CONSIDERATIONS ON A STANDARDIZED
PEDESTRIAN TEST METHODOLOGY

by

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INTRODUCTION

Since the end of 1980 three research institutes: Bundesanstalt für Straßenwesen (BASt), Organisme National de Sécurité Routière (ONSER) and Instituut Voor Wegtransportmiddelen (TNO) cooperate in the field of standardized pedestrian tests. The aim of the study is to propose a standardized test methodology which could be applied to pedestrian safety tests carried out for research purpose or carried out for compliance testing of passenger cars. The project was supported by the EEC Biomechanics Program, Phase 3. ONSER conducted 7 cadaver tests. The BASt conducted 26 dummy tests with 50% Hybrid II and 6 years child pedestrian dummies in the same test configurations. TNO carried out a literature study and evaluated the requirements of a mathematical pedestrian model. The BASt acted as project leader.

SELECTED RESULTS OF LITERATURE STUDY

The relative share of pedestrians killed in traffic accidents lies in European countries between 13% and 33% of all fataly injured. In the Federal Republic of Germany in 1980 3.095 pedestrians were killed in traffic accidents.

It is a well known fact, that mainly children and old people over 65 years are involved in pedestrian accidents. So the highest share (with 308) of injured pedestrians per 100.000 persons is found in the age group between 6 and 10. The highest fatality rate is found in the age group over 65 with 15,6 out of 100.000 persons in this age group (1979). The curve of the height distribution of involved pedestrians shows two peaks, one in 1,23 m height for children and the second in 1,64 m height for old persons [1].

The passenger car is most frequent (∿ 70 - 80%) the opponent in pedestrian accidents. The primary impact occurs mostly on the car front (∿ 75%) and here mostly on the right car front side (∿ 30%) while the pedestrian is hit almost ever on his side and in over 90% of the cases while walking or running [2, 3, 4].

Due to the collision speed, different values exist from different accident analyses, but it can be said, that the 50% value lies between 25 and 35 km/h and that 90% of the collisions occur under 45 respectively 55 km/h. In about 60% of the cases the car was breaking before impact [summarized in 5].

Many studies show injury distributions for different pedestrian groups and different car shapes /¯4, 6, 7, 8_7. The results are not repeated here in detail.

One main classification of car shape is the classification in pontoon (P)- and wedge (V)-form cars. An examination of the relationship between injury severity and the car shape showed that the overall pedestrian injury severity was about in the same range for pontoon- and V-form cars, but the patterns of injuries were different. Serious head injuries in conjunction with serious lower leg injuries are typical for the V-form. The pontoon-form was found to have a higher incidence of serious head injuries in conjunction with injuries to the pelvis and femur. In the case of child accidents, the trapezoidal form (T-type), as a subgroup of the pontoon-form, causes injuries of the thorax or the abdomen, depending on the height of the children. The traumatisation scale (product of injury severity and injury frequency) only considers injury severity and injury frequency; it will give no indication of the long term consequences, for example healing time or disability which may be an important feature for pedestrians who are frequently elderly.

CHOSEN METHODOLOGY FOR PEDESTRIAN TESTS

Based on the knowledge of safety of today's typical production cars, the aim of the pedestrian impact tests in this study was to focus on problems of pedestrian kinematics and loadings. Furthermore it was intended to keep the test configuration as close as possible to real world pedestrian accidents. The general cause of injury is the initially impacting vehicle structure and the head impact. If the pedestrian is an adult, the bumper typically strikes the lower leg or knee and the front edge of the bonnet strikes the upper leg or pelvis. If however the pedestrian is a 6 years old child, the bumper strikes the upper leg and the front edge of the bonnet strikes the thorax or abdomen. The main conclusion for the test configuration from accident data was to achieve direct head contact to the vehicle.

Assessing the results of the literature study, the intention was to employ a test method as close as possible to a test configuration, which could be used as a commonly agreed standardized test methodology.

Due to the height distribution of pedestrian accident victims, the 6 years child dummy (119 cm) and the Hybrid II pedestrian dummy (175 cm) were selected as test objects.

To compare dummy and cadaver kinematics the cadavers were of nearly the same height as Hybrid II. Tests with child cadavers were not considered because of their unavailability. The weight of adult cadavers did not differ significantly from average weight distribution.

In depth at-the-scene accident studies have enabled to correlate injury severity and impact velocity. For today's vehicle designs pedestrian struck at impact speeds below 30 km/h normally sustain only minor injuries. Serious or fatal injuries are usually sustained at impact speeds greater than 50 km/h. The test velocities of this study were fixed to 30 and 40 km/h /¯8_7.

Besides other parameters the vehicle front shape determines pedestrian kinematics and loadings. The primary vehicle contacts are the main sources for leg and pelvic injuries for adult pedestrians. The severity of head injuries is determined by the location of the contact as well as by impact speed. In order to keep the number of test car types low, two in France and Germany well represented vehicle types were selected for this project:

Citroen GSA with V-contour and short hood

Audi 100 with P-contour and long hood.

It was decided to brake the test cars immediately after first contact and to adjust the car in braking position during the whole test. The car deceleration was chosen to 6 m/s^2.

According to statistical data of primary impact areas in car-pedestrian collisions the pedestrian was impacted at his left side.

From other simulated car-to-pedestrian tests with dummies it was concluded, that the arm of the impacted body side plays an important role in kinematics of upper trunk and head. Therefore it was decided to force the test objects to perform a minor rotation along the vertical body axis, so that the upper trunk hits the bonnet beside the arm and therefore the arm does not influence the head impact /¯9_7.

After several pretests the test objects were positioned in a walking bearing with the right foot forward. Furthermore the trunk of the test objects was turned 25o towards facing impact on the vehicle, see Figure 1.

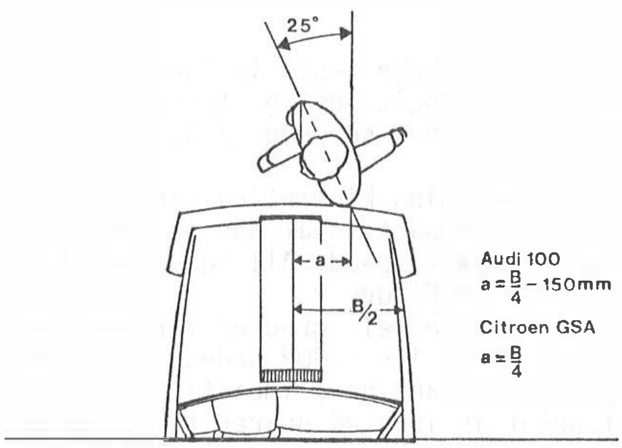

Figure 1: Dummy position at impact (sketch)

The pedestrian dummy tests were performed at the crash test facility of the BASt. The dummies were equipped at the provided locations with triaxial accelerometers in the head, chest and pelvis. In addition, the legs of the adult dummy were equipped with accelerometers built into the knees and feet in lateral direction.

It was not succeeded to adjust the dummy joints in such a manner that the weight distribution between ground force and retention force was 70:30 as it was planned. A more feasible method of dummy joint adjustment was evaluated and practised in the test program:

- dummy joints were adjusted according to FMVSS 208
- dummy was positioned in the retention system in the desired bearing
- dummy leg and hip joints were tightened in such a way, that the dummy slowly began to collapse when he was released.

Each test configuration: 2 dummies, 2 car types and 2 velocities was repeated three times. The cadavers were equipped with accelerometers at the following locations:

- head triaxial in the mouth
- chest triaxial screwed on T4
- pelvis triaxial screwed on sacrum
- knee uniaxial, transverse (Y) left leg
- ankle uniaxial, transverse (Y) left leg.

Due to the low stiffness of cadaver joints the weight distribution between ground force and retention force was about 30/70. In fact, there was practically no vertical displacement of head between the release time and the impact due to gravity.

For this study 7 cadaver tests: 4 with the Citroen GSA (2 at 40 km/h and 2 at 30 km/h) and 3 with the Audi 100 (2 at 40 km/h and 1 at 30 km/h) were conducted at the test facility of ONSER.

TEST RESULTS

The evaluation of these tests is focused on kinematics and on injury related parameters. The results of the tests correspond quite well to those presented in the literature, see e.g. /_9, 10_7.

The results concerning kinematics can be separated in two parts: analysis of trajectories and impact locations of the different members of the body and analysis of head impact speed. All head impact locations of dummy and cadaver tests are shown in Figure 2.
The dummy head impact points are well grouped for each test configuration (except those in brackets: Audi 100 - 90^{o} pedestrian impact, Citroen - left arm influenced dummy rotation and head impact). With increasing test speed the dummy head impact point is located nearer to the windshield respectively to the lower windschield frame. The throw-on-length of the dummy head normalized to the dummy height is higher for the V-contour (Citroen) than for the P-contour (Audi).

The main difference in dummy and cadaver kinematics is caused by the different pelvis motion. The dummy hip motion can be described by a "rolling" while the cadaver hip is to a higher extent "slipping" on the front end of the hood. This may be caused by the observed lateral bending of the cadaver knees, which could not be simulated by the dummy knee. Therefore the throw-on-length on the car front is for the cadaver higher than for the dummy (The cadaver in test PBT 13 was impacted in 90^{o} position).

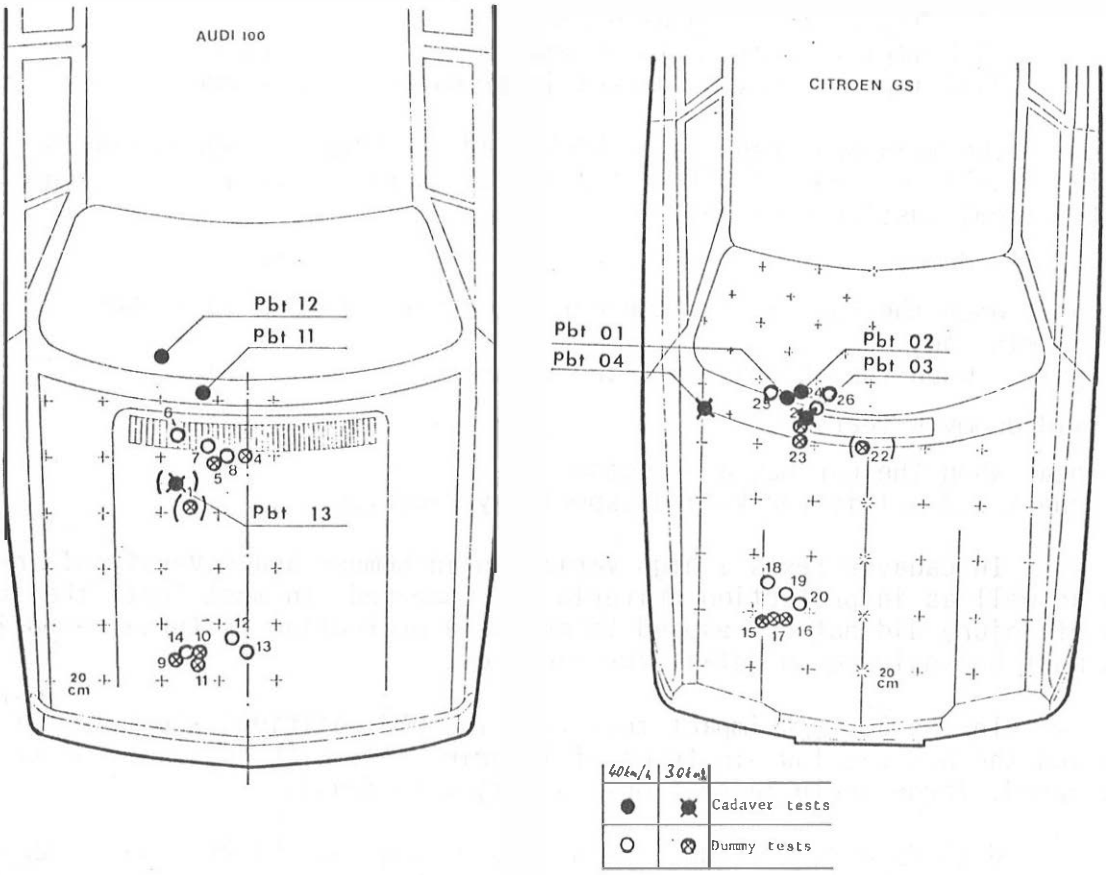

Figure 2: Head impact locations of all dummy and cadaver tests

The head impact velocity is for the dummy tests slightly higher than car impact speed. For the V-contour head impact velocity is remarkably higher than for the P-contour. In cadaver tests the head impact velocity for P-contour is lower than the car impact velocity. Cadaver head impact speeds are for the P-contour higher than those of the dummy.

If the different dummy parts impact areas of similar stiffness of the car dummy loadings show a good reproducibility of injury criteria parameters. Measuring data variation in pedestrian tests is in the same range as in full scale car impact tests against the rigid wall. See f.i. some exemplary data:

HIC, 50% male dummy, 40 km/h Audi tests: 272, 474, 346
SI, 50% male dummy, 40 km/h Citroen tests: 201, 242, 146
HIC, child dummy 6 years, 40 km/h Audi tests: 620, 590, 706
SI, child dummy 6 years, 40 km/h Citroen tests: 418, 230, 289.

If however the dummy impacts areas of the car front with different local stiffnesses very high variations in dummy loads must be expected. The main areas of the car front where this problem is essential is the windshield frame (and A-pillar). In the Citroen tests at 40 km/h HIC was measured for the 50% male dummy to:

444 impact location windshield
1422 impact location lower windshield, near frame
3311 impact location direct lower windshield frame.

The main body regions of high loadings (due to high variations in measuring results of knee- and feet-accelerations no conclusions could be found for them) must be seen in:

- 50% male dummy
  - head when the car has a V-contour (at P-contour with lower hood length too)
  - pelvis when the car has a P- and V-contour
- child dummy 6 years
  - head when the car has a V-contour
  - chest and pelvis for V- and especially P-contour.

In cadaver tests a high variation in number and severity of injuries as well as in protection criteria was observed. In most tests the severity of injury did not correspond to measured protection criteria. Head injuries must be analysed in detail for each test.

In the 30 km/h impact test (PBT 13, 90^{o} position) the head hit the bonnet and the HIC was low. In terms of injuries only with Audi car, at 40 km/h impact speed, large scalp lacerations (AIS 2) were found.

With GS car, although the HIC was generally higher than 1000 only a cephalhematoma (PBT 01) was observed as the subject hit the windshield frame.

At thorax level, injuries appear in the two impact speeds and with the two car types. But lesions are less severe with GS car than with Audi 100 car. In fact, thorax was broken in all cases where maximal acceleration values were higher than 60 g, except PBT 03 (48 g).

At pelvic and lower limb levels, the differences induced by the front car shape are more evident. With the Audi 100 the impact location is near the hip and in the three tests pelvic fractures were noticed. Also important lesions at lower limbs were observed, particularly at 40 km/h impact speed with especially important knee ligamenteous ruptures.

With GS impacting car, lower limb lesions did not appear at 30 km/h impact speed. But at 40 km/h impact speed there were noticed numerous injuries, more especially osseous lesions but also (PBT 02) knee ligamenteous ruptures.

Due to the high variation in cadaver injuries and the low number of cadaver tests no general conclusions can be made especially in comparing the corresponding dummy- and cadaver test configuration.

DISCUSSION OF POSSIBLE STANDARD TEST METHODOLOGIES

The testing of pedestrian protection of cars can be done in three ways:

- full scale tests with dummies
- body segment impactor tests
- mathematical calculations with dynamic models.

For all three groups of possible test methods or a combination of them, some important input parameters should be taken from accident statistics and analysis:

- impacts of children and adults
- impact velocities (25 km/h to 45 km/h range)
- impacts with a car or a buck in a dived braking position.

In the following the three possible test methods will be discussed and open problems and dependencies between them will be shown.

FULL SCALE TESTS

Full scale tests can be performed with cadavers, present child and adult pedestrian dummies and furthermore with new pedestrian dummies, which may be developed in the future.

Cadaver tests are necessary for research, especially for establishing biomechanical tolerance levels and protection criteria, as well as for evaluation of parameters, which should be measured in dummy tests. It can be expected, that performance test to evaluate car pedestrian safety will not be done with cadavers.

Full scale tests with dummies give the most comprehensive data of loads on pedestrians in accidents. They are relative expensive, very complex and variation in dummy loadings can be explained by the variation in the stiffness of car structures at different impact points. Due to the complex pedestrian kinematics full scale tests have to be done in an advanced stadium of car development and construction. Furthermore controlled improvements of dummy loads by small changes in vehicle design are difficult to detect.
Full scale pedestrian tests as the only performance criteria for car pedestrian safety can not be recommended as an unique standard test, but they are necessary for determining parameters and criteria for component tests and for the validation of mathematical models.

