Benefit estimation of measures concerning the Euro NCAP pedestrian rating and other secondary safety systems on the basis of real-world pedestrian accidents

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Abstract - The paper presents a methodology for the benefit estimation of several secondary safety systems for pedestrians, using the exceptional data depth of GIDAS. A total of 667 frontal pedestrian accidents up to 40kph and more than 500 AIS2+ injuries have been considered. In addition to the severity, affected body region, exact impact point on the vehicle, and the causing part of every injury, the related Euro NCAP test zone was determined.
One results of the study is a detailed impact distribution for AIS2+ injuries across the vehicle front. It can be stated, how often a test zone or vehicle part is hit by pedestrians in frontal accidents and which role the ground impact plays. Basing on that, different secondary safety measures can be evaluated by an injury shift method concerning their real world effectiveness.

As an example, measures concerning the Euro NCAP pedestrian rating tests have been evaluated. It was analysed which Euro NCAP test zones are the most effective ones. In addition, real test results have been evaluated. Using the presented methodology, other secondary safety like the active bonnet (pop-up bonnet) or a pedestrian airbag measures can be evaluated.

INTRODUCTION

The aim of this study was the evaluation of the new Euro NCAP pedestrian rating system and other secondary safety measures for pedestrians on the basis of real world pedestrian accidents. Therefore a method for the evaluation of secondary safety measures based on the influence on road safety has to be developed. The paper describes the used accident dataset of GIDAS and the development of the estimation method. The result of this new benefit estimation method will be shown for different Euro NCAP pedestrian rating levels exemplarily.

DATASET OF GIDAS

For the present study accident data from GIDAS (German In-Depth Accident Study) was used. GIDAS is the largest in-depth accident study in Germany. The data collected in the GIDAS project is very extensive, and serves as a basis of knowledge for different groups of interest.
Due to a well defined sampling plan, representativeness with respect to the federal statistics is also guaranteed. Since mid 1999, the GIDAS project has collected on-scene accident cases in the areas of Hannover and Dresden. GIDAS collects data from accidents of all kinds and, due to the on-scene investigation and the full reconstruction of each accident, gives a comprehensive view on the individual accident sequences and its causation.
The project is funded by the Federal Highway Research Institute (BASt) and the German Research Association for Automotive Technology (FAT), a department of the VDA (German Association of the Automotive Industry).

Sample criteria and Master-dataset

The study is carried out on the basis of the current GIDAS dataset, effective 01.07.2008. For the creation of the master-dataset only accidents with at least one pedestrian are chosen. In the cases with two or more pedestrians, only the first pedestrian hit by the vehicle is considered. Thus, one case in the master-dataset represents one pedestrian respectively one vehicle.
Taking all reconstructed accidents with a collision of a vehicle and a pedestrian into account 1821 cases can be found in the dataset.
The first sample criterion is the vehicle class. The study considers all accidents with passenger cars of the M1 type (according to the UN-ECE definition). Out of all 1821 pedestrian accidents, a number of 1284 accidents meet this condition.

In the next step, only accidents with a frontal impact of the pedestrian are taken into account. Furthermore, special types of accidents have been excluded from the analysis. These are accidents, where no "typical" frontal impact occurred, for example:

- run-over accidents, where the pedestrian already laid on the road
- accidents where a pedestrian was crushed between two vehicles
- side-swipe accidents, where the pedestrian was hit by the external mirror but not by any other part of the vehicle front

At least, the accidents are grouped by the collision speed. The impactor velocity in Euro NCAP tests and within the test definitions of the Directive 2003/102/EC is 40km/h. Above these velocity, there is only a very limited potential of secondary safety measures. Furthermore, there are hardly any impacts on the bonnet expected. Thus, a distinction is drawn between accidents with a collision speed up to 40km/h and above.

Due to the above mentioned facts, the study considers only accidents with a collision speed up to 40km/h. This leads to the final master-dataset which consists of 667 frontal pedestrian accidents with M1 vehicles and collision speeds up to 40km/h. That means, that 36,6% of all pedestrian accidents (667 out of 1821) are principally addressed by legislation and Euro NCAP tests.

Descriptive Statistics

At this point, some information on the master-dataset is given. The distributions of relevant accident parameters as well as some vehicle data and injury severity distributions are displayed to get an overview on the pedestrian accident scenarios.

Accident site and accident scene

As expected, the majority of pedestrian accidents happened in towns. The already large proportion of in-town accidents in the German pedestrian accident scenario (94% in 2006) is further increased by the restriction to accidents with collision speeds up to 40km/h in the study. The distribution of the accident scene shows that more than half of all pedestrians are hit by the car while crossing a straight road. Another 38% collide with the car on crossings and T-junctions. These are mostly accidents where the vehicle turns off to the left or right side without giving way to the pedestrian.

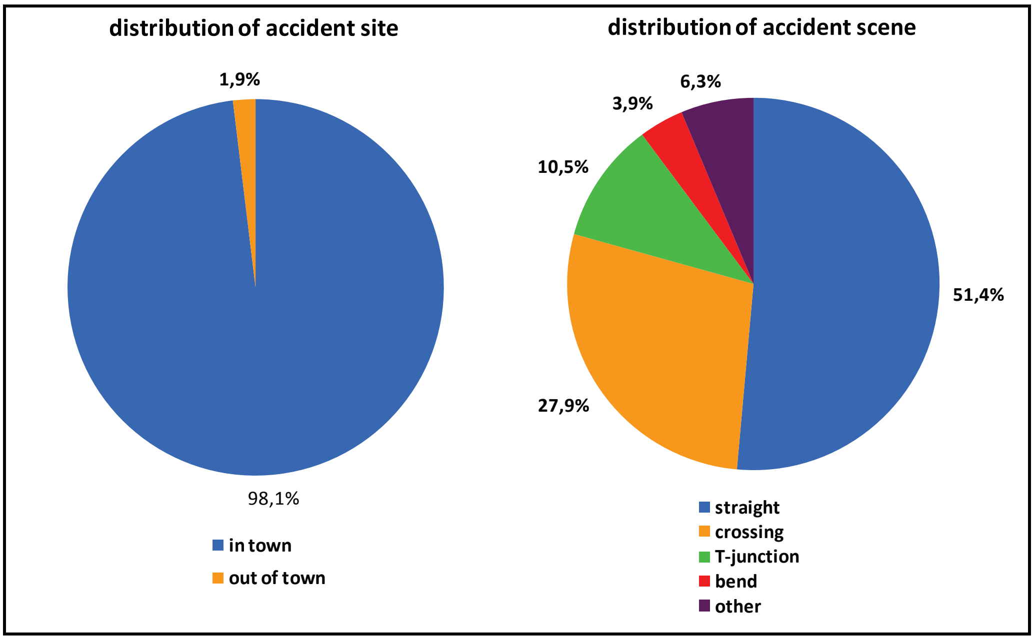

Figure 1. Distribution of accident site and accident scene (n = 667)

Collision speed

The study deals with frontal pedestrian accidents with collision speeds up to 40km/h. The following chart shows the distribution of collision speed in the dataset (figure 2).

