EC) No. 631/2009 all use a plane at 60 degrees to the vehicle longitudinal plane to define the bumper corners for vehicles. The area tested is within the limits of the bumper corners (66 mm inside on both sides).

After initial proposals for pedestrian test procedures included the definition of bumper corners using a 45 degree plane to the vehicle longitudinal axis, this was changed to the 60 degree plane used currently. This 60 degree definition seems to have been prompted through discussions surrounding the efforts of EEVC WG 10 in drafting pedestrian test procedures early in the 1990s. The motivation is likely to have come from an intention to harmonise definitions with the low-speed bumper test procedure within UN Regulation 42.

Amongst other groups, Euro NCAP has noticed that bumper corners of modern vehicles have tended to migrate away from the sides of the vehicles, minimising the area defined for testing. In response to this trend they have adopted legform test procedures which allow testing to extend to include stiff structures underlying the bumper skin. However, concerns have been raised as to whether the EEVC and Flex-PLI test tools behave reasonably and provide reliable injury metrics when testing beyond the 60 degree plane bumper corners.

The trend for decreasing bumper test areas was observed through a survey of modern vehicles. Some new models of car can have a testable area which represents as little as 40 percent of the vehicle width.

Three vehicles were selected for testing and underwent a series of tests with the EEVC legform impactor and then the Flex-PLI. This testing demonstrated that:

- Outside of the current bumper test area there are hard structures which give results indicating their potentially injurious nature
- The legform impactors rotate substantially in oblique impacts with the bumper
- If it was desired to test at wide positions of the bumper, a practical solution to reduce the rotation of the legform might be to rotate the vehicle with respect to the impactor launching direction. However, this solution may not be feasible for all test houses without substantial changes to accommodate such a setup.

Pedestrian casualty data from the UK and Germany were reviewed to see how vehicle-pedestrian contacts were distributed across the width of the vehicle and how the injury risk was distributed also. This analysis showed that pedestrians were struck by and could receive leg injuries from all regions of the vehicle front. It was not obvious that any one region was particularly safe or injurious based on the small samples considered.

Based on the test results and accident analysis the level of benefit was estimated for extending the area of the bumper tested. Conservatively, assuming such a change would require a small area of the vehicle width to be revised for some vehicles, it was anticipated that 35 to 207 moderate injuries could be mitigated in Europe each year. This led to a central estimate of a benefit of about € 20 million.

Along with a ‘do nothing’ option, four different options have been proposed for ways of extending the test area to encompass the hard points around the end of the bumper beam. These are described in the report and the main changes to the regulations that would be required to implement them are suggested. This includes the potential accompanying solution of turning the vehicle with respect to the direction in which the legform is launched to reduce the incident angle with the bumper. This extra change is only necessary if the rotation of the legform during the impact is considered too problematic to allow longitudinal tests outside of the current test area.

It is not known to what extent these options are feasible.

Based on discussions during the Task Force – Bumper Test Area meetings supporting the Informal Group on Pedestrian Safety Phase 2, it seems as though a candidate proposal from ACEA may be closest to being adopted. Some issues with this option have been discussed in this report in an attempt to capture the discussions taking place within the Task Force.

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# Appendix A Information obtained from review of historic EEVC documents

As described in Section 2.1, a review of EEVC documents was undertaken to find information supporting the historic change in pedestrian protection bumper test procedures from using a 45 degree plane to the currently defined 60 degree plane. The following text describes the history of the development of the bumper test procedure and the groups contributing to this development. It has a particular focus on each of the documents identified around the time when the switch from 45 to 60 degrees took place and describes the information in a chronological manner starting with four steps leading up to the time of the change.

1. Working Group 7 (WG7) on Pedestrian Injury Accidents reviewed pedestrian accident data in Europe.
    a. The group reported to the ninth Experimental Safety Vehicles (ESV) conference in 1982 (European Experimental Vehicles Committee Working Group 7, 1982).
2. The EEVC then set up an ad-hoc group to make proposals for safety improvements.
    a. This group reported to the tenth ESV conference in 1985 (European Experimental Vehicles Committee ad hoc group, 1985).
    b. At the same conference, Harris (1985) proposed a set of pedestrian test procedures in outline.
3. Later in 1985, the UK Department for Transport submitted detailed test procedures to the United Nations Economic Commission for Europe (UNECE) Groupe de Rapporteurs on Crashworthiness (GRCS) (Department of Transport, 1985).
    a. This document was based on the proposals in the two 1985 ESV papers.
4. In 1986, the UK Department for Transport submitted a document with detailed test procedures to the European Commission’s (EC) advisory group European Regulations, Global Approach – Safety (ERGA Safety) (Department of Transport, 1986).
    a. This was based on the above UNECE GRCS document and the EEVC ad hoc group paper. This document and the GRCS document both define the corner of the bumper using a plane at 45°.

The latter proposal, document ERGA S60 (Department of Transport, 1986), was discussed by ERGA Safety, who recommended that the EEVC carry out further work. EEVC WG10 was set up in 1987 to carry out this work, chaired by John Harris of TRRL. The European Commission also set up a contract with a number of research organisations to part fund the required work, though this contract was not signed until 1990. These contractors carried out almost all of the work undertaken by WG10 in the first phase (to early 1991). The work was divided up so that these contractors were responsible for specific aspects. The contractors and their responsibilities were:

- Transport and Road Research Laboratory (TRRL, UK): upper legform to bonnet leading edge test; WG10 chair

- Institut National de Recherche sur les Transports et leur Sécurité (INRETS, France): legform to bumper test
- Bundesanstalt für Straßenwesen (BASt, Germany): headform to bonnet top test
- Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (TNO, The Netherlands): computer simulations; compatibility
- Association Peugeot SA / Renault (APR): compatibility

The first meeting of EEVC WG10 was in January 1988. These continued through to an eighth meeting in October 1990 (subsequent meetings were described as 'extra' meetings starting with the first extra meeting in September 1991). In April 1990, there was a meeting of the coordinating committee for the contract, which appears to have been the first such meeting. There were a further three such meetings, though no minutes of the last meeting were found in TRL's WG10 papers. The meeting minutes of these WG10 and coordinating committee meetings were reviewed by TRL. Nothing of relevance was found (i.e. relating to the bumper corner definition) up to and including the seventh WG10 meeting in June 1990.

With respect to the September 1990 meeting of the coordinating committee the following sentences from the minutes are relevant:

- "The paper promised by the chairman on the definition of test areas is urgently required by TNO."
- "The chairman agreed to modify the ERGA 60 proposal… "

This proposal is the previously mentioned ERGA S60 document (Department of Transport, 1986). An anonymous and undated document appears in TRL's WG10 archive chronologically slightly before these minutes, but it is reasonable to assume that it is the first requested document, which was presumably produced soon after this meeting. Making this assumption, it can be cited as Harris (1990). This document still defines the corner of the bumper using a plane at 45°.

The next meeting of the coordinating committee was scheduled for the morning of 22 October 1990, before the full WG10 meeting started in the afternoon. Unfortunately, TRL's WG10 papers didn't include any minutes for the coordinating committee meeting. However, it seems unlikely that this meeting would have discussed detailed issues concerning the test area.

The minutes of the following, full WG10 meeting (22-23 October 1990) record that "The chairman distributed copies of his draft proposal for EEC type-approval, specifications, tests and conformity of production. The Group went through the paper section by section and commented as follows:-". With respect to the corners of the bumper, the minutes have "Geneva reg. 42 uses 60 degrees to C/L to define the corners of the bumper". From this statement it is assumed that there was a suggestion that the pedestrian protection bumper corner definition should be changed to use a 60° plane definition in the interests of harmonisation. Unfortunately, TRL's WG10 papers don't contain a copy of the draft pedestrian protection proposal that was distributed, but it seems likely that it still used the 45° plane. Nothing more is recorded in the minutes about the discussion on the bumper corners definition. It may have been quite a brief discussion, given that the working group was working through the entire draft test procedure. It was also the last meeting of this phase of WG10, and the last before a proposal for the test procedures was due to be submitted to the EC. Although the minutes record the bumper corner discussion apparently as a comment, it seems that it was actually a decision to change to using a plane at 60° or effectively became so.

At some time in the month's following, the new WG10 test procedures were produced by updating the version distributed at the October 1990 meeting. Reports were also prepared by TRRL describing the work of EEVC WG10 and the test procedures. In addition, the contractors each produced one or more reports describing their contribution to the overall project (including TRRL about the upper legform to bonnet leading edge test).

The following reports and papers were prepared by TRRL as chair of WG10 and the consortium of contractors, and in TRRL's name describing the whole of WG10's work to date:

- Report to the European Commission (Harris, 1991a). This report was on behalf of the Consortium, i.e. the EC contractors. Unfortunately, TRL's WG10 papers didn't include the first version of this to be submitted to the EC. The version that TRL holds is a revised version dated 17 December 1991. This report also includes the test procedures, in a series of annexes. These test procedures define the bumper corners using a 60° plane. The main text of the report doesn't mention the bumper corners.
- Paper to the 13th ESV conference, November 1991 (Harris, 1991b). This paper, on behalf of EEVC WG10, describes the test procedures but doesn't include a copy of them. The bumper corners are not mentioned.
- Report to the UK Department of Transport (Harris et al., 1991). This report, previously mentioned, is dated July 1991, and includes the test procedures, in a series of annexes. This is the earliest version of the test procedures produced since the October 1990 WG10 meeting that TRL still holds. As with the very similar report for the EC, the test procedures define the bumper corners using a 60° plane but the main text doesn't mention the bumper corners.
- Paper to the Autotech 1991 conference (Lawrence and Harris, 1991). The bumper corners are not mentioned.
- Paper to the Safety 91 Conference (Harris, 1991c). The bumper corners are not mentioned.

The contractors' reports that were potentially relevant to the current project are those by INRETS concerning the development of the legform to bumper test and those by TNO and APR concerning compatibility:

- Report by INRETS to the European Commission (Cesari and Alonzo, 1990). This covers accident data, legform design, protection criteria and testing, but has virtually nothing on the legform to bumper test procedure itself. Neither the bumper test area nor the bumper corner are mentioned.
- Paper by INRETS to the 13th ESV conference, 1991 (Cesari *et al*., 1991). This has an additional section on computer modelling but otherwise the same comment applies.
- Paper by INRETS to the 14th ESV conference, 1994 (Cesari *et al*., 1994). This covers further development of the legform and tests carried out with it, but it doesn't mention the bumper corners.

- Report by TNO to the European Commission (Janssen *et al*., 1990). Under the compatibility topic there is a literature review with a 'conflicting requirements' sub-section. Bumper regulations USA Part 581, Canada CMVSS 215 and ECE 42 are mentioned, as is FMVSS 208 (Occupant Crash Protection). There is also a 'vehicle classification' section that looks at the measurement method for the test procedures. The bumper reference line and the bumper height are reviewed, but not the bumper corners.
- Report by APR to the European Commission (Brun-Cassan, 1991). This has a section on bumper compatibility between pedestrian protection requirements and existing regulations. The following regulations are mentioned: Europe - ECE Regulation 42, USA - Part 581, Canada - CMVSS 215 and Saudi Arabia – SSA273. However, neither the bumper test area nor the bumper corners are mentioned.

A paper by Grösch and Heiss (1989) that was referenced by both the above TNO and APR reports was also checked. This discusses the conflicting requirements for bumpers for pedestrian protection and to meet the then existing requirements (US Part 581, CMVSS 215, ECE-42 and EWG 70/156; the last of these, however, was the old type-approval framework Directive, rather than a bumper regulation). Though this issue of conflicting requirements is discussed in more depth here than was found in the previously mentioned papers, there was still no mention of the bumper test area or the corners of the bumper.

As was mentioned above, meetings of EEVC WG10 resumed in September 1991. Further work was carried out to develop further the impactors and the test procedures. The last WG10 meeting was in September 1994. WG10 produced a report dated November 1994 (European Experimental Vehicles Committee, 1994). This again described the test procedures, especially the changes made since 1991, and contained the latest version of the test procedures in an appendix to the report. Though the bumper corners are mentioned in the main text, the way that they are defined is not.

There were still outstanding issues when WG10's mandate ended in 1994. Work seems to have carried on unofficially by the former members of WG10. An update of the test procedures was supplied to the EC in 1996 and a paper produced for the 1996 ESV conference (Janssen, 1996). This paper was based on the 1994 report but also includes activities by the former members of WG10. It contains nothing on the definition of the bumper corners.

EEVC WG17 was set up in 1997, mainly to review and update the WG10 test methods. Many of the members were former WG10 members. They produced their report in early 1999, but which was dated 1998. By 2002 they were planning a further update, with the prospect that the EC could soon be turning it into legislative requirements.

While testing for Euro-NCAP, TRL became aware of a vehicle with a significantly reduced bumper test zone. TRL made the following proposal to the May 2002 meeting of EEVC WG17.

> “Corners of bumpers: An off-road vehicle recently tested at TRL was found to have the corners of bumpers, as currently defined, well inboard. The tested area was (from memory) roughly between the inner ends of the headlights. This is because the current definition of the corners uses a plane surface at only 30° to the lateral plane. It is therefore suggested that the angle in Annex II, Paragraph 2.2.5 and in Figure 2 be changed from 60° to 45°. It should be noted that the performance of the legform at these bumper angles might not be quite the same, as it will spin to some extent. Nevertheless, it will still be able to indicate front structures that are particularly dangerous, and any test in these areas is better than none. Without this extension of test area it will be possible for manufacturers to put the bumper supports and underlying longitudinal members into a non-tested area.” (EEVC WG17 / Doc 186)

The minutes of the meeting record agreement that “Further study is required before the definition of the bumper corner is changed by holding the straight edge at 45º rather than at 60º (see also doc 184)”. The document referred to notes that “the 60 degree definition of the Bumper Corner Reference Point is consistent with existing Bumper Legal requirements including, Regulation 42, FMVSS 581 and CMVSS 581”. WG17’s caution against making such a relatively last-minute change in the test procedures is understandable. As far as the current authors are aware, no attempt was made by WG17 or TRL in the months or years after this meeting to carry out the suggested further study. WG17’s updated report (European Enhanced Vehicle-safety Committee, 2002), again with the latest version of the test procedures in an appendix, does not mention the bumper corners in the main text.

# Appendix B AIS codes used to select injuries to the lower extremity and categorise the injured body region

- Whole leg
    - 811000 (amputation)
    - 813000 (crushing)
    - 815000 (compartment syndrome)
- Upper leg
    - 820299 to 820406 (femoral artery or vein)
    - 851800 to 851824 (femur)
- Knee
    - 820699 to 820806 (popliteal artery or vein)
    - 840402 to 840406 (collateral or cruciate ligaments)
    - 841002 and 841004 (patellar tendon)
    - 850802 to 850899 (knee)
    - 852400 (patella)
- Lower leg
    - 851602 to 851699 (fibula)
    - 852402 to 853499 (tibia)
- Ankle
    - 840200 to 840204 (Achilles tendon)
    - 850202 to 850299 (ankle)
    - 853200 (talus)
- Foot
    - 815002 (degloving injury of toe(s))
    - 850400 to 850404 (foot joint)
    - 851002 to 851299 (metatarsal, phalangeal or interphalangeal joint, subtalar, transtarsal or metatarsal joint)
    - 851400 (calcaneous)
    - 852000 (foot)
    - 852200 (metatarsal or tarsal)
    - 853602 to 853699 (toe)

- Unknown or unclassifiable
    - 811002 and 811004 (amputation above or below knee)
    - 813002 and 813004 (crushing above or below knee)
    - 815004 and 815006 (degloving injury – thigh, calf, knee, ankle, sole of foot, entire extremity)
    - 816000 to 816006 (penetrating injury – varying levels of tissue and blood loss)
    - 810099 to 810806 (skin – abrasions, contusions, lacerations and avulsions)
    - 821002 to 821299 (other named arteries)
    - 830202 to 830699 (nerves)
    - 840600 to 840804 (muscles and tendons)
- Excluded (hip and pelvis)
    - 850602 to 850699 (hip)
    - 852600 to 852610 (pelvis)
    - 852800 (sacroilium)
    - 853000 (symphysis pubis)

# Appendix C Accident data – assessment of biasing factors

The OTS and GIDAS data provide information on the age, sex and movement of the pedestrian, the vehicle registration year and the speed of the collision. Each of these variables has been examined to determine if there is a difference in the distribution across categories of contact position e.g. are females more commonly hit on the nearside of the vehicle than males? The following section describes this analysis and provides the specific results for each variable.

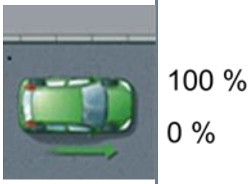
## C.1 Pedestrian and vehicle factors

Please note that due to small sample sizes (especially within the OTS sample) care should be taken when drawing conclusions based on the output from the statistical tests.

A chi-squared test of independence is used to test for a difference in the distribution of males and females across categories of contact position. As with the chi-squared goodness-of-fit test, the p-value generated is interpreted in a similar way.

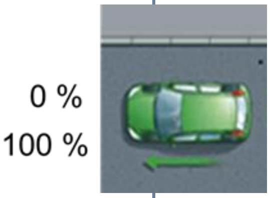
Table C-1 displays the number of OTS casualties by gender and contact position.

**Table C-1: Number of OTS cases by gender and contact position**

| | Gender | | | |
|---|---|---|---|---|
| **Contact position** | **Female** | **Male** | **Unknown** | **Total casualties** |
| 0-20  | 8 | 10 | 0 | 18 |
| 20-40 | 4 | 10 | 0 | 14 |
| 40-60 | 12 | 10 | 1 | 23 |
| 60-80 | 8 | 14 | 0 | 22 |
| 80-100 | 12 | 17 | 2 | 31 |
| Unknown | 2 | 6 | 0 | 8 |
| **Total** | **46** | **67** | **3** | **116** |

The chi-squared test (excluding those with unknown contact position and/or unknown gender) shows that the distribution of female casualties across categories of contact position is significantly different (at the 10% level) from the distribution of male casualties. The test has a p-value<0.10.

**Table C-2: Number of GIDAS cases by gender and contact position**

| | Gender | | |
|---|---|---|---|
| **Contact position** | **Female** | **Male** | **Total casualties** |
| 0-10 | 28 | 37 | 65 |
| 10-20  | 58 | 58 | 116 |
| 20-30 | 47 | 54 | 101 |
| 30-40 | 35 | 30 | 65 |
| 40-50 | 43 | 42 | 85 |
| 50-60 | 38 | 45 | 83 |
| 60-70 | 26 | 28 | 54 |
| 70-80 | 43 | 33 | 76 |
| 80-90 | 26 | 36 | 62 |
| 90-100 | 19 | 32 | 51 |
| **Total** | **363** | **395** | **758** |

The chi-squared test shows that the distribution of female casualties across categories of contact position is significantly different (at the 5% level) from the distribution of male casualties. The test has a p-value<0.05.

A Kruskall-Wallis test can be used to compare the age distribution of casualties across the categories of contact position. Only summary data were available for the GIDAS sample and hence this test could not be performed. The test on the OTS sample showed that the distribution of age across the bumper was not significant at (the 10% level). The test has a p-value of 0.59. This indicates that there is no difference in the age of casualty by contact position.

A chi-squared test of independence is used to test for a difference in the distribution of pedestrian movement across categories of contact position. Chi-squared tests have limitations on the minimum cell frequencies; as such the sample size of pedestrian casualties with movement recorded as 'in the path of vehicle' and 'unknown' are too small and have been excluded from this analysis. Hence, the test is used to test for a difference in the distribution of nearside and offside movement across categories of contact position.

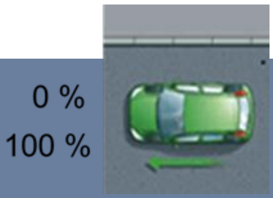
**Table C-3: Number of OTS cases by movement of pedestrian and contact position**

| | Pedestrian movement | | | | |
|---|---|---|---|---|---|
| **Contact position** | **In the path of vehicle** | **Nearside** | **Offside** | **Unknown** | **Total casualties** |
| 0-20 | 0 | 5 | 13 | 0 | 18 |
| 20-40<br><br> | 1 | 7 | 5 | 1 | 14 |
| 40-60 | 2 | 13 | 8 | 0 | 23 |
| 60-80 | 1 | 15 | 5 | 1 | 22 |
| 80-100 | 5 | 18 | 6 | 2 | 31 |
| Unknown | 1 | 4 | 3 | 0 | 8 |
| **Total** | **10** | **62** | **40** | **4** | **116** |

The chi-squared test (excluding those with unknown contact position) shows that the distribution of pedestrian casualties from the nearside across categories of contact position is significantly different (at the 5% level) from the distribution of casualties crossing from the offside. The test has a p-value<0.05. As can be expected from the definition of the contact position, pedestrians crossing from the nearside are commonly struck by contact positions between 80-100 and 60-80 and those crossing from the offside are commonly hit by the position 0-20.

Within the GIDAS data, pedestrian casualties with movement recorded as 'walking in same direction', 'oncoming', 'staying' and 'unknown' have been excluded from the chi-squared analysis due to small counts. The test is used to test for a difference in the distribution of nearside and offside movement across categories of contact position.

### Table C-4: Number of GIDAS cases by movement of pedestrian and contact position

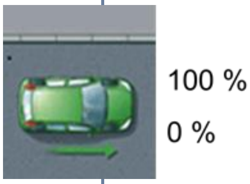
| | Pedestrian movement | | | | | |  |
|---|---|---|---|---|---|---|---|
| **Contact position** | **Walking in same direction** | **Comes from right side (n/s)** | **Comes from left side (o/s)** | **oncoming** | **staying** | **unknown** | **Total casualties** |
| 0-10 | 5 | 44 | 10 | 2 | 4 | 0 | 65 |
| 10-20 | 14 | 69 | 30 | 1 | 0 | 2 | 116 |
| 20-30 | 12 | 52 | 28 | 3 | 4 | 2 | 101 |
| 30-40 | 4 | 33 | 25 | 2 | 1 | 0 | 65 |
| 40-50 | 9 | 34 | 41 | 1 | 0 | 0 | 85 |
| 50-60 | 3 | 45 | 32 | 1 | 1 | 1 | 83 |
| 60-70 | 3 | 28 | 21 | 1 | 0 | 1 | 54 |
| 70-80 | 3 | 27 | 40 | 1 | 4 | 1 | 76 |
| 80-90 | 9 | 17 | 30 | 0 | 4 | 2 | 62 |
| 90-100 | 5 | 8 | 34 | 1 | 1 | 2 | 51 |
| **Total** | **67** | **358** | **290** | **13** | **19** | **11** | **758** |

The chi-squared test shows that the distribution of pedestrian casualties from the nearside across categories of contact position is significantly different (at the 5% level) from the distribution of casualties crossing from the offside. The test has a p-value<0.05. Similarly, to the OTS sample this is to be expected i.e. pedestrians crossing from the nearside are commonly struck by the nearside of the bumper; those crossing from the offside are commonly struck by the offside.

As with the casualty age, a Kruskall-Wallis test can be used to compare the distribution of year of registration across the categories of contact position. Only summary data were available for the GIDAS sample and hence this test could not be performed. The test on the OTS sample showed that the distribution of year of registration across the bumper was not significant at (the 10% level). The test has a p-value of 0.60. This indicates that there is no difference in the year of registration by contact position.

Table C-5 shows the number of OTS cases by speed of collision and contact position.

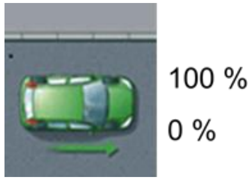
**Table C-5: Number of OTS cases by speed of collision and contact position**

| | Speed of collision | | | | |
|---|---|---|---|---|---|
| **Contact position** | **Very low speed** | **<30mph** | **>30mph** | **Unknown** | **Total casualties** |
| 0-20  | 3 | 11 | 3 | 1 | 18 |
| 20-40 | 6 | 8 | 0 | 0 | 14 |
| 40-60 | 1 | 16 | 5 | 1 | 23 |
| 60-80 | 2 | 18 | 1 | 1 | 22 |
| 80-100 | 1 | 25 | 5 | 0 | 31 |
| Unknown | 3 | 4 | 1 | 0 | 8 |
| **Total** | **16** | **82** | **15** | **3** | **116** |

No statistical tests could be performed to assess the difference in the speed of collision across categories of contact position in the OTS sample due to small cell frequencies. Only summary data were available for the GIDAS sample and thus no tests could be performed for these data either.

Summary statistics for the OTS and GIDAS samples by contact position across the bumper are given in Table C-6 and Table C-7. Where values are unknown for each factor (speed, sex, age, registration year, movement of pedestrian) these have been excluded from the calculation.

**Table C-6: Summary statistics of OTS cases by contact position**



| | | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Unknown |
|---|---|---|---|---|---|---|---|
| Number of casualties | | 18 | 14 | 23 | 22 | 31 | 8 |
| Mean collision speed (mph) | | <30mph | <30mph | <30mph | <30mph | <30mph | <30mph |
| Proportion of female (%) | | 44 | 29 | 55 | 36 | 41 | 25 |
| Mean pedestrian age (years) | | 36 | 30 | 38 | 28 | 35 | 13 |
| Mean year of registration (year) | | 1996 | 1997 | 1997 | 1999 | 1996 | 1998 |
| Movement of pedestrian | In path of vehicle | 0% | 0% | 9% | 5% | 11% | 13% |
| | N/S (left side) | 28% | 58% | 57% | 71% | 67% | 50% |
| | O/S (right side) | 72% | 42% | 35% | 24% | 22% | 38% |

**Table C-7: Summary statistics of GIDAS cases by contact position**

| | | 0-10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | 80-90 | 90-100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of casualties | | 65 | 116 | 101 | 65 | 85 | 83 | 54 | 76 | 62 | 51 |
| Mean collision speed (kph) | | 23 | 28 | 26 | 26 | 28 | 28 | 29 | 29 | 27 | 27 |
| Proportion of female (%) | | 43% | 50% | 47% | 55% | 51% | 46% | 48% | 57% | 42% | 38% |
| Mean pedestrian age (years) | | 33 | 44 | 37 | 43 | 34 | 34 | 39 | 36 | 37 | 36 |
| Mean year of registration (year) | | 1998 | 1997 | 1997 | 1996 | 1996 | 1996 | 1998 | 1997 | 1997 | 1996 |
| Movement of pedestrian | walking in same direction | 8% | 12% | 12% | 6% | 11% | 4% | 6% | 4% | 15% | 10% |
| | comes from right side | 68% | 59% | 51% | 52% | 40% | 54% | 52% | 36% | 27% | 16% |
| | comes from left side | 15% | 26% | 28% | 38% | 48% | 39% | 39% | 53% | 48% | 66% |
| | oncoming | 3% | 1% | 3% | 3% | 1% | 1% | 2% | 1% | 0% | 2% |
| | staying | 6% | 0% | 4% | 2% | 0% | 1% | 0% | 5% | 6% | 2% |

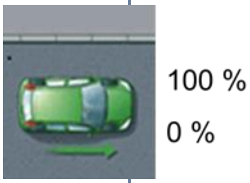
0 %

100 %

Table C-8 and Table C-9 show the number of OTS and GIDAS cases by contact position across the bumper, restricted to cars registered from 2000 onwards; these tables are a subset of the cases from Table 4–1 and Table 4–3.

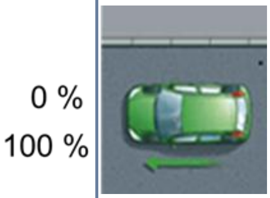
Where possible (given the restricted sample sizes and small cell counts) chi-squared tests performed on these two datasets show similar results to those outlined above.

**Table C-8: Number of OTS cases by contact position across the bumper (cars registered from 2000 onwards)**



| Contact position | Number of casualties |
|---|---|
| 0-20 | 3 |
| 20-40 | 6 |
| 40-60 | 5 |
| 60-80 | 10 |
| 80-100 | 10 |
| Unknown | 5 |
| **Total** | **39** |

**Table C-9: Number of GIDAS cases by contact position across the bumper (cars registered from 2000 onwards)**

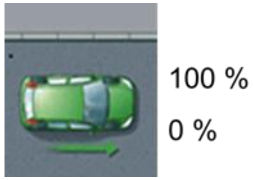


| Contact position | Number of casualties |
|---|---|
| 0-10 | 25 |
| 10-20 | 38 |
| 20-30 | 31 |
| 30-40 | 20 |
| 40-50 | 20 |
| 50-60 | 25 |
| 60-70 | 16 |
| 70-80 | 27 |
| 80-90 | 25 |
| 90-100 | 17 |
| **Total** | **244** |

Summary statistics for the OTS and GIDAS samples by contact position across the bumper for cars registered from 2000 onwards are given in Table C-10 and Table C-11.

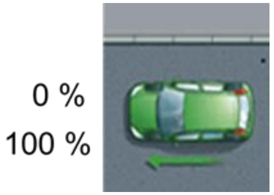
**Table C-10: Summary statistics of OTS cases by contact position (cars registered from 2000 onwards)**

| | | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Unknown |
|---|---|---|---|---|---|---|---|
| Number of casualties | | 3 | 6 | 5 | 10 | 10 | 5 |
| Mean collision speed (kph) | | <30mph | <30mph | <30mph | <30mph | <30mph | <30mph |
| Proportion of female (%) | | 0 | 50 | 75 | 20 | 50 | 0 |
| Mean pedestrian age (years) | | 46 | 39 | 31 | 19 | 32 | 13 |
| Mean year of registration (year) | | 2004 | 2003 | 2002 | 2003 | 2003 | 2003 |
| Movement of pedestrian | In path of vehicle | 0% | 0% | 0% | 0% | 0% | 20% |
| | N/S (left side) | 33% | 60% | 80% | 80% | 70% | 60% |
| | O/S (right side) | 67% | 40% | 20% | 20% | 30% | 20% |



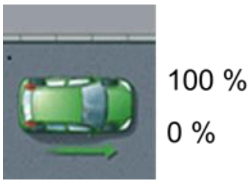
### Table C-11: Summary statistics of GIDAS cases by contact position (cars registered from 2000 onwards)

| | | 0-10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | 80-90 | 90-100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of casualties | | 25 | 38 | 31 | 20 | 20 | 25 | 16 | 27 | 25 | 17 |
| Mean collision speed (kph) | | 23 | 26 | 21 | 24 | 28 | 21 | 30 | 27 | 26 | 28 |
| Proportion of female (%) | | 48% | 53% | 58% | 70% | 30% | 60% | 63% | 56% | 40% | 41% |
| Mean pedestrian age (years) | | 32 | 52 | 41 | 43 | 38 | 36 | 44 | 38 | 31 | 43 |
| Mean year of registration (year) | | 2004 | 2004 | 2004 | 2003 | 2004 | 2003 | 2005 | 2004 | 2003 | 2003 |
| Movement of pedestrian | walking in same direction | 4% | 16% | 13% | 10% | 15% | 4% | 6% | 7% | 12% | 18% |
| | comes from right side | 64% | 45% | 52% | 45% | 40% | 68% | 63% | 30% | 16% | 6% |
| | comes from left side | 20% | 34% | 32% | 35% | 45% | 28% | 25% | 56% | 60% | 65% |
| | oncoming | 4% | 0% | 0% | 5% | 0% | 0% | 0% | 0% | 0% | 6% |
| | staying | 8% | 0% | 3% | 5% | 0% | 0% | 0% | 7% | 4% | 0% |



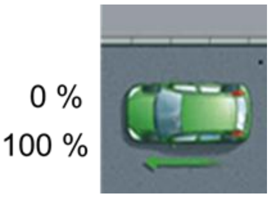
# Appendix D Accident data – injury risk

**Table D-12: Number of OTS injuries by body region and contact position for AIS 1 injuries**



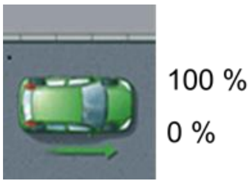
| | Unknown | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|---|
| whole leg | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| upper leg | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| knee | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| lower leg | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| ankle | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| foot | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| unknown or unclassifiable | 5 | 13 | 14 | 20 | 28 | 33 | 113 |
| Total | 5 | 13 | 15 | 20 | 29 | 33 | 115 |

**Table D-13: Number of GIDAS injuries by body region and contact position for AIS 1 injuries**



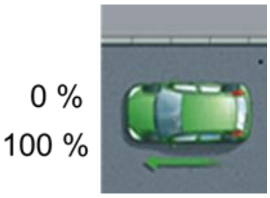
| | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|
| whole leg | 0 | 0 | 0 | 0 | 0 | 0 |
| upper leg | 2 | 1 | 2 | 3 | 2 | 10 |
| knee | 12 | 13 | 9 | 14 | 5 | 53 |
| lower leg | 14 | 13 | 9 | 9 | 7 | 52 |
| ankle | 2 | 2 | 0 | 1 | 1 | 6 |
| foot | 5 | 2 | 1 | 3 | 0 | 11 |
| unknown or unclassifiable | 2 | 0 | 3 | 2 | 0 | 7 |
| excluded (hip or pelvis) | 0 | 0 | 0 | 1 | 1 | 2 |
| Total | 37 | 31 | 24 | 33 | 16 | 141 |

### Table D-14: Number of OTS injuries by body region and contact position for AIS 3 injuries



| | Unknown | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|---|
| whole leg | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| upper leg | 0 | 1 | 0 | 1 | 3 | 4 | 9 |
| knee | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| lower leg | 0 | 1 | 1 | 0 | 0 | 0 | 2 |
| ankle | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| foot | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| unknown or unclassifiable | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 0 | 2 | 1 | 1 | 4 | 4 | 12 |

### Table D-15: Number of GIDAS injuries by body region and contact position for AIS 3 injuries



| | 0-20 | 21-40 | 41-60 | 61-80 | 81-100 | Total |
|---|---|---|---|---|---|---|
| whole leg | 0 | 0 | 0 | 0 | 0 | 0 |
| upper leg | 1 | 1 | 1 | 1 | 0 | 4 |
| knee | 0 | 0 | 0 | 0 | 0 | 0 |
| lower leg | 5 | 0 | 4 | 6 | 2 | 17 |
| ankle | 0 | 0 | 0 | 0 | 0 | 0 |
| foot | 0 | 0 | 0 | 0 | 0 | 0 |
| unknown or unclassifiable | 0 | 0 | 0 | 0 | 0 | 0 |
| excluded (hip or pelvis) | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 6 | 1 | 5 | 7 | 2 | 21 |