TECHNICAL PAPER

RELATIONSHIP BETWEEN PEDESTRIAN PROTECTION TEST PROTOCOLS AND A REAL SCENARIO

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Paper Number 11-0402

ABSTRACT

Of the one and a half million accidents which occur in the Euro-15 area every year, and which cause nearly 40,000 deaths, pedestrians account for 15% of these, i.e. about 6,000 per year. The percentage of pedestrians killed in road accidents is about 12% for Canada, USA and Australia, while in Korea and Japan pedestrian fatalities account for as much as 30% and 40% of road deaths.
Organizations like Euro NCAP, EEVC and the new Regulation, together with vehicle manufacturers are seeking solutions through the development of advanced safety systems and accurate methods for testing these systems.
IDIADA carried out two studies related to pedestrian protection and the relation of protocol to real world accidents. The first study was focused on real world accidents involving pedestrians, and was divided into two parts:

- Assessment of vehicle speed influence. Sixty-two cases, collected by the Municipal Police and the Public Health Service Agency in which pedestrians were involved in accidents were studied in Barcelona city. 75.1% of accidents occurred during the day, with an ISS 4-5 level of injury, and an ISS 3-4 at night.
- Study about speed as a cause of accidents. 75.3% of drivers made a braking avoidance maneuver. The average speed before the accident was 50.8 km/h and the impact average velocity was 24.78 km/h.

As a result, injury level related to vehicle speed was evaluated. The speed threshold between slight and severe injuries is at about 40 km/h. This value is very similar to the impact velocity used in the current tests to evaluate pedestrian protection in passive safety testing, as for example in Euro NCAP.

The objective of the second study was to test the influence of the vehicle design, mainly the front-end, on pedestrian head injuries in the case of run-over. Several accident simulations were performed using the program MADYMO® in which a pedestrian's head was impacted into a different point of the hood depending on the situation.
The head impact position changes according to vehicle category: collisions in compact and roadster sports cars take place within the limits set by Euro NCAP for adult head impactor while, in the off-road 4x4 class, some points are located below the lower limit for the adult head.

If the analysis focuses on the pedestrian's head impact angle and speed against the hood of the car, the following conclusions can be expounded:

- For the same vehicle, impact speed and angle of the adult head against the hood are virtually unchanged although the pedestrian's speed is different.
- If impact speed is higher, the collision involves worse consequences.
- The shape of the front part of the vehicle is not decisive in the severity of pedestrian injuries.
- Further testing is needed to verify that parameters defined by the EEVC, Euro NCAP or pedestrian Regulation are entirely valid according to real world scenarios.

Main conclusion of the study and the analysis of actual accident data was that current pedestrian testing protocols are reliable enough to be taken into account when a vehicle pedestrian protection level is assessed.

INTRODUCTION

In order to reduce the number of deaths due to road accidents, the European Commission introduced the 'White Paper' called 'European Transport Policy

for 2010: Time to Decide'. The main aim was to propose to European Community level the halving of the number of road accidents (reducing the number at 20.000 deaths) for the year 2010 (based on statistics from 2000).
To achieve a reduction in the number of deaths, vehicle manufacturers have been 'forced' to meet certain requirements in order to validate their vehicles with respect to the protection of pedestrians.
Also, at the consumer level, the safety program initiated by the independent organization Euro NCAP, which includes the safety of the occupants, the children and the pedestrians, has become very important in terms of the credibility of information provided and consumer awareness of the importance of acquiring a vehicle that meets minimum standards of safety. Consumers have been found in Euro NCAP a very useful tool to get clear and comparative information on behaviour of vehicles available in Europe under different types of test.
Currently European testing procedures, European Directive testing and Euro NCAP tests, are based on procedures developed by the European Community and the working groups EEVC. In the last decade, vehicle manufacturers have incorporated the protection of pedestrians, by improving external and internal design of the vehicle, into their strategy. Because there are areas of the vehicle which have proven very difficult to obtain a minimum level of protection, vehicle manufacturers have developed other types of assistance to improve the protection offered. New developments in active and passive safety have proven their impact on the reduction of victims, around 15.000 between 1992 and 2002.
Although Euro NCAP has encouraged manufacturers to improve the protection of vehicle occupants in a road accident (currently, most vehicles receive 5 out of 5 stars), incentives to improve pedestrian protection have not had the same consequences (few vehicles received 3 stars from a maximum of 4). With the introduction of European Directives at European level, manufacturers have made more additional efforts to improve pedestrian safety.
The current pedestrian test protocols are representative of situations that can occur in real life, but they do not give an accurate picture. For example, the kinematics of the head in a real test is difficult to reproduce using the head impactor.
For that reason, Applus+ IDIADA has made several investigations and studies to assess both the trial protocols and reproducibility of real accidents in the laboratory of pedestrians, the suitability of the use of new impactors and influence of different parameters on the results of pedestrian tests.
The updating of test methodologies will help manufacturers in the field of pedestrian protection, from passive and active safety point of view. In fact changes in protocols can be made to include the influence of different types of vehicles such as the Off-Road or MPV (Multi Purpose Vehicles) and recommendations for new structural designs of vehicles such as the increased use of plastics and energy absorption in frontal areas, as in lights and bumpers.
The proposed in-depth analysis was divided into two sections and was carried out in Barcelona during 2009.

STUDY OF ACCIDENTS IN ORDER TO PROVIDE A MEANS TO ANALYZE THE ACCURACY OF SPEED IMPLEMENTED IN REGULATION AND EURO NCAP TESTS

The first part of the study shows how the vehicle speed affects the safety of pedestrians in urban accidents. The main aim of this part was to determine what reductions would prevent accidents with pedestrians and, therefore, victims and injuries. This was achieved through the study of vehicle speed as the cause of the accident and the effect of speed on the severity of pedestrian injury.

Influence of Vehicle Speed

The first step of the study was the statistical analysis of accidents in Barcelona. This was made through a selection process of possible cases based on a strict method of filter:

- Initial selection criteria: a vehicle accident which involves at least one injured person who needed medical attention; the collision point is known. 823 cases were selected for this initial evaluation.
- The Municipal Police and the Public Health Service Agency had access to 484 medical files of these cases, from the following hospitals: Hospital Clínic, Hospital del Mar, Hospital Sant Joan de Déu, Hospital de Sant Pau, Residencia de la Vall d'Hebron and the Hospital de la Creu Roja.
- Details of braking distances before and after the impact point and projection distance of the pedestrian after the impact were provided for a total of 93 cases.
- The total number of relevant cases was further reduced as the ISS (Injury Severity Score = Injury Severity Score) could only be provided by the health administration for a total of 62 initial cases.

Speed as Cause of the Accident

The speed of the vehicle, namely excessive speed, is a crucial factor in all accident scenarios. The level of injury in impacts against pedestrians can be scaled as a result of a lack of safety measures. It was observed that 75,3% of drivers of vehicles anticipated the accident and made an evasive maneuver, usually braking sharply trying to avoid collision with the pedestrian. The Figure 1 presents statistically the necessary reduction in speed to achieve a reduction in the percentage of accidents.

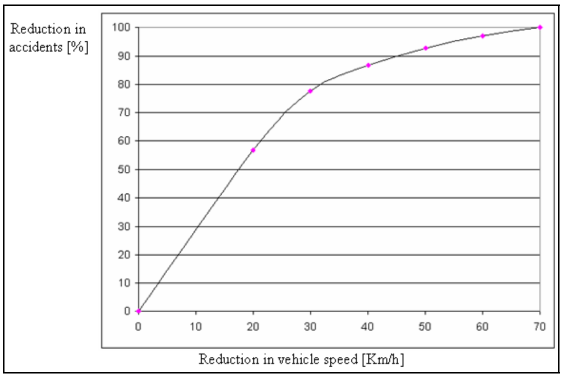


Figure 1. Necessary reduction in speed to achieve a reduction in the percentage of accidents.

It was observed that the average vehicle speed before braking was 50,8 km/h and the average impact speed after the braking manoeuvre was 24,78 km/h. As result from this graph, it was suggested that a 20% reduction in the speed limit in urban surrounding areas would lead to a 60% reduction in accidents involving pedestrians. It is even more significant the fact that a 40% reduction in vehicle speed would lead to 85% reduction of accidents. Accordingly, it is clear that a small reduction in vehicle speeds implies direct consequences on the number of accidents where pedestrians are involved. If this trend was applied, a great rate reduction of the speed could achieve a decrease of the number of accidents almost to zero. Currently, in the main testing protocols, impactors, which represent different human limbs are thrown at a speed of 40 km/h. These tests are very limited in this regard, as actual impacts may occur at any speed.
In order to assess the impactors velocity at testing (40 km/h), the calculation of impact velocity for all cases studied after the application of filters was carried out. To establish this speed value in a reliable way, other variables such as pedestrian projection distance, braking distance before the collision and braking distance after the collision were determined. The level of severity of the injuries was also included according to data from Public Health Administration database, the information was classified using the parameter AIS (Abbreviated Injury Scale), where injuries are encoded using the ISS method.

Abbreviated Injury Scale (AIS) is an anatomical based scoring system to determine the severity of single injuries based on the survivability of the injury. AIS-Code is a scale of one to six, one being a minor injury and six being life-threatening. An AIS-Code of 6 is not the code for a deceased patient, but the code for an injury with a very high lethality. An AIS-Code of 9 is used to describe injuries for which not enough information is available for more detailed coding, e.g. crush injury to the head.
The AIS scale is a measurement tool for single injuries. A universally accepted injury aggregation function has not yet been proposed, though the Injury Severity Score and its derivatives are better aggregators than a mere look at the maximum AIS-Code (MAIS) as used by most biomechanic researchers.

Table 1.
Abbreviated Injury Scale.

AIS-Code	Injury
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum

Injury Severity Score (ISS) is an established medical score to assess trauma severity. It correlates with mortality, morbidity and hospitalization time after trauma. It is used to define the term major trauma, i.e. a major trauma (or polytrauma) is defined as ISS>15.
The ISS is based upon the AIS. To calculate an ISS for an injured person, the body is divided into six ISS body regions. These body regions are:

- Head or neck - including cervical spine.
- Face - including the facial skeleton, nose, mouth, eyes and ears.
- Chest - thoracic spine and diaphragm.
- Abdomen or pelvic contents - abdominal organs and lumbar spine.
- Extremities or pelvic girdle - pelvic skeleton.
- External.

To calculate an ISS, take the highest AIS severity code in each of the three most severely injured ISS body regions (A, B, C in Equation 1), square each AIS code and add the three squared numbers for an ISS.

$$ISS = A^2 + B^2 + C^2 \quad (1).$$

The ISS scores range from 1 to 75 (i.e. AIS scores of 5 for each category). If any of the three scores is a 6, the score is automatically set at 75. Since a score of 6 ("unsurvivable") indicates the futility of further medical care in preserving life, this may mean a cessation of further care in triage for a patient with a score of 6 in any category. A score between 1-8 is considered mild and between 9-75 is considered severe).

Results

The distribution of impact velocity for ISS parameter can be seen in Figure 2.

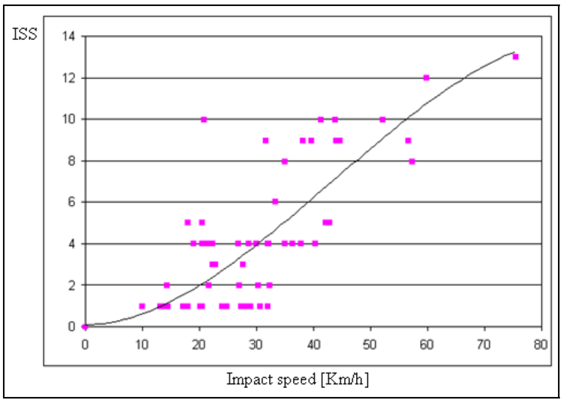


Figure 2. Distribution of impact velocity for ISS parameter.

There is a wide distribution of results. However, it can also be represented as a dual algorithm, as shown. As a result, it was possible to represent the risk probability of injury through a Weibull distribution. Figure 3 shows this distribution, accounting for minor injuries, ISS from 1 to 8, and severe injuries ISS of 9 or greater.

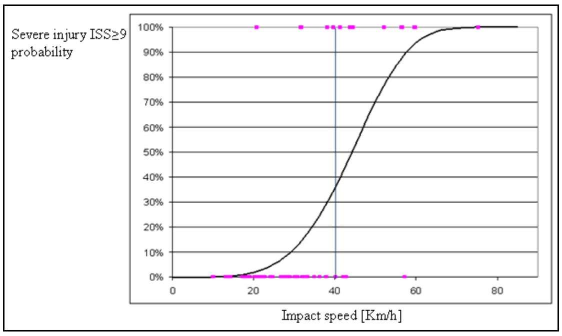


Figure 3. Weibull distribution.

The figure above shows how the distribution is fairly uniform including slight and severe injuries. Slight injuries are the result of low speed impacts while serious injuries are related to impacts at higher speeds. Another important issue shown in this chart is that the boundary between slight and severe injury is at 40 km/h. The fact that the limit matches up with this value, proves that impact speed protocol based on a study of real accidents used in the Euro NCAP test is appropriate.

STUDY OF ACCIDENTS TO DETERMINE THE CORRELATION WITH THE EXISTING IMPACT AREAS IN THE PROTOCOLS AND THE RELATIONSHIP BETWEEN ACTUAL PEDESTRIAN ACCIDENTS AND RESULTS OF THE SAME VEHICLES IN EURO NCAP TESTS

The in-depth study of accidents done to provide data to analyze the accuracy of the speeds currently used in Euro NCAP and European Regulation tests was carried out in Barcelona during 2009 and is divided into 2 sections.
This second part of the study was focused on an in-depth analysis of the influence of the frontal part of the vehicle in the kinematics of the pedestrian's head during an impact. To validate these results, several virtual configurations with different impact positions for head impactor, impact velocity and impact angle were carried out.

Significance of the Shape of the Vehicle's Front

In the previous section of the study it was proved that impact speed of the vehicle has a direct influence on the severity of pedestrian injuries. To understand the importance of the shape of the vehicle's front, the kinematics of pedestrian's head must be considered. This includes the impact position of the head, impact speed and the impact angle of the head against the vehicle. Applus+ IDIADA carried out a study and several virtual reconstructions taking these parameters as variables in order to assess the influence of the vehicle's front in pedestrian injuries.
Aided by the simulation program MADYMO®, pedestrian models to perform the calculations were created. The dummy used for the simulation was a model of the stood up Hybrid III 50%, which is based on the Hybrid III dummy 50% standard but modified to define the lumbar spine, abdomen, pelvis, legs, ankles and feet. Four categories of variables were chosen to evaluate this study (Table 2).

Table 2.
Simulation variables.

Pedestrian speed	0 km/h 5 km/h 10 km/h
Vehicle speed	30 km/h 40 km/h 50 km/h
Vehicle class	Family Car Off-Road 4x4 Roadster sport
Pedestrian position against the vehicle	10% 25% 50%

A schematic illustration of these configurations is shown in Figures 4 and 5. EASI CRASH® and Animador® were the programs used to plot the results.

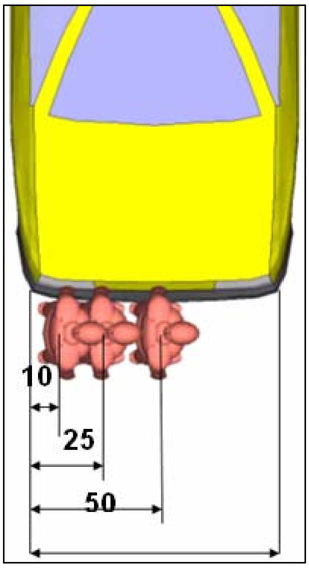


Figure 4. Place of the vehicle's front when the run over occurs.

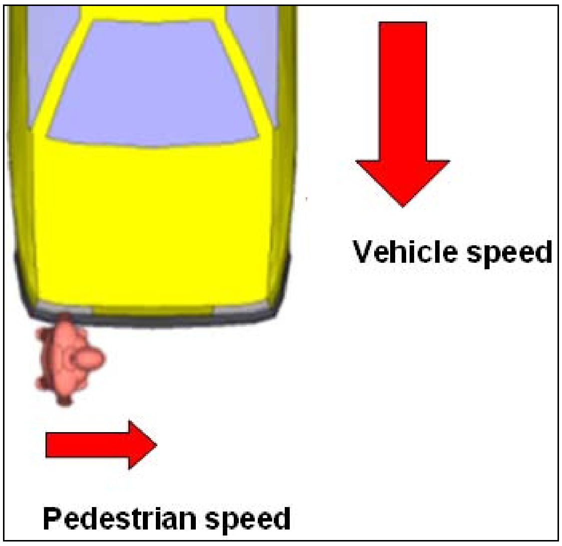


Figure 5. Direction of the pedestrian and the vehicle.

<u>Simulations of the impactor head.</u> The simulation was carried out according to the requirements specified in the Euro NCAP protocol. Standard models for child and adult heads were used. The impact zone for adult head was located between WAL2100 and WAL1500 while boundaries for child head were WAL1500 and WAL1000, as established by this protocol.

Table 3, Table 4 and Table 5 show simulation results depending on the position of impact, vehicle speed and speed of pedestrian.

Table 3.
Simulation results depending on impact position.

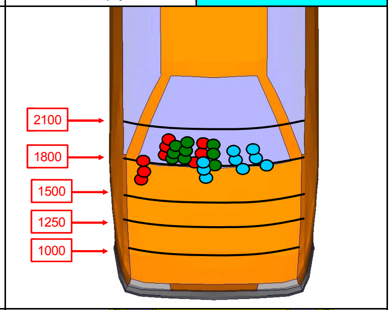
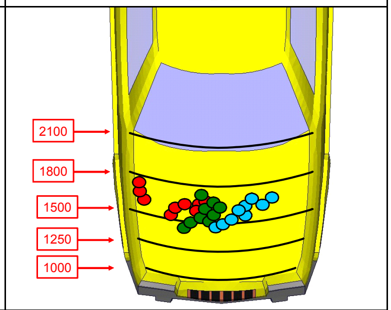
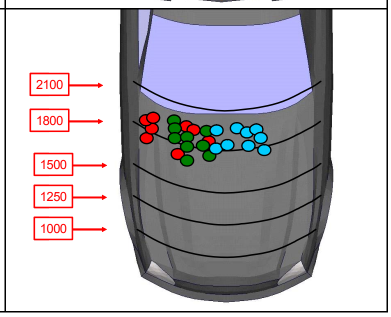
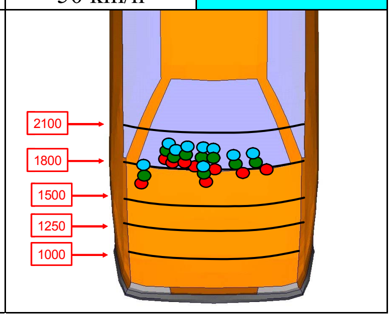
Impact position	10%	(red)
	25%	(green)
	50%	(cyan)
Family Car		
Off-Road 4x4		
Roadster sport		

Table 4.
Simulation results depending on vehicle speed.

Vehicle speed	30 km/h	(red)
	40 km/h	(green)
	50 km/h	(cyan)
Family Car		

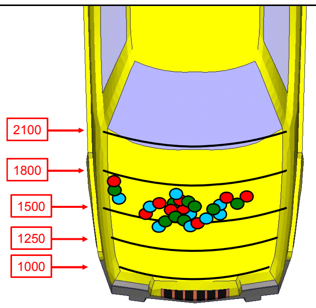
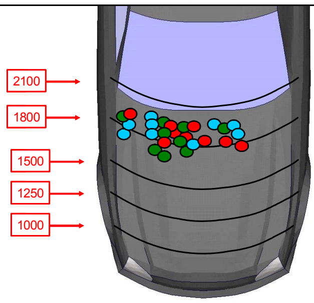
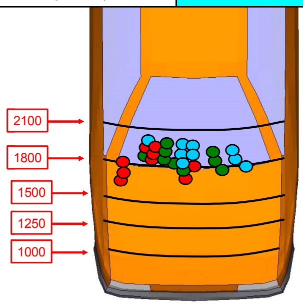
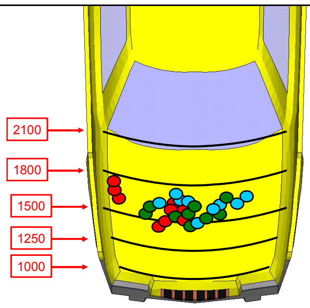
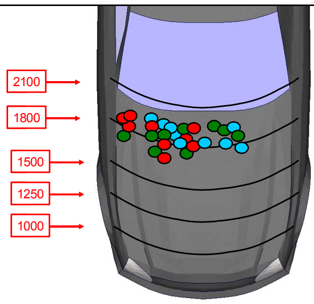
Off-Road 4x4	
Roadster sport	

Table 5.
Simulation results depending on pedestrian speed.

Pedestrian speed	0 km/h	
	5 km/h	
	10 km/h	
Family Car		
Off-Road 4x4		
Roadster sport		

Simulation results show the differences in the impact area between the three classes of vehicles.

All impacts for Family Car and Roadster Sport models are located between the boundaries defined by Euro NCAP for adult head impactor (WAL1500 - WAL2100). In contrast, Off-Road 4x4 vehicles show different results, most impacts are located between WAL1500 and WAL1800. However, some points were located below the lower limit for adult head WAL1500.

Simulation of impact angle and head speed.

The impact angle and velocity of the head were also important parameters for this study. A simulation was carried out altering these parameters and the vehicle speed (30 km/h, 40 km/h, 50 km/h), pedestrian speed (0 km/h, 5 km/h, 10 km/h) and positions of impact (10%, 25%, 50%). The fact that three different classes of vehicles were tested allows the identification of the most influential parameters concerning the vehicle front shape and its effect on the kinematics of the pedestrian's head. Simulation results are shown in Table 6, 7, 8, 9, 10, 11, 12, 13 and 14. The angle of impact (degrees) is in italics while the head impact velocity (km/h) is shown in normal typeface.

Table 6.
Simulation results for impact position of 10% (Family Car).

FAMILY CAR	Pedestrian speed [km/h]		
Vehicle speed	0	5	10
30 km/h	*-89.9* 12.24	*-82.0* 18.54	*-58.6* 27.72
40 km/h	*-89.2* 23.76	*-61.1* 36.72	*-48.4* 35.50
50 km/h	*87.5* 30.42	*-52.3* 42.73	*-52.2* 45.18

Table 7.
Simulation results for impact position of 10% (Off-Road 4x4).

OFF-ROAD 4X4	Pedestrian speed [km/h]		
Vehicle speed	0	5	10
30 km/h	*-55.5* 19.22	*-68.8* 19.55	*-63.5* 17.46
40 km/h	*-51.3* 30.6	*-83.1* 28.26	*-66.1* 20.88
50 km/h	*-65.6* 36.18	*-85.9* 37.44	*-63.4* 50.26

Table 8.
Simulation results for impact position of 10% (Roadster sport).

ROADSTER SPORT	Pedestrian speed [km/h]		
Vehicle speed	0	5	10
30 km/h	*-43.8* 25.09	*-52.4* 30.64	*-52.9* 35.21
40 km/h	*-48.3* 46.44	*-69.0* 30.42	*-47.6* 39.96
50 km/h	*-32.8* 55.44	*-59.9* 34.92	*-47.2* 54.9

Table 9.
Simulation results for impact position of 25% (Family Car).

FAMILY CAR	Pedestrian speed [km/h]		
Vehicle speed	0	5	10
30 km/h	*-57.5* 25.56	*-58.4* 31.32	*-55.2* 32.62
40 km/h	*-75.4* 34.99	*-58.9* 39.42	*-58.3* 39.78
50 km/h	*-51.3* 43.56	*-50.9* 48.17	*-54.7* 45.54

Table 10.
Simulation results for impact position of 25% (Off-Road 4x4).

OFF-ROAD 4x4	Pedestrian speed [km/h]		
Vehicle speed	0	5	10
30 km/h	*72.2* 8.03	*-59.6* 15.59	*-58.1* 25.74
40 km/h	*77.7* 18.18	*-76.6* 12.6	*-64.7* 34.20
50 km/h	*71.0* 22.32	*-88.1* 23.76	*-67.4* 41.76

Table 11.
Simulation results for impact position of 25% (Roadster sport).

ROADSTER SPORT	Pedestrian speed [km/h]		
Vehicle speed	0	5	10
30 km/h	*-52.4* 32.62	*-57.4* 27.40	*-64.1* 24.80
40 km/h	*-49.4* 41.04	*-61.0* 37.19	*-63.9* 44.28
50 km/h	*-50.3* 53.64	*-60.7* 50.04	*-65.4* 49.07

Table 12.
Simulation results for impact position of 50% (Family Car).

FAMILY CAR	Pedestrian speed [km/h]		
Vehicle speed	0	5	10
30 km/h	*83.2* 25.20	*-65.6* 18.97	*-63.0* 26.53
40 km/h	*75.4* 21.96	*-55.6* 27.54	*-59.8* 30.96
50 km/h	*-81.1* 32.29	*-58.1* 37.44	*-47.8* 38.16

Table 13.
Simulation results for impact position of 50% (Off-Road 4x4).

OFF-ROAD 4x4	Pedestrian speed [km/h]		
Vehicle speed	0	5	10
30 km/h	*-58.2* 21.13	*-53.5* 15.48	*-70.3* 20.27
40 km/h	*-67.0* 35.64	*-68.8* 36.63	*-89.6* 17.10
50 km/h	*-67.2* 28.98	*-69.4* 48.82	*80.9* 26.82

Table 14.
Simulation results for impact position of 50% (Roadster sport).

ROADSTER SPORT	Pedestrian speed [km/h]		
Vehicle speed	0	5	10
30 km/h	*-63.6* 19.98	*-56.6* 27.94	*-63.3* 29.52
40 km/h	*-52.3* 20.16	*-71.2* 21.31	*-56.9* 41.94
50 km/h	*-71.1* 29.52	*-59.9* 42.12	*-60.4* 54.72

The different front shape of vehicles from these three classes results in different points of impact on the bonnet and angle values in terms of speed and head impact.
The results above demonstrate that the shape of the front vehicle is a capital feature in the studied categories.
Some of the results of the studied configurations are close to the parameters defined by the EEVC, Euro NCAP or pedestrian regulation. However, many others are different. This fact suggests that, although the recommendations provided by these organizations are not wrong, further testing should be performed to fully verify these results.
Vehicle speed and impact speed are two of the main important factors in the resulting impact speed in pedestrian run over. This is significant because this increase in the impact speed could end in serious injury or death.
After analyzing the results, it has also been proved that the front of the car is not a crucial factor in causing the injury or death.

CONCLUSIONS

Pedestrian protection issue is currently one of the problems to which organizations and governments are trying to find an answer. Organizations such as Euro NCAP, EEVC and the New Regulation, together with vehicle manufacturers are seeking solutions through the development of advanced safety systems and accurate methods for testing these systems.
This paper presented a double study as follows:

- The first one to evaluate the influence of vehicle speed, where a defined number of cases in the city of Barcelona where pedestrians were involved in accidents were selected. After a filtering process, 62 cases containing the details required to draw conclusions were studied. In these cases, it was found that 75,1% of accidents occurred during the day, with an average level of injury of ISS 4-5 and ISS 3-4 at night.
- The second one was a study of speed as a cause of accidents. It was found that 75,3% of drivers anticipated the accident and made an evasive braking manoeuvre. The average speed before the accident was 50,8 km/h while average impact velocity was 24,78 km/h. A 20% reduction in speed was proposed, as it would involve a 60% reduction in pedestrian accidents on roads. A 40% reduction in speed would get an 85% reduction in pedestrian accident rates.

Finally the level of injury related to vehicle speed was assessed. The boundary speed between slight and severe injuries, using the ISS parameter, was defined at about 40 km/h. This value matches up with the impact velocity used in the tests of organizations such as the Euro NCAP, which show that this is a suitable speed to carry out this kind of trial.
The main aim of the second study was to test the influence of the front vehicle design in pedestrian head injuries in case of run over. To carry out this second study, a series of accident simulations in which the person's head impacted into a different point of the bonnet depending on the scenario have been performed. The parameters changed in these simulations were:

- Vehicle class:
  - Family Car.
  - Off-Road 4x4.
  - Roadster Sports.
- Vehicle Speed:
  - 30 km/h.
  - 40 km/h.
  - 50 km/h.
- Pedestrian speed:
  - 0 km/h.
  - 5 km/h.
  - 10 km/h.
- Impact position of the pedestrian against the vehicle:
  - 10%.
  - 25%.
  - 50%.

The head impact position depends on vehicle class: while in Family Cars and Roadster Sports collisions occur within the boundaries set by Euro NCAP for adult head impactor, in Off-Road 4x4 some points are located even below the lower limit ascribed for adult head.
Regarding the pedestrian's head impact angle and speed against the bonnet of the car, following conclusions can be reached:

- In simulations with the same vehicle speed, impact angle and speed of the adult head against the bonnet were nearly unchanged although the pedestrian speed is different.
- Further testing to verify that such parameters defined by the EEVC, Euro

NCAP or Pedestrian Regulation are entirely valid is needed.

- The impact speed negatively affects pedestrian injury severity; that is, the higher the impact speed, the worse the consequences of the collision.
- The front vehicle shape is not the main cause in pedestrian injury severity.