Because of the criticism on the dummies, which are currently in use, some changes in dummy components should be done in the next future to build a more satisfactory dummy for full scale tests. For instance the shoulder and the thorax of side impact dummies could be taken for improved pedestrian dummies. Knee joints with lateral compliance with a measuring device for knee bending moment or collapsing leg bones could be developed too. More realistic dummy kinematics may result from this. Maybe it is possible for those tests, that a 90^{0} dummy position can be realized, which seems to be the typical impact position as derived from accident investigations on scene. For a standardized full scale dummy test further parameters have to be defined exactly, depending on the selected standardized dummy type(s):

- dummy standing position
- measuring parameters
- protection criteria for pedestrian impacts

- instrumentation and data processing
- calibration and torques of dummy-joints
- ground friction
- dummy release.

BODY SEGMENT IMPACTOR TESTS

These tests are generally simple and cheap, because they do not need large and special test grounds and facilities. They are well repeatable and show the stiffness and energy absorbing capability of car structures. They can be used for standard tests and also for the development of car structures for a satisfactory pedestrian protection. It is not possible to get information by impactor tests on improving overall car shape or the kinematics of a pedestrian hit by the car. Results of other research projects (summarized for instance in the report of the EEVC working group 7, unpublished) have shown the problem of determining a representative mass of the impactor. Another problem is the impact velocity of a body segment (f.i. the head), which depends on the car shape and even of the stiffness of other car structures (f.i. bumper and leading edge) which were impacted by other body parts (f.i. legs and pelvis) before. In this phase of the project no investigations on developing methods of body segment impactor tests, were conducted, but the results from simulated car-to-pedestrian collisions are useful for further research in this field.

Three different component-tests seem to be important:

- head impact tests
- bonnet leading edge tests
- bumper tests.

Some open problems have to be discussed: head impact tests can be carried out with a headform, which is propelled on a defined place of the car front with a defined velocity and under a defined impact angle. The mass of the headform is dependent on the kinematics of the pedestrian and this is dependent of the car shape; because a great amount of rotation of the pedestrian means, that the effective head mass will be increased by a proportion of the torso mass.

The point of impact is dependent, f.i. on the pedestrian characteristics like height, the car shape, the stiffness of impacted structures and the velocity of the car, just as the impact angle of the head form. The impact velocity of the head is dependent on car velocity and the rotation of the dummy. A possibility to determine the relevant parameters for component testing is, to get all needed information from a full scale dummy pretest or from results of a satisfactory mathematical model and then to perform component tests over the whole car width with a head form. These component tests should be carried out for adult and child head impact areas.

For bonnet leading edge tests it has to be taken into account, that the effective mass of the adult pelvis is not equal to the effective mass of the child thorax hit by the bonnet leading edge. There are also differences in the protection criteria of the two body parts. This problem has to be claryfied before defining a bonnet leading edge test. There are less problems with the selection of impact velocities and impact points, because of the short time duration between leg-bumper-contact which means less free possible kinematics in the first phase of contact. The whole car width should be tested.

A bumper test can be conducted by a bumper mounted on a car or a test trolley which impacts a sophisticated leg form or using an impactor with a leg shape impactor, which is propelled by a gun or a pendulum device, similar to the US-bumper test proposal /11/. According to this test method, passenger cars will be impacted in the bumper region by a pedestrian lower leg simulator with a weight of 7 pounds (3.2 kg). The impactor will have to travel at 20 mph (32 km/h), its maximum acceleration will not have to be greater than 100 g for a time period longer than 3 ms. The rebound velocity will not have to be greater than 60 percent of the impact velocity.

The effective mass of the legform is dependent on the bumper height. The lower the bumper height, the lower the effective mass has to be chosen. Full scale dummy tests or results of a satisfactory mathematical model can help to calculate the correct impactor mass for different bumper heights. When using an impactor, the maximum values of the impactor response have to be defined. The force or acceleration depends on the relative bumper height in reference to the bone or knee ligament resistance at the impact zone of the leg.

MATHEMATICAL CALCULATIONS WITH DYNAMIC MODELS

Mathematical models, once formulated, allow to make calculations on vehicle structures and pedestrian kinematics very easy. A wide range of variation of vehicle shape and deformation characteristics, pedestrian height, speed and impact locations can be simulated. A requirement for realistic input data for a model is the knowledge of local stiffnesses of car structures hit by the pedestrians. This makes previous component tests necessary.
At first a choice is to be made between a 2D and a 3D model. The kinematics of a pedestrian, impacted laterally by a car, are of a threedimensional nature. So the model in principle should be three-dimensional. A disadvantage, however, of a 3D mathematical simulation is the great number of input data that have to be specified and the relatively high computer costs. After the 3D model has been validated the 2D model can be validated against the 3D model.
It seems to be sufficient for the moment being to model only the primary impact. Minimally eleven elements should be required for modeling the pedestrian: eight elements to simulate legs and arms, 2 elements for the torso and 1 element for the head. The model must be able to simulate at least side (oblique) impacts.

Several authors on pedestrian models mention the importance of the joint-characteristics. So, much attention should be given to this subject. A point of special interest is the lateral deflection or fracture of the knee-joint, which should be modelled as realistic as possible.

In real-life pedestrian accidents and in cadaver tests, fractures of the leg(s) are frequently observed. The model should be able to simulate the fractures in order to determine their effect on the kinematics of the pedestrian.

The friction between the pedestrians feet and the ground has a great influence on the leg loads. Therefore, this friction must be modelled in a realistic way.

As regards the vehicle geometry and material properties, the model should be able to simulate a wide range of vehicle geometry characteristics.

The main output data which certainly must be listed are the kinematics of the pedestrian (plot-figures), the accelerations of the head, chest, pelvis, knee and ankle, several contact forces and some injury criteria, e.g. the HIC.

A development of more realistic pedestrian dummies is also necessary for an optimization of mathematical models. A verification of mathematical model has to be done by cadaver tests or accident reconstructions. For the future a standardization of requirements for mathematical models should be evaluated. Figure 3 shows summarizing the dependencies between the discussed test methods.

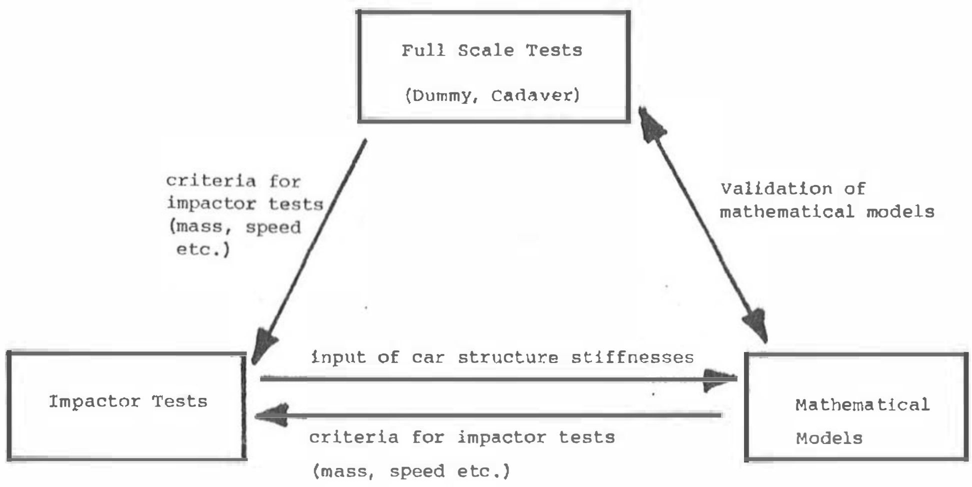

Figure 3: Dependencies of test methods for pedestrian protection

CONCLUSIONS

The statistical data of pedestrian accidents show the need for a practicable standard test for improving the vehicle design for better pedestrian protection. Although many problems are still open a step to step approach can be realized. It can be concluded, that under the chosen test methodology, presented in this paper, the variations of dummy loadings are in the same range as in other established standardized car impact tests. For the next future a combination of full scale- and body segment impactor tests seems to be practicable. A full scale test with an adult- and child dummy, possibly carried out in one test, has to be conducted without exceeding defined maximum values for head, chest and pelvis and - if a device for measuring knee bending moments is established - for the leg. The results of impact speeds for the different dummy body segments can be chosen for the impact velocity of body segment impactor tests with defined masses. In these impactor tests the whole car width within a frame of possible real impacts can be tested. A pedestrian dummy test combined with impactor tests is not as expensive as a car impact test against a rigid barrier, because the car destructions occur only on some front parts. So it can be made sure, that the car front structure will be designed also under consideration of pedestrian protection.

Calculations with dynamic mathematical models, once verified satisfactory, in combination with impactor tests are a cheaper solution which could be introduced in the later future.

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