PEDESTRIAN PROTECTION – LOOKING FOR POTENTIALS

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1 Abstract

Pedestrian protection represents one the most intensively discussed issues in the European safety community, involving the European parliament, member state governments, consumer protection groups, research institutes, automobile manufacturers and engineers. Nobody can deny the need for protective measures to save some 9000 people's lives annually in Europe. However, the question arises as to which technology is the most efficient to achieve this goal.

EEVC-WG17 has defined four component tests to quantify the protection potential of car fronts as a substitute for a full size vehicle impact. EuroNCAP has tested each car following these procedures assigning a star rating. The tests will prompt major modifications of passenger car fronts thereby partially conflicting with design features introduced in response to other requirements such as environmental protection.

After a detailed review of recent car-to-pedestrian accident data, it becomes evident that modern aerodynamic car front shapes reduce the injury risk, especially to the upper leg and pelvis.

Of more relative importance for severe to fatal injuries is the secondary impact of a pedestrian onto the road surface. We should investigate means to influence the kinematics without compromising certain vehicle designs.

In order further to enhance pedestrian protection, we must look beyond passive safety measures alone and give accident avoidance a much higher priority in cars. This can lead to the desired substantial progress. Nevertheless, pedestrian safety will remain a combined effort with all disciplines in traffic environment.

Keywords
accident, statistics, passive safety, active safety, pedestrians

2 Accident data

Obviously, to derive the proper countermeasures it is most important to begin with the accident data.

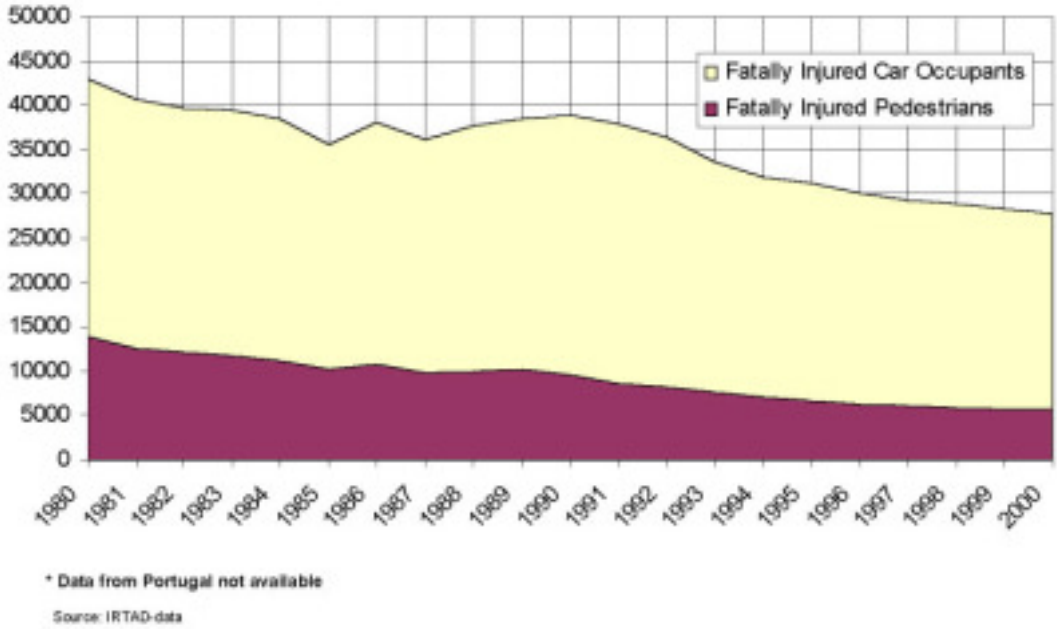

Fig. 1: IRTAD pedestrian accident data (Europe)

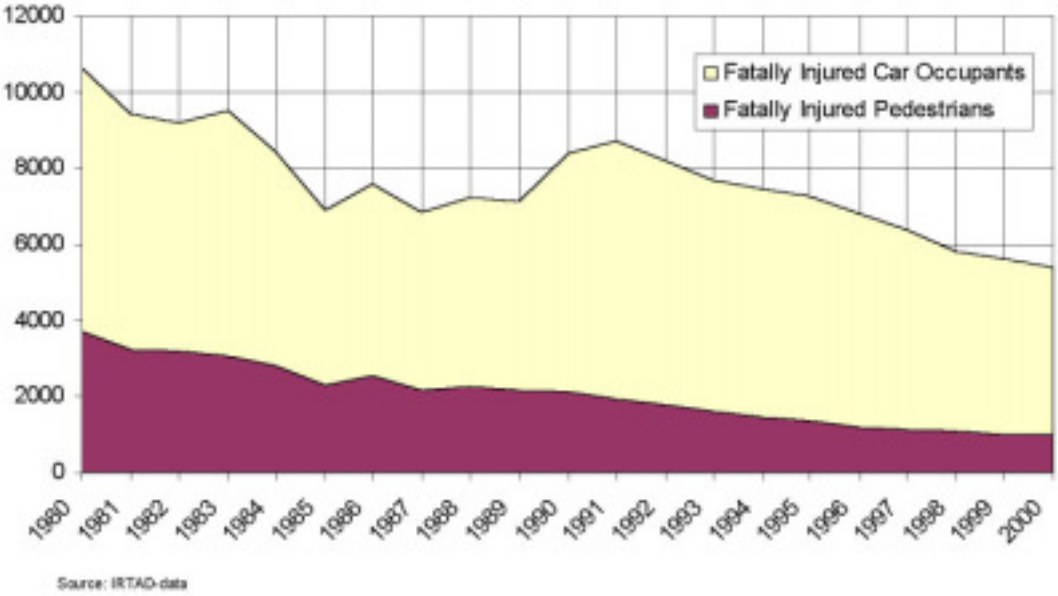

Fig. 2: BAST pedestrian accident data (Germany)

The IRTAD data (Fig. 1) shows that some 6,500 pedestrians (+2,500 2-wheelers) in the EU sustained fatal injuries in 2000, most of them in car accidents. In addition, 90,000 pedestrians were seriously injured. Though this absolute number is not acceptable, the relative trend over time has to be recognised. In spite of continuously increasing car density and mileage since 1980, we can see a steady decline of fatal pedestrian and car occupant accidents both in Europe as a whole and in Germany in particular.

The EU curve shows a fatality reduction of ~42% in the past decade between 1990 and 2000 and seems to continue in the near future. This trend is consistent with progress towards the target sought by the

European Union's Directive 6065/2000 after full implementation of the pedestrian component tests. The decline is recorded for all age groups.

Of the following explanations may be adduced for this increase in safety levels:

- Quick and professional medical rescue
- More separate lanes for pedestrians and 2-wheelers
- 30 kph speed limits in urban areas and enforcement
- Traffic education of children
- Improved crash avoidance with electronic support systems
- Improved head lights
- Less aggressive front ends of cars

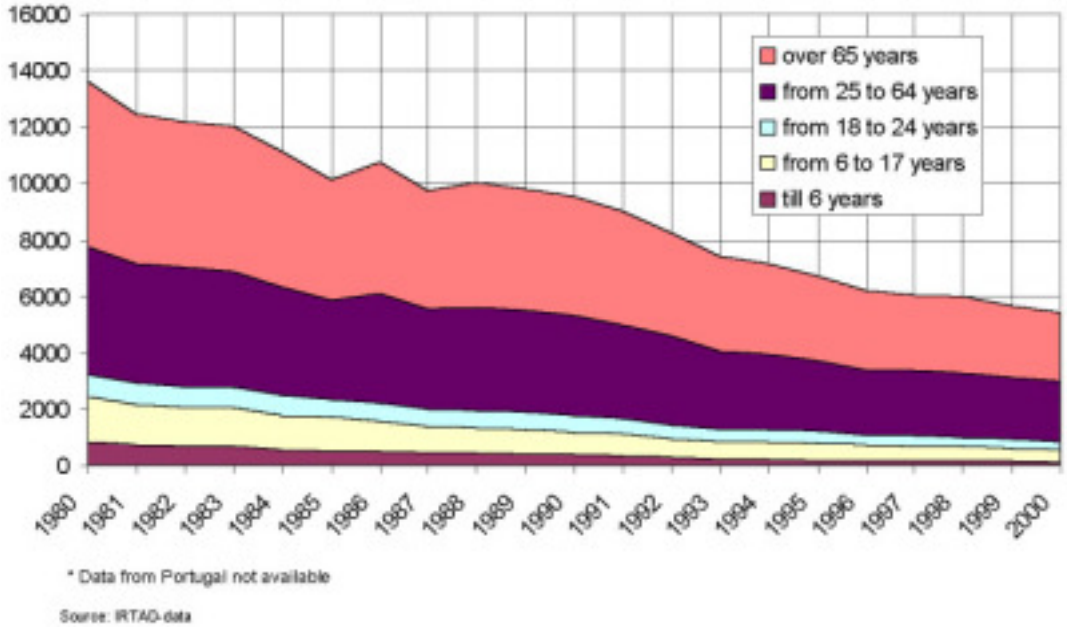

Fig. 3: All injuries over age groups (Europe)

It may be noted that elderly people over 65 represent the largest group among the injured pedestrians.

At the IRCOBI conference in 2001, Otte presented in-depth pedestrian accident data of the German BAST data base, analysed at MUH. The selection of accidents is fairly representative for the large scale traffic scenario.

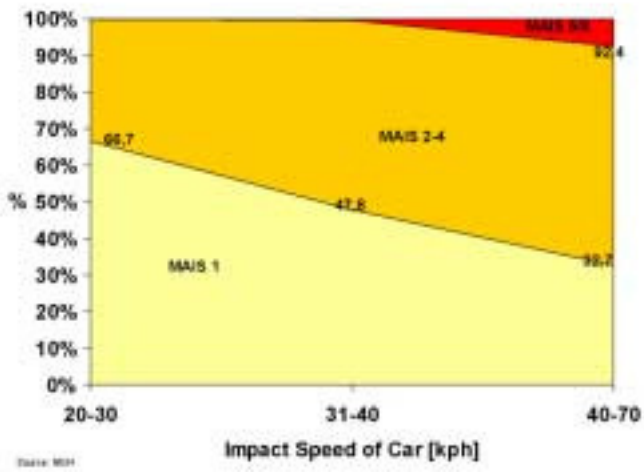

Fig. 4: Injury severity over collision speed (293 accidents)

It can be seen that severe injuries are significantly related to higher speeds. Most severe injuries of MAIS 5^+ levels are registered at speeds above 40 kph only.

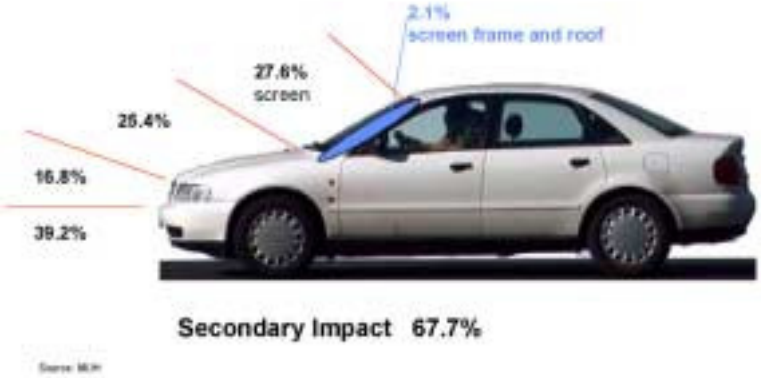

Fig. 5: All injuries from contact zones at impact speeds 20-40 kph (n= 204)

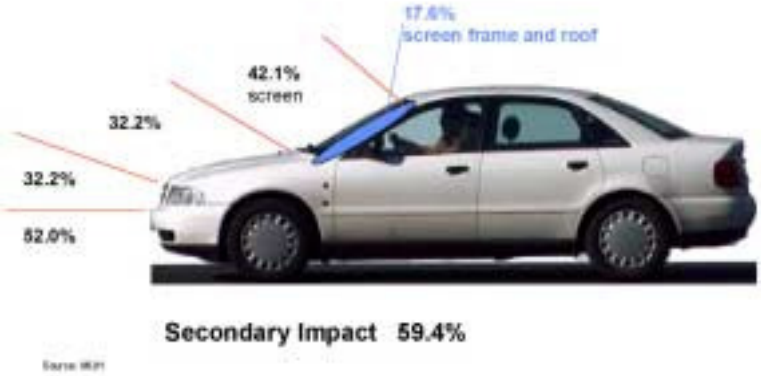

Fig. 6: All injuries from contact zones at impact speeds 41-70 kph (n= 89)

Injuries at lower speeds are more often caused by secondary impact with the road surface. However, in the particular MUH sample shown in Fig. 6, the risk of secondary impact might be underestimated as front end structures like those of vans and one box designs were excluded (Otte 2002). According to the AGU (F. Walz, M. Muser: working group of accident mechanics, Zürich), the pedestrian may be seriously injured while landing head-on onto the road surface following impact with this particular type of vehicle.

At higher speed the primary impact against the car front becomes more relevant. Bumper and head impacts to the windscreen area are most frequently the injury causation, the latter predominantly for adults only. Children mainly impact the front area of the hood and not the windscreen.

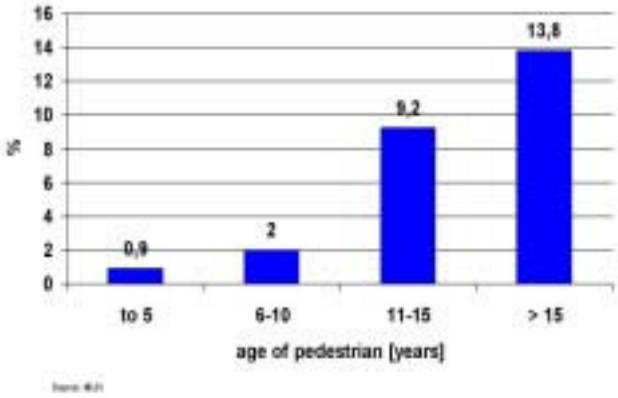

Fig. 7: Portion of head impacts at windscreen area related to pedestrian age groups (n=2272)

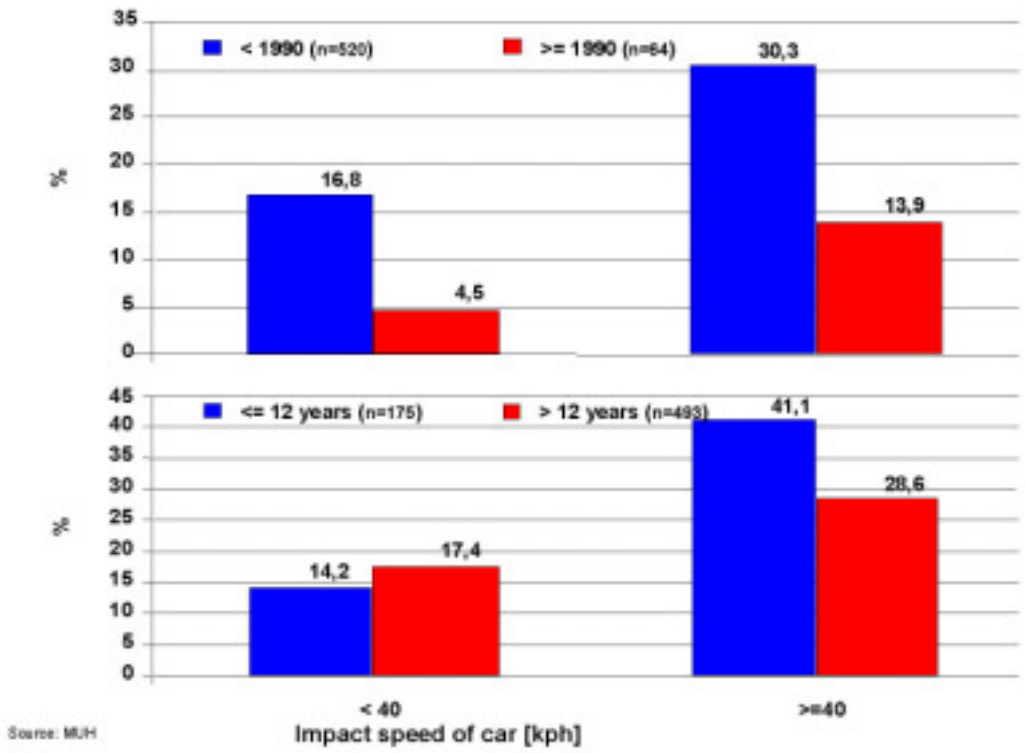

Fig. 8: Hood leading edge as cause of injuries

The following conclusions may be drawn from accident analysis:

- The absolute number of pedestrian fatalities has decreased over time. Elderly people over 65 present the largest group of injured pedestrians
- Impact speed and pedestrian age largely define the injury severity
- Impact speeds greater than 40 kph cause more severe injuries
- At lower impact speeds, the secondary impact of the pedestrian onto the road surface is more important than the primary impact against the car's front end
- MUH has found few upper leg and pelvis injuries resulting from contact with the lower and streamlined hood of modern cars
- For adults, the head impact into the windscreen and window frame is more important than the hood impact

Any appropriate pedestrian test has to take these facts into account to reproduce the real risk in any component test.

3 Pedestrian impact physics

We should also consider the pedestrian impact kinematics. As an example a pedestrian with m_1= 80 [kg] mass is hitting the front of a an average car with m_2= 1600 [kg] mass driven at u_2= 40 [kph] speed. The mass ratio is then 1: 20. In the case of a fully plastic impact, the velocity after the impact is equal and cannot be influenced.

$$v_1 = v_2 = \frac{m_1 * u_1 + m_2 * u_2}{m_1 + m_2}$$

In the case of a fully plastic impact the change of velocity would amount to Δv= 38,1 [kph] for the pedestrian and Δv= 1,9 [kph] for the car, respectively.

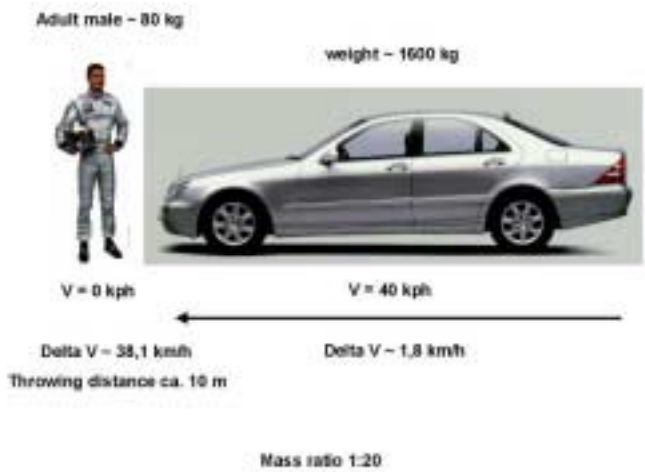

Fig. 9: Fully plastic impact

The car experiences a very small change of velocity, whereas the pedestrian is abruptly accelerated up to the speed of the car. The same incident would happen in the case of a passenger car hitting a heavy truck in a full frontal crash.
This simple consideration makes it clear that no car can be really described as being 'pedestrian friendly' because of the unfavourable mass ratio. In other words the pedestrian will always remain vulnerable and the designation 'pedestrian friendly' is misleading.

Passenger car structures can only be reasonably optimised for compatibility among cars themselves in a narrow mass ratio of ~1:2, i.e. better self protection for the occupants. Thus all attributes like soft impact zones are not adequate for a car-pedestrian impact; a car will always be aggressive to the pedestrian in terms of energy and exchange of momentum. Due to this physical fact, there seem to be two realistic options to achieve injury outcome reductions:

1. Energy absorbing impact zones with little form aggression in the front structure of cars. The force peak level during loading is then reduced.
2. Braking the car immediately before the collision takes place.

A further important parameter is the specific pedestrian kinematics in an accident. In most cases the pedestrian is not fully loaded and rotates somehow over hood, fender or roof. The first contact with the front end can be partly influenced whilst the secondary impact with the road surface depends mainly on the actual circumstances like vehicle speed and geometry. he injury outcome will remain a question of impact speed (primary impact), actual kinematics and the body part hitting the road surface (secondary impact).

Up to some 40 kph impact speed the collision sequence occurs as follows:
Adult pedestrian

- Lower leg contacts the bumper
- Upper leg hits the leading edge of the hood
- Pelvis hits the first part of the hood
- Chest and arm contact the centre of the hood
- Head hits the far part of the hood or the windscreen

Child pedestrian up to 150 cm:

- Upper leg and pelvis contact the bumper
- Abdomen and thorax hit the leading edge of the hood
- Head hits the first part of the hood

Every component test should reflect this difference in kinematics.

4 Passive safety car measures

Earlier examples of car measures

Having taken the physics into consideration, we can recognise that the careful layout of a ‘soft’ car front is rather challenging for a design engineer. There are numerous other constraints to consider.

Some twenty years ago, the car industry started with positive examples for the design of a reasonable exterior:

- Yielding head lights
- Yielding flanges between hood and fender
- Yielding or removal of ornaments like brand symbols
- Hidden axis of the windshield wipers
- Rounded shapes replaced sharp parts
- Bumpers with energy absorbing foam

Use of these carefully detailed design measures was effective in reducing local loading during first contact.

Later, a major step forward was the need to save fuel for environmental protection. From there on, reduction of aerodynamic drag was an important target to meet. Effort to achieve a drag coefficient below 0.3 set clear boundaries for styling since then. In the '90s, all cars had to follow positive trends in utilising yielding front ends, lower bumpers and a lower leading hood edges.

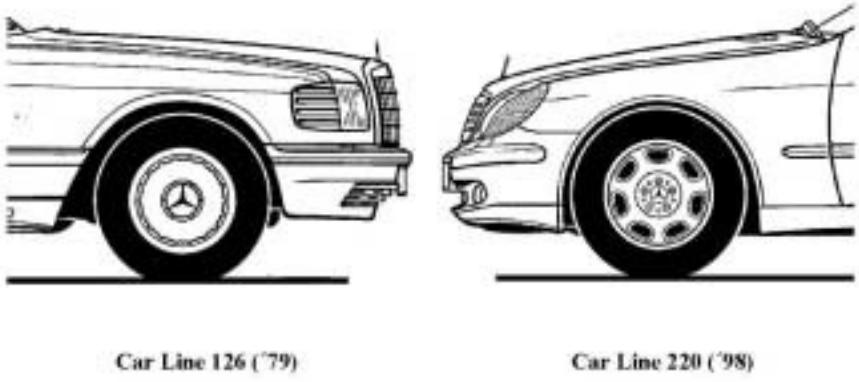

Fig. 10: Comparison of two generations of Mercedes S-class vehicles

Unfortunately, there are also examples where conflicting targets prompted an adverse effect: The clearance between hood and engine is generally too limited for effective energy absorption because of stiff engine components below the hood. Though modern technology allowed a reduction in the overall engine dimensions (i.e. V6-cyl. replaced inline-6cyl. engines), new components such as turbo chargers or air-conditioners became standard equipment and needed additional space. A more balanced layout during the concept phase of car development will be required in future.

Insurance companies must pay significant amounts of money for low speed repair damage. They urge the car industry to reinforce front ends for standard tests up to 16 kph collision speeds. Therefore, integrated bumpers became stiffer to save expensive parts in the front area.
In recent years a new passenger vehicle type, the van, was developed. There is great customer demand for this type as it offers large interior space combined with good economy. The front end, with a rather steep shape, can act like a ramp and initiate rotation of the pedestrian hitting the road surface.

There are attempts to enhance passive safety for pedestrians, e.g. by increasing the clearance of the

hood to stiff components below, while the body first contacts the front end. More sophisticated measures like airbags on the hood to soothe the pedestrian impact may well protect against the primary impact but can also open a new field for product liability due to the ensuing greater complexity of pedestrian accidents.

Component tests developed by EEVC WG17 pedestrian safety

In order to quantify the pedestrian 'friendliness or aggressiveness' of a particular car, EEVC working group 10 has developed four component tests. A long discussion preceded as to whether a full scale vehicle test would be better suited than subsystem tests. It was decided to pursue component tests to avoid the poor repetitiveness of dummy impacts.

Fig. 11: Component tests for 4 body regions

Injury criteria were associated with the measurements. Accident data was used to calibrate the injury criteria.

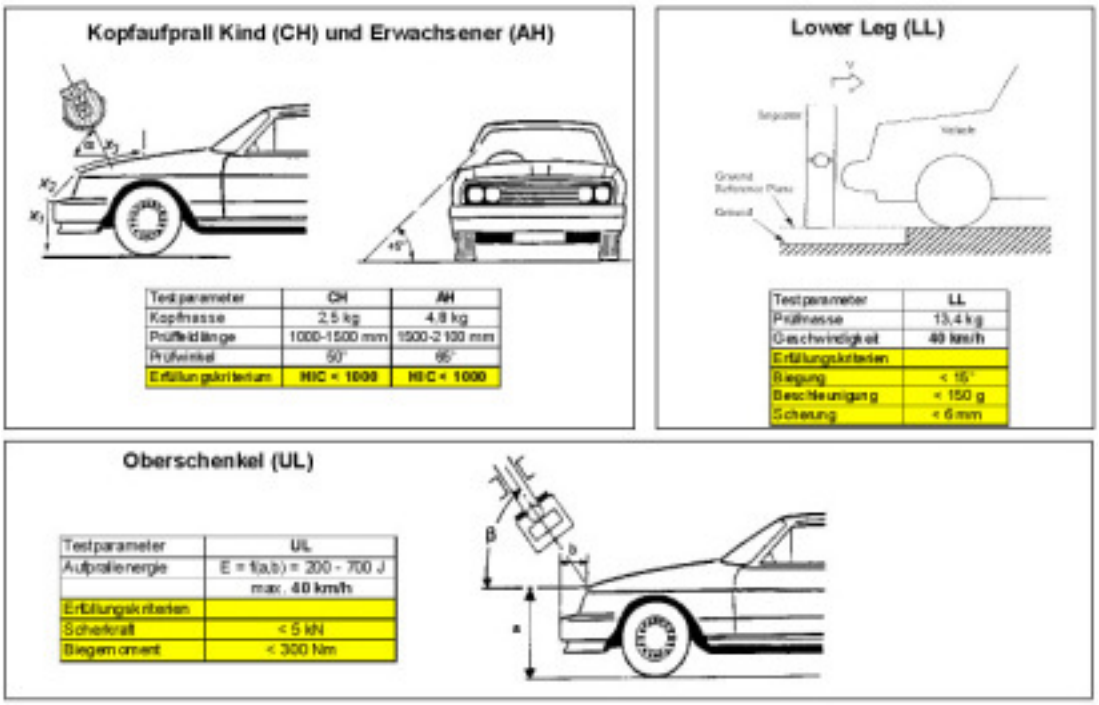

Fig. 12: Component tests with injury criteria

After the report was published in 1994, discussion soon began as to what extent the tests are really representative. The European manufacturers objected to the tests in detail. They presented a cost/benefit analysis for the modification of every car to pass the tests. Also WG17 was mandated to review the WG10 tests from 1994 and propose possible adjustments taking into account new data. An update report was released in Dec. 1998.

Following intervention by the European Parliament, the European Commission will decide in 2002 if it intends to delay full implementation of the four component tests and either accept a voluntary agreement with industry or if it will take immediate action for legislation. ACEA's voluntary agreement would comprise implementation of the lower leg to bumper test and the child head to hood test supplemented by quick introduction of ABS braking (2003), daytime running lights (2002), and the ban on rigid bull bars (2002). In a joint review in 2004, the need for full implementation of the EEVC tests beginning 2010 should be clarified.

Most important and independently of financial aspects is the prerequisite that the tests are representative for real life accidents. The state-of- art knowledge, for the greater part covered by the EEVC WG17 report, can be summarised as follows:

Lower legform:
There was no discussion that this test is able to improve the bumper design and reduce the number of complicated knee fractures.

Upper legform:
New aerodynamic, streamlined front ends with rounded hood forms already show a much lower risk. Moreover, children may suffer more severe thoracic and/or head injuries at the front hood if optimisation is aimed for adults only. Experts still doubt that this test may really reproduce femur and pelvic fractures because of the different kinematics. Until there is more scientific background, this test should be suspended to avoid wrong designs.

Child and short adult headform:
In most accidents the head strikes the first third of the hood. This test against the hood is well suited to monitor the risk. A uniform head mass of 3.5 kg covering the 6 year old child up to the 5 percentile female should be used. It would allow a more accurate optimisation for sufficient energy absorption.

Adult headform:
The head strikes the rear hood and the windscreen only in most accidents below 40 kph. In general, laminated glass can well reduce the injury risk if not impacted near the frame. Therefore, the head test against the hood is not well suited to monitor an adult's risk and should be deleted. On the other hand, depending on the actual circumstances the laminated glass and the frame can also be the cause of severe head injuries, on which optimisation should accordingly be focused.

EuroNCAP tests

In order to promote the introduction of 'pedestrian compatible' cars EuroNCAP has tested some 130 cars using the WG10/17 test procedures. Since phase 1 the results have been published with colour tables indicating the risk. All cars received 1 or 2 out of 4 stars until 2001.

Fig. 13: EuroNCAP star rating

The Honda Civic was the first car to receive 3^+ stars with 26 points. EuroNCAP announced on 5 June 2001 that "the Honda Civic is the first car tested which is designed to balance the safety of both occupant and pedestrian protection. With a 72% score the Civic almost achieved a four star EuroNCAP pedestrian rating (75% threshold for four stars) and offers double the level of pedestrian protection offered by many of the cars tested by EuroNCAP to date".

The question arises as to what extent such a car is really more pedestrian compatible than another car. Of course, market incentives are strong and it seems favourable to test each car. However, for as long as half of the test procedures are not scientifically approved, it is questionable that the full implementation will achieve additional potentials in cars beyond the countermeasures that have been already implemented. (EEVC-WG17 stated: This has resulted in an increase of the acceptance levels for the upper legform to bonnet leading edge test. This was required because an imbalance between recent accident statistics and the performance of modern cars in pedestrian tests (e.g. EuroNCAP) was observed).

The test assesses the risk in a primary impact only, but accident statistics tell us that the secondary impact depending on car shape and speed can be more important. This is the case especially with “new” car front geometry such as vans and one-box-designs. Also according to accident data most severe injuries are found above 40 kph. EuroNCAP as an important incentive program cannot be satisfied with the ranking of test results that cover and refine a small percentage of the possible potential only. Therefore, EuroNCAP cannot claim in general terms that the actual component tests define whether a car offers good pedestrian protection or not.
Moreover, the implementation of passive safety means cannot solve the desired target of saving 2,000 pedestrian lives annually across the EU. EuroNCAP should go further and award active safety measures, which can be more effective either in avoiding the accident or at least in reducing the injury severity.

EuroNCAP should:

- Investigate the relation between injury severity and impact speed
- Investigate the ratio between windscreen and frame vs. hood impact injuries
- Investigate the influence of the secondary impact onto the road surface
- Delete the upper legform and the adult headform tests from the actual test program
- Promote crash avoidance based on vehicle analysis and tests.

5 Active safety car measures

The pre-crash-phase in real world accidents

The pre-crash phase has a great potential in terms of pedestrian safety. It has not yet been considered to the full extent. DaimlerChrysler has noticed that in 2/3 of all real world accidents, a relatively long time precedes the impact.

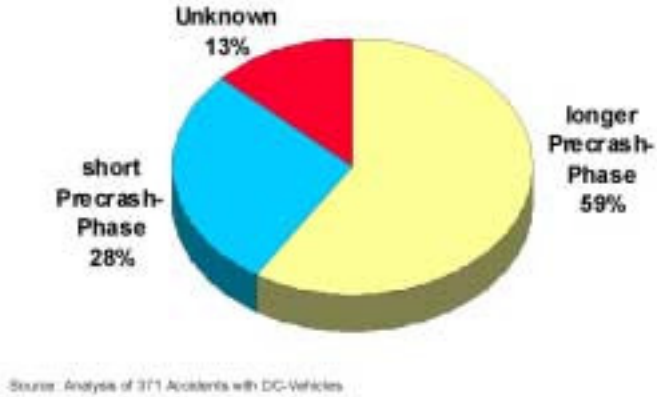

Fig.14: Pre-crash-Phases in Accidents

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Such dynamic situations can be caused by critical driving manoeuvres like:

- sudden, full braking (panic breaking)
- swerving
- different road surface friction left and right
- full spring travel of the suspension
- great steering angle velocity

Potentials using the pre-crash-phase

How effective such a phase can be is demonstrated with an example of the Brake Assist System (BAS), which is more and more becoming standard in car lines.

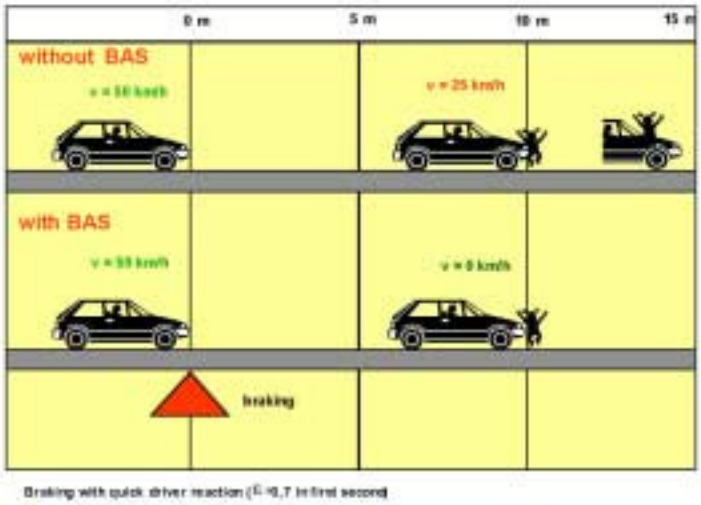

Fig.15: Accident situation with Brake Assist (BAS)

The BAS reacts on the driver's braking. Depending on the brake pedal velocity, it automatically activates full brake pressure. An average driver can thereby gain a significantly shorter braking distance in emergency cases, which might avoid impact or at least reduce impact velocity. ESP (Electronic Stability Program or Vehicle Stability Control), the more advanced vehicle dynamic system, is found more and more on different car models. It monitors critical driving situations. An

automatic controlled braking of the wheels is able to stabilise the car again and avoid the risk of incidentally hitting a pedestrian in slippery road conditions.

Pre-crash detection

A further future potential offers an active, driver independent automatic intervention of an electronic system. Yet the parameters for an impending accident have to be defined. For example, the actual distance to the pedestrian and the velocity of the approach present such information.

Deduction of a near accident with a pre-crash-system comprises the following potentials:

- Accident avoidance or accident severity reduction by means of driver warning
- Accident avoidance or accident severity reduction by activation of dynamic driving systems (ABS, ASR, ESP). Early driver warning of critical situations will follow eventually.

A more detailed look at the timing while braking is shown in Fig. 16

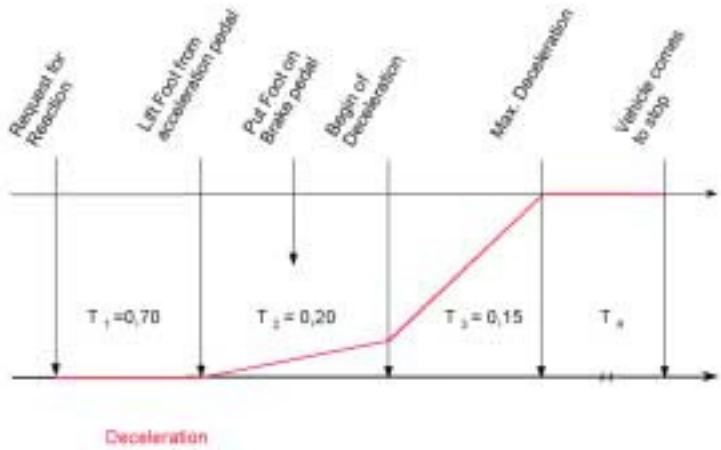

Fig.16: Time phases while braking

A realistic example can illustrate the performance of Automatic Braking compared to ABS and ABS+BAS. The car approaches a pedestrian in a straight line at 40 kph. The driver first detects the pedestrian at 12m and reacts immediately. With automatic braking, the car would be equipped with a (radar-)sensor with a range of 6m ahead of the car. Independently of the driver's reaction, it will automatically activate the ABS brake at 6m before the point of impact. Stopping distances and velocities at the point of impact are evaluated and shown in Fig. 17.

$$s_1 = v_1 * T_1$$

$$v_2 = v_1 - \frac{1}{2} * a_E * T_2 ; s_2 = \frac{1}{2} * (v_1 + v_2) * T_2$$

$$v_3 = v_2 - a_E * T_3 - (a_{\max} - a_E) * T_3$$

$$s_4 = \frac{v3^2}{a_{\max}} ; v_4 = 0$$

$$s_{ges} = s_1 + s_2 + s_3 + s_4$$

$$v_C = \sqrt{v_3{}^2 - 2 * a_{\max} * (D - s_1 - s_2 - s_3)}$$

The following values are assigned (wind drag, roll resistance and different friction were not considered):

Parameter	ABS	BAS	Autom	
$v_{1:}$ Initial velocity of car	11,11	11,11	11,11	m/s
$a_{E:}$ deceleration with engine drag torque	1,00	1,00	1,00	m/s²
a_{max}: max. deceleration (coefficient of friction = 0,9)	7,06	8,829	8,829	m/s²
brake performance after build-up time (80% or 100%)	80%	100%	100%	1
D= Distance car to pedestrian	12,0	12,0	12,0	m
Range controlled by (radar-) sensor	-	-	6,0	m
$T_{1:}$ reaction time driver, no braking	0,70	0,7	[0,54]	s
T2: pedal change or active system reaction time; linear increase of engine drag torque	0,20	0,1	0,05	s
T3: build-up time ABS; engine drag torque const. + brake torque linear increase	0,15	0,08	0,08	s
T4: full brake performance				s

Table 1: Parameters for comparison of brake performance

- In all 3 cases:
  - The distance needed for braking exceeds the distance to the pedestrian
  - The point of impact happens while the car is fully braking
  - BAS profits from an earliest possible detection of the pedestrian.

- <u>ABS (BAS) braking</u>: The car travels some 7.78 m without braking; after that, it depends on the driver if he can fully activate the ABS. With BAS the full pressure of 100% is reached within a shorter build-up time, which results in most effective braking. The car's velocity at the pedestrian point of impact in 12 m is reduced from 40 kph to 36.5 (31.0) kph. The car reaches the rest position in 19.26 (16.20) m.
- <u>Automatic braking</u>: T_1 is below the driver's reaction time and needed until the sensor trigger range is reached. T_2 is a short electronic response of 0,05 secs after detection of the event. T_3 is needed to build up full pressure. The car will hit the pedestrian with a collision velocity of 20.9 kph (~52%!) and stops at only 13.90 m.

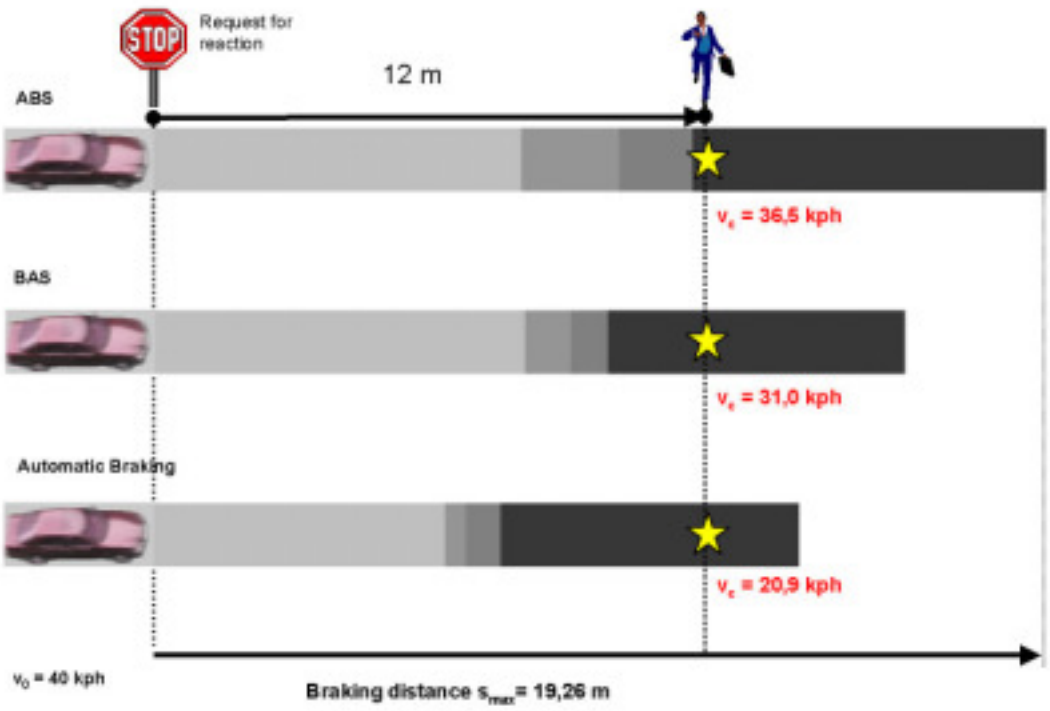

Figure 17: Comparison of braking distances

The positive effect of automatic braking can be logically empathised in real crashes. It may be hard to assess the overall potential in accident statistics for the whole fleet.

6 Conclusions

The number of pedestrians suffering severe or fatal injuries from car impacts has continuously decreased since 1991. This is due to combined efforts in all areas of traffic environment.

Design countermeasures were first implemented in ESV vehicles and appeared some 20 years ago in production cars. According to physics, the injury reduction potential of passive safety countermeasures is limited and can be influenced by:

- Yielding, energy absorbing front ends
- Careful front shape design to influence the point of impact and the kinematics.

In the '90s, the front ends of all cars have been considerably modified for low aerodynamic drag. The hood front leading edge of modern cars now causes less than 5% of femur and pelvic fractures in adults. New features are now under development, but should not be promoted as universal remedies. In turn, more emphasis should be given to the secondary impact onto the road surface.

EuroNCAP tests, based on EEVC sub-component tests, help to give pedestrian protection a higher public awareness. However, at the moment ratings should be based predominantly on lower leg impact and child/short adult head impact onto the hood.

Instead, EEVC WG17 and safety researchers should carefully examine pedestrian and 2-wheeler kinematics, which are insufficiently reproduced by impactor testing. This includes the pedestrian impact against the windshield and the frame as well as his secondary impact onto the road surface.
The impact speed of the car has the most important influence on injury severity. Active safety measures are based on electronic devices, which support the driver in the short pre-impact phase. ABS and BAS need to become standard equipment in all cars. Future systems must detect a pedestrian at the earliest moment. They should automatically reduce vehicle speed by braking and in addition trigger

passive safety measures like hood lift. In this way, they can effectively either avoid the accident or reduce the accident severity. Moreover, they have a double potential both in car-to-pedestrian accidents and in car crashes. According to the e-Europe Action Plan of the European Commission, active safety elements should be expedited by manufacturers as a matter of priority but also awarded by EuroNCAP as the most efficient countermeasure for pedestrian safety.
Accident research should be extended to crash avoidance analysis, in order to obtain more information on accident causation and feedback on active safety systems.

Pedestrian protection has a high public awareness profile. The whole safety community is addressing the challenge of achieving further reductions in pedestrian injuries. All disciplines involved need to co-operate with great responsibility.

Acknowledgement

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