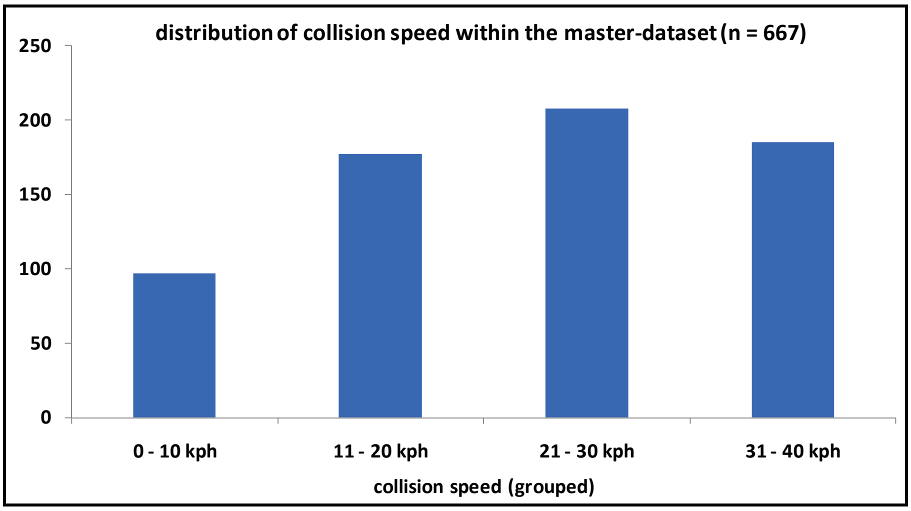

Figure 2. Distribution of collision speed (n = 667)

Vehicle data - Year of market introduction

The front design of vehicles is decisive for the pedestrian kinematics and injury causation in case of a frontal impact. The design is changing over time and thus, it is important to know how old the vehicles in the dataset are. The year of market introduction is shown for all 667 vehicles (figure 3).

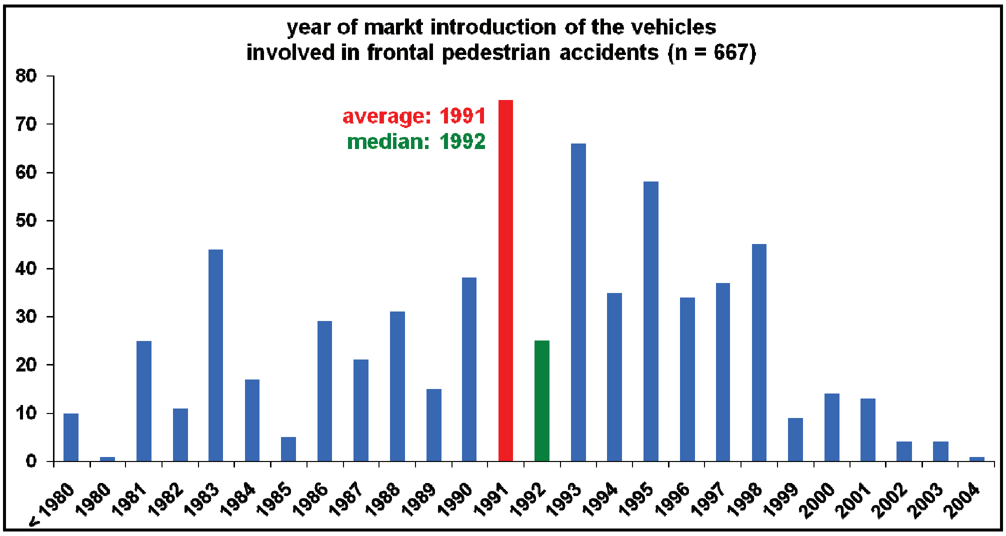

Figure 3. Year of market introduction of all 667 vehicles in the master-dataset

It can be seen that from the today's point of view, the vehicles are rather old. Considering the respective day of accident for each case, the vehicle introduced into the market 11,3 years ago on average. Furthermore, only few modern vehicles can be found in the dataset due to the small market penetration and the small number of reconstructed cases with modern vehicles.

The above shown distribution should be considered during the benefit estimation because most of the vehicles did not have to comply with the current statutory provisions concerning pedestrian protection. The vehicles in the master-dataset do not reflect the current vehicle fleet and most of them did not benefit from recently achieved progresses in pedestrian safety.

Age of the involved pedestrians

Among the collision speed and the impacted part of the vehicle, the age of the pedestrian has a bearing on the injury severity outcome. Due to the human physiological properties, elder people often sustain worse injuries than younger people. Otherwise, children are hit by other vehicle parts than adults. Especially the head impact areas of children differ substantially from the impact zones of adults. In the following illustration, the distribution of the age of the pedestrians in the master-dataset is compared to the distribution within the German pedestrian accident scenario (year 2006). There are small differences between the distributions, especially in the proportion of children.

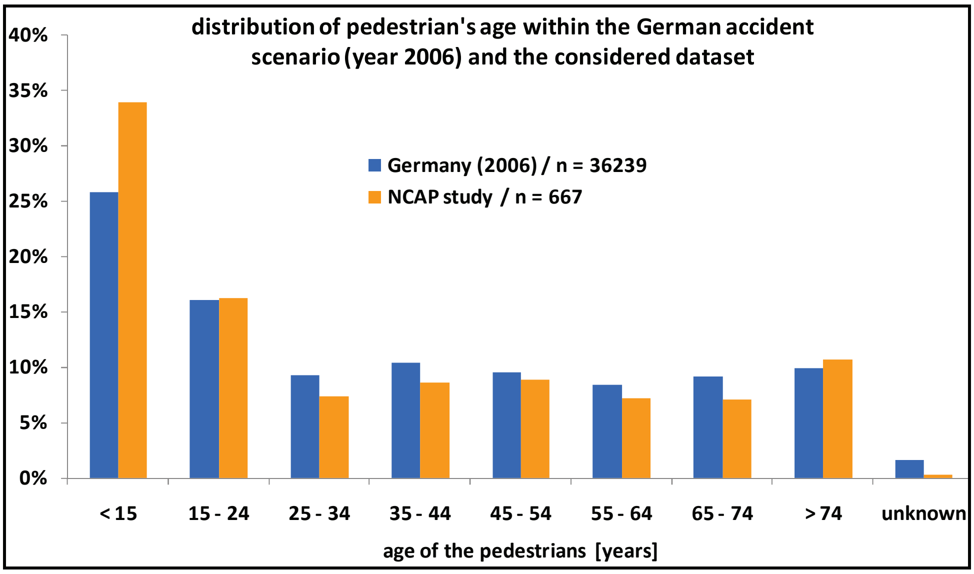

Figure 4. Distribution of age of the involved pedestrians

Injury data

There are 667 accidents in the dataset, representing 667 injured pedestrians. Looking on the injury level, a total of 2045 single injuries can be found in the master-dataset. As shown in figure 5, the majority of all injuries are slight injuries (AIS1). Severe injuries, defined as AIS2 to AIS6 injuries, make up 25,4%. There are 519 AIS2+ injuries in the dataset which will be used for the benefit estimation.

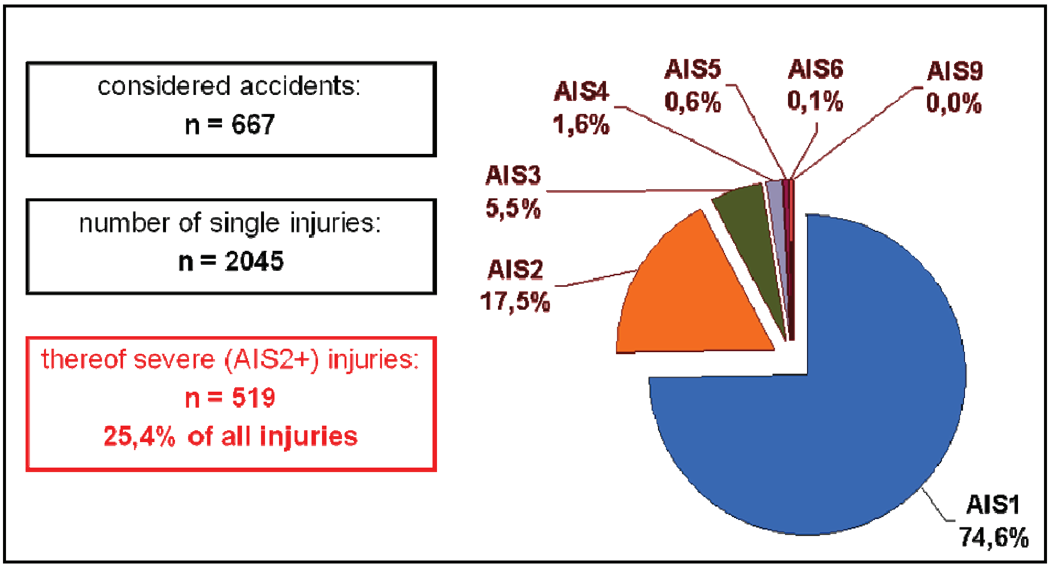

Figure 5. Distribution of injury severity in the master-dataset (n = 2045)

DEVELOPMENT OF THE ESTIMATION METHOD

The following chapter describes the development of the Evaluation methods used in the study. Furthermore, all definitions are explained as well as the assumptions made for the analysis.

Estimation of the individual Euro NCAP test zones

For the intended benefit estimation of the Euro NCAP test procedures it is necessary to evaluate every single Euro NCAP test zone. For this purpose, the 60 single Euro NCAP test zones have to be determined individually for every single vehicle model. After that, every actually sustained injury in the 667 real-world accidents can be allocated to a particular Euro NCAP test zone if it occurred in such an area. The determination of the test zones is done on the basis of CAD models, according to the Euro NCAP testing protocol. Due to the different shapes, bonnet lengths and heights, every single vehicle model has to be measured.

The following illustration (figure 6) shows the resulting Euro NCAP grid (with its 60 test zones) and the used definitions with an example.

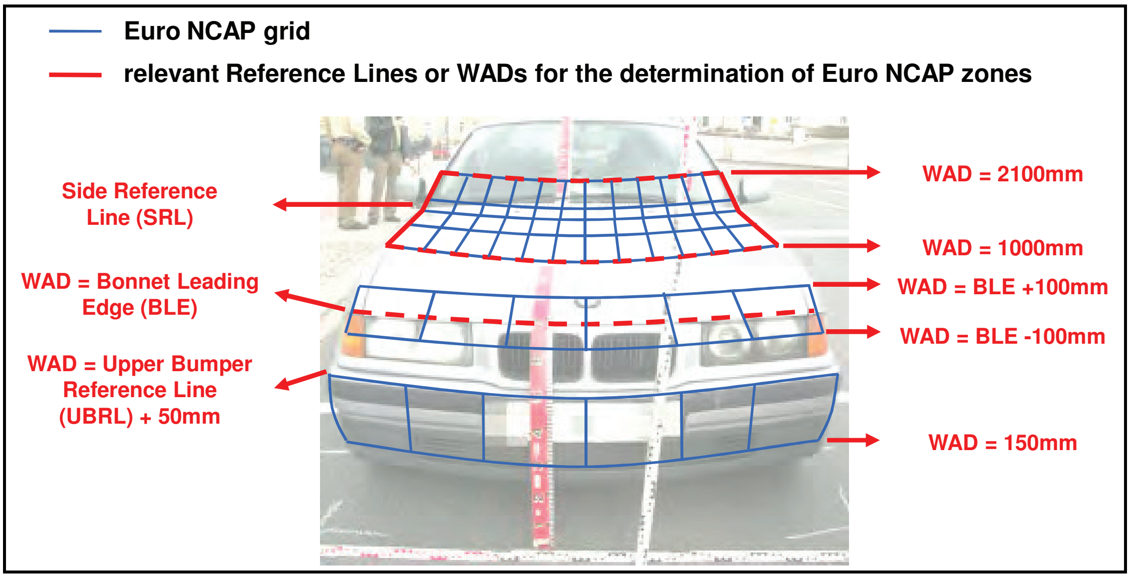

Figure 6. Determination of the Euro NCAP zones

The vehicle is descended from a real-world accident out of the master-dataset and is hereafter used for the explanation of the methodology.

Case-by-case analysis

Prior to the benefit estimation, a detailed case-by-case analysis is done for every accident, using a variety of different variables. The aim of this part of the analysis is the merging of impact data and injury data. The used methodology is again illustrated on the basis of a real-world accident out of the master-dataset.

In the first step, detailed injury information is extracted out of the GIDAS database. The following parameters, encoded for every single injury, are used:

- injury description (name)
- type of injury (fracture, contusion, laceration etc.)
- entire AIS code, including the severity value (AIS1 to AIS6)
- injury location (exact body region)
- injury causing part

As shown in figure 7, the pedestrian in the example case sustained four injuries. The worst of them, a complicated tibia fracture, leads to the resulting injury severity of MAIS3, which is the maximum AIS value of all single injuries.

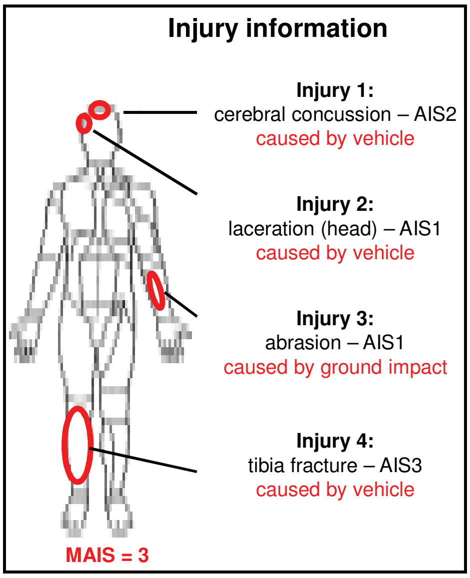

Figure 7. Injury information (example case)

In addition to the medical information, a lot of vehicle data and impact data are investigated at the accident scene for every pedestrian accident within the GIDAS project. Chiefly, the impact points at the vehicle are important for the injury causation and the accident reconstruction. Therefore, every impact point at the vehicle is measured exactly and can thus be described by its WAD (using a measuring tape, see figure 8) and the lateral distance from the vehicle's longitudinal axis (y-value).

The following illustration shows the collision partner in the example case, a BMW 3-series (E36). The three impact points, which could be found at the vehicle, are marked with blue arrows. The relevant WAD and y-values are listed besides.

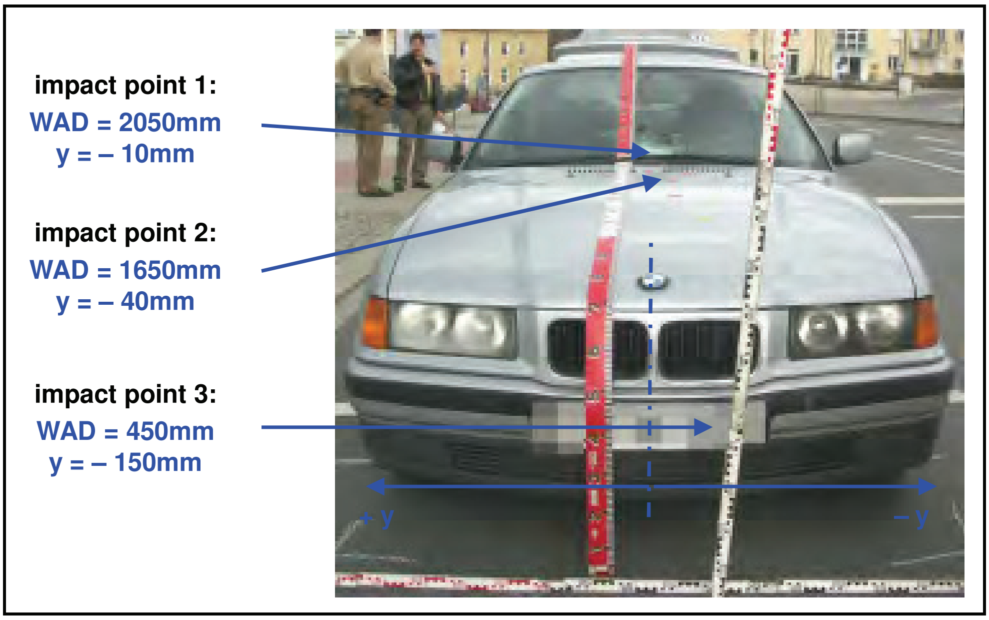

Figure 8. Involved vehicle and investigated impact points (example case)

In the next step, injury data and vehicle/impact data are merged. Every single injury that occurred at the vehicle is allocated to an impact point.

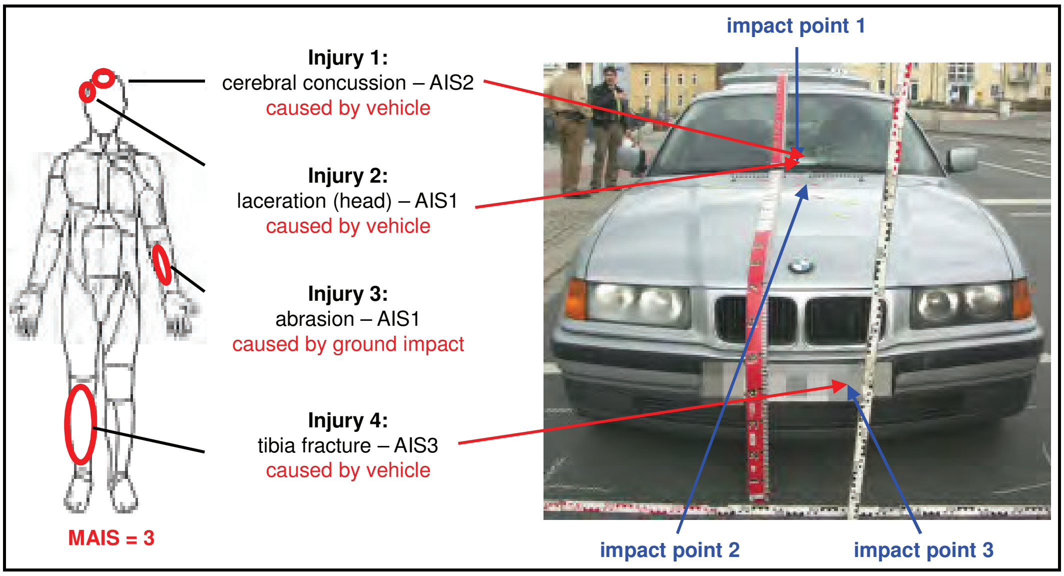

Figure 9. Allocation of single injuries and impact points (example case)

As illustrated in figure 9, the two head injuries in the example case can be allocated to impact point 1. The third injury was caused by the ground impact and is not assignable to an impact point. The fourth injury is allocated to the impact point 3 at the bumper. In the next step the single injuries are allocated to the Euro NCAP test zones. The 60 Euro NCAP test zones are determined separately for every vehicle model, using WAD and y-values. All injuries have been allocated to an impact point and thus, they also have WAD and y-values. So, every injury can be assigned to a Euro NCAP test zone.

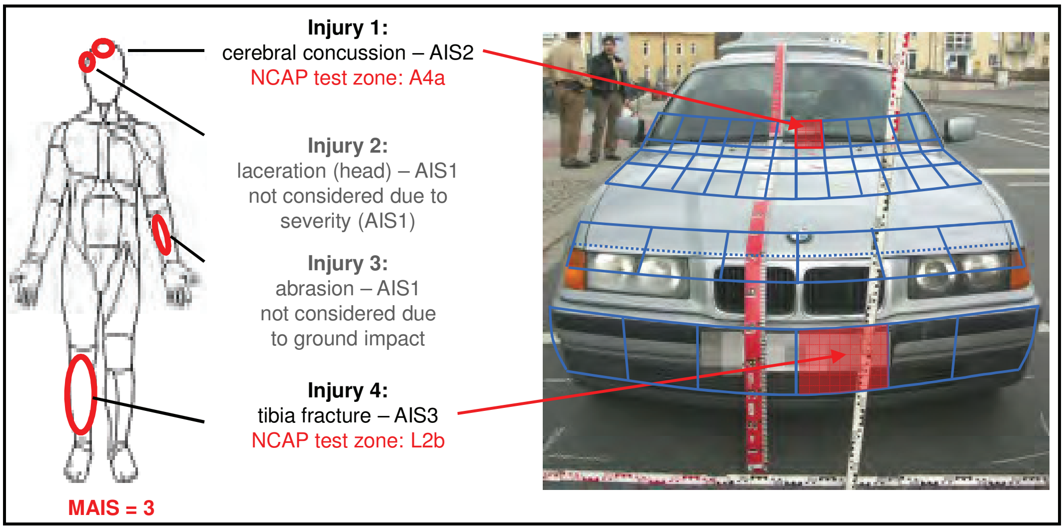

Figure 10. Allocation of single injuries to the Euro NCAP test zones (example case)

Only AIS2+ (severe) injuries are considered for the analysis. According to this restriction, the pedestrian in the example case sustained two severe injuries in a Euro NCAP test zone (figure 10).

- The first injury (AIS2) occurred in the Adult Head test zone A4a.
- The second injury is not considered due to the severity (AIS1).
- The third injury was caused by the ground and can not be allocated to a Euro NCAP test zone.
- Finally, the fourth injury (AIS3) was caused by the bumper, within the Euro NCAP test zone L2b (Lower Leg).

This method is used for all 667 accidents. As a result, all 519 AIS2+ injuries in these accidents can be either allocated to a Euro NCAP test zone or to another vehicle zone or to the ground impacts.

Injury Shift Method

Aim of the study is the evaluation of the Euro NCAP pedestrian rating method and the benefit estimation of different rating results. This means that the performance of particular Euro NCAP test zones has to be evaluated. Due to the fact, that real-world accident databases do not contain any information about the Euro NCAP testing parameters like HIC, bending moment, (knee) bending angle, (leg impact) force, and (lower leg) acceleration, the evaluation can not take place on the basis of these physical parameters. For this reason, the Euro NCAP test zones are estimated on the basis of their colour.

Within the Euro NCAP pedestrian rating, all 60 test zones are judged on the basis of several physical parameters which are listed in the previous paragraph. Afterwards, a characteristic colour is assigned to every test zone, namely green for a good pedestrian protection, yellow for an adequate pedestrian protection and red for a marginal one. This colour code can be used for the estimation of effectiveness of single test zones. Thereby, it is assumed that the actually sustained severity of an injury could be reduced by a green or yellow test zone. That means the AIS value of an injury is shifted downwards if the injury was sustained in a Euro NCAP zone which is coloured green or yellow within the present distribution. This method is called injury shift. The extent of the injury severity reduction depends on the colour of the particular test zone which should be evaluated. As shown in figure 11, it is assumed that the injury severity in a green Euro NCAP test zone decreases stronger than in a yellow one. Generally, the severity of an injury can be shifted towards AIS1 at the maximum. It is assumed that no injury is entirely avoided (AIS0).

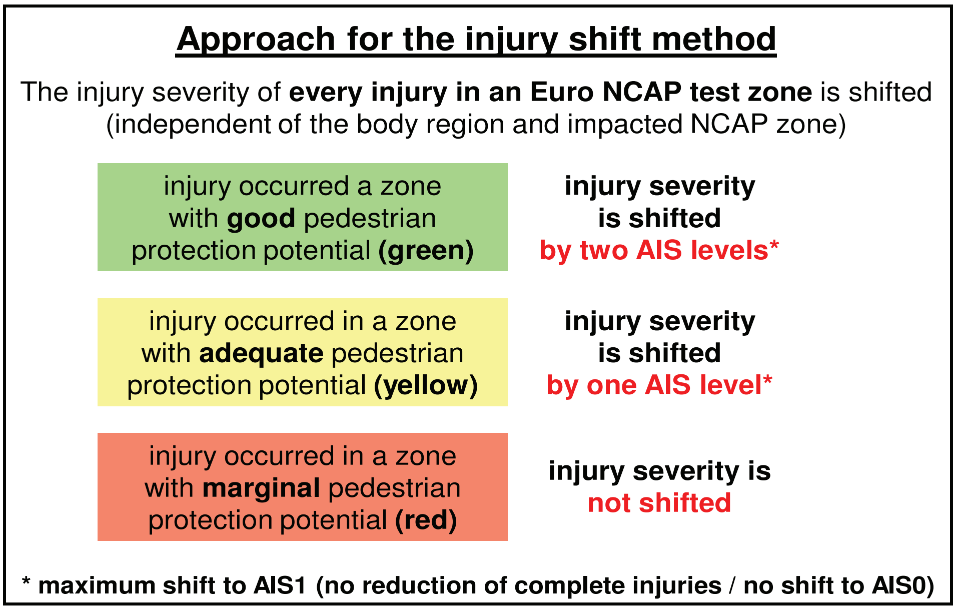

figure 11. Assumptions of the injury shift method

It can be derived from the figure that injuries in red Euro NCAP test zones are not shifted which means that red zones have no injury reduction potential. The methodology of the injury shift method is explained on the basis of an example within the following chapter.

Within the present study, all AIS2+ injuries which are sustained on the vehicle front are used for the analysis. It can be expected that optimised impact zones will even have a positive effect on injuries in all body regions. An optimised head impact zone on the bonnet, for instance, could mitigate injuries to the thorax or abdomen. Furthermore, child head injuries are also regarded if they are caused by the bonnet leading edge, although this vehicle part is essentially addressed by tests concerning upper leg and pelvis injuries. By using this approach it is assumed that all injuries in all body regions will benefit from secondary safety measures.

Benefit estimation

For every real-world accident in the master-dataset it is known which kind of injuries the pedestrian has sustained and which impact zones were responsible for the injuries. Along with the measured Euro NCAP test zones for every vehicle it is now possible to evaluate any Euro NCAP colour distribution regarding its actual real-world benefit. The figure 12 shows an example for such a colour distribution (left side) as it may result from a Euro NCAP rating test (reaching about 15 Euro NCAP points). This colour distribution is then assumed to all vehicles in the master-dataset. Using the injury shift method, it is calculated how the injury severity outcome will be if all M1 vehicles in frontal pedestrian accidents would have these distribution. For this purpose, an assumption has to be made concerning the original pedestrian safety performance of the vehicles in the master-dataset. Basically, it is assumed that all vehicles in the GIDAS dataset will solely have red test zones which corresponds to zero Euro NCAP points (see right picture in figure 12).

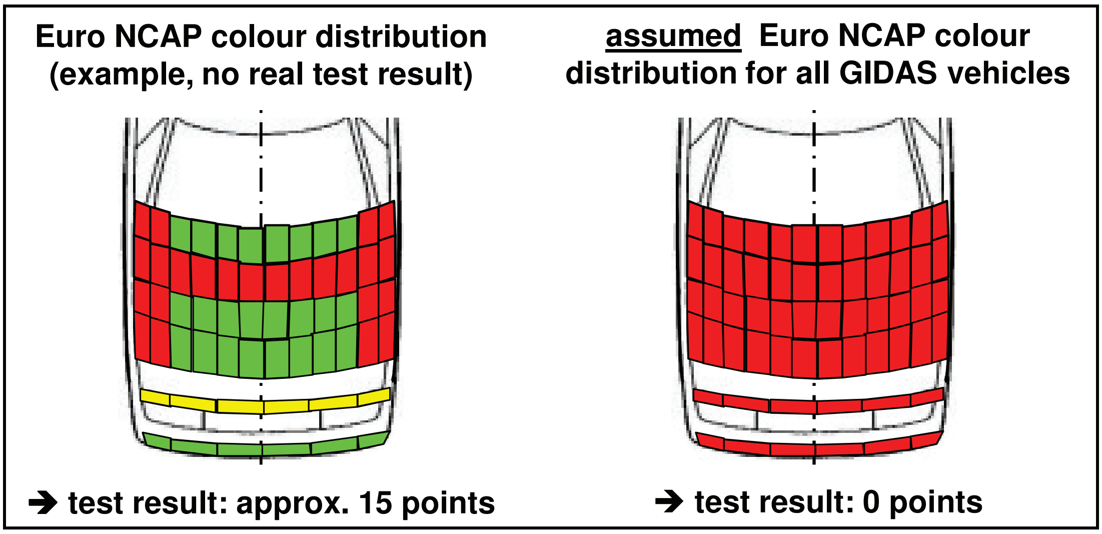

Figure 12. Euro NCAP colour distribution (example) / Assumed GIDAS distribution

Due to the fact that the vehicles in the GIDAS dataset are rather old, this assumption seems to be suitable. Unfortunately, the actual pedestrian protection performance is unknown for the majority of the vehicles in the dataset due to missing Euro NCAP test results. However, especially in windscreen and bonnet test zones a better performance is realistic even for older vehicles. Hence, this assumption is very conservative and leads in any case to an over-estimation of the total benefit.
With this in mind, the benefit is calculated on the basis of the severity of every single injury. As described, the severity of all AIS2+ injuries in green or yellow test zones is shifted downwards according to the assumptions in figure 11. Afterwards, the injury severity (represented by the MAIS) of the pedestrian is re-calculated. Depending on the number, the severity and especially the causation of the single injuries, the MAIS of a pedestrian is reduced or remains constant.

The following illustration shows the methodology with an example (figure 13). On the basis of the above-mentioned example case, three different Euro NCAP colour distributions are evaluated. The distributions are chosen in such a way as to show different resulting MAIS values for the pedestrian.

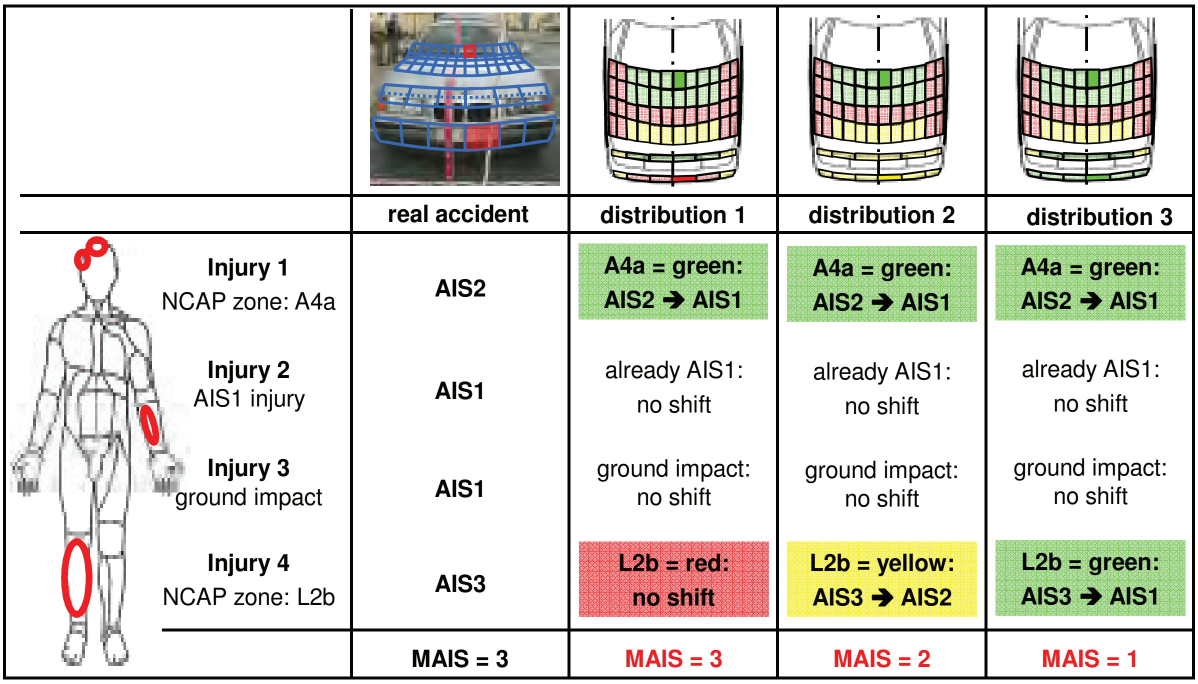

Figure 13. Evaluation of Euro NCAP colour distributions (injury shift method)

The pedestrian in the real-world accident suffered two AIS2+ injuries in Euro NCAP test zones. His injury severity is MAIS3, resulting from his tibia injury. Now, the three different Euro NCAP colour distributions are assumed to the accident vehicle. According to the colour in the test zones A4a and L2b the injury severity is either shifted (green or yellow zone) or remains unchanged (red zone). As a result, the pedestrian will have a re-calculated injury severity of MAIS3, MAIS2 or MAIS1.

This procedure is done for every pedestrian in the dataset. The overall benefit of a Euro NCAP colour distribution is then calculated. The benefit is defined as the number (or proportion) of reduced MAIS2+ injured pedestrians. In the above given example, only the third distribution (rightmost column) will achieve such a reduction.

ANALYSES AND RESULTS

This chapter contains information about the single steps of the analysis and the related results. In addition to the intended estimation of different Euro NCAP colour distributions, the detailed impact distribution is regarded. It can be derived where pedestrians suffer their AIS2+ injuries in frontal accidents with passenger cars.

Impact distribution

As described, all AIS2+ injuries are either allocated to a Euro NCAP test zone or to another (non-tested) vehicle zone or to the ground impact. Furthermore, a detailed analysis concerning single Euro NCAP zones is done. At first the general distribution of all 519 AIS2+ injuries is shown. It can be derived from the diagram that about 55% of all AIS2+ injuries were sustained in Euro NCAP test zones. Nearly one third of the injuries were caused by the ground impact and the remaining 14% occurred in non-tested vehicle areas.

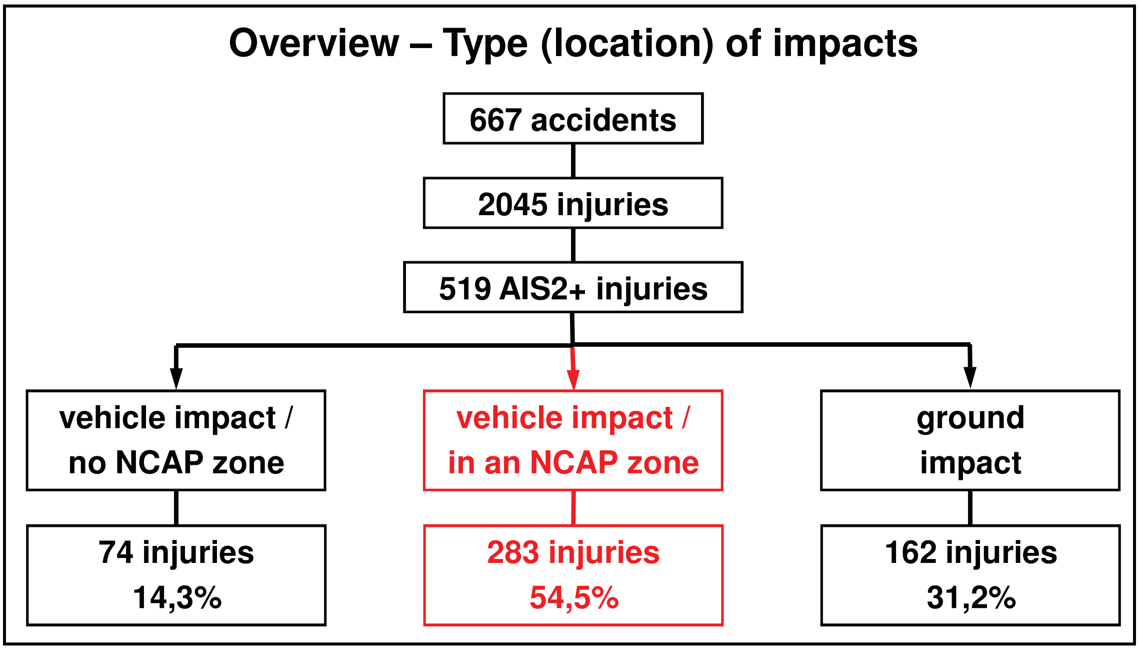

Figure 14. Type (location) of impact (AIS2+ injuries)

In the next step, a detailed distribution is generated for injuries in Euro NCAP test zones. Using the results of the injury allocation to Euro NCAP zones (figure 10), the distribution of all 283 AIS2+ injuries in Euro NCAP test zones can be derived (figure 15).

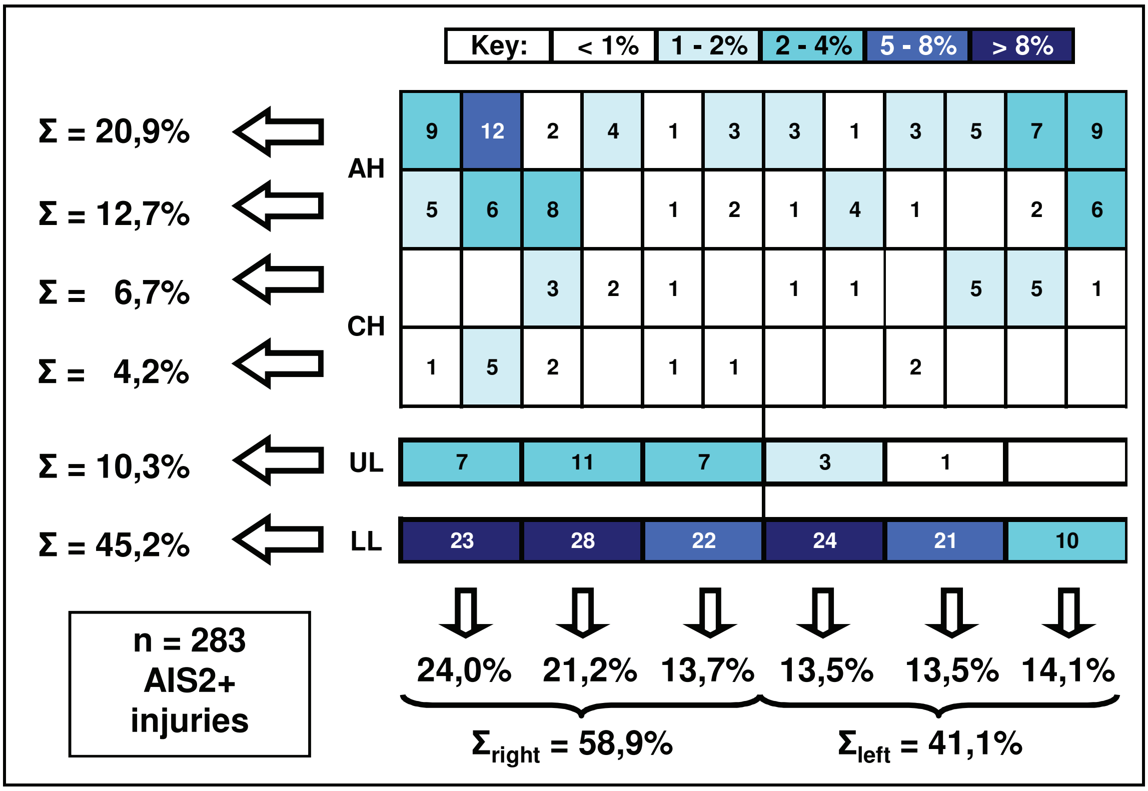

Figure 15. Distribution of impact zones (AIS2+ injuries)

In addition to the absolute number of impacts, the frequencies are illustrated by a colour scale. Furthermore, the proportions of single test rows (horizontal) and within the six vertical columns are displayed.

Different conclusions can be drawn out of this figure. At first, it can be seen that the pedestrian impacts, which finally caused AIS2+ injuries, are not symmetrically distributed. The majority (59%) of the pedestrians are hit by the right side of the vehicle which is a result of the right-hand traffic in Germany. Considering the distribution within the single test rows, it can be stated that approximately half of all AIS2+ injuries (45%) occur in the Lower Leg test zone. This area is by far the most frequent injury causing area for AIS2+ injuries at the vehicle. Another third of the impact points are located within the Adult Head test zones and 11% are found in the Child Head test area.
Impacts in the Upper Leg test row make up about 10%. At that, it has to be considered that the comparably high numbers of AIS2+ injuries in this zone result from the high proportion of old vehicles in the dataset. These vehicles often have sharp-edged bonnet leading edges and thus, they caused severe injuries in this test area. However, the number of such injuries will strongly decrease in pedestrian accidents with modern vehicles.

Estimation of several Euro NCAP colour distributions

Using the above shown methodology, several Euro NCAP colour distributions can be estimated concerning their real-world benefit in the pedestrian accident scenario. Within the present study, different kinds of Euro NCAP colour distributions have been evaluated. The next chapters give an overview on the distributions that have been estimated.

Theoretical Euro NCAP colour distributions

The use of theoretical shapes can answer the questions, which benefit for the real accident scenario can be expected from the optimisation of single impact zones and how the Euro NCAP rating method does factor in the real injury causation. For this reason, seven idealised Euro NCAP colour distributions have been generated. Afterwards, their real-world benefit was estimated and the actual benefit was compared to the related Euro NCAP rating result. The following illustration shows the seven used Euro NCAP colour distributions and the corresponding Euro NCAP point scores.

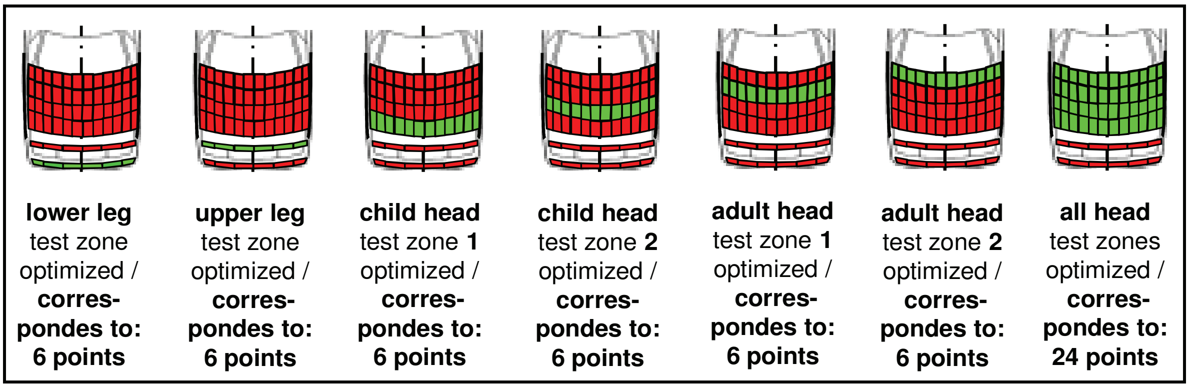

Figure 16. Theoretical Euro NCAP shapes

Within this paper, the results are not described in detail. In general, it can be derived from the data that every optimised Euro NCAP test row will lead to less MAIS2+ injured pedestrians. However, the benefit between the single test rows differs substantially. The smallest benefit can be expected from the optimisation of the child head impactor test zones which results from the shown impact distribution. A rather small benefit is also calculated for optimised upper leg test zones. Due to its high number of impacts, an optimised lower leg test area will have the greatest benefit, considering the reduction of MAIS2+ injured pedestrians. An optimised lower leg test row (achieving six Euro NCAP points) can save more pedestrians from being MAIS2+ injured than an optimised head impact test area (achieving 24 Euro NCAP points). From this point of view the lower leg test zones seems to be underestimated towards the head impact zones.

Euro NCAP colour distributions

Analogous to the estimation of theoretical Euro NCAP colour distributions it is possible to evaluate real test results concerning their real-world benefit. By doing this, the performance of vehicles can be compared and it can be stated how well the Euro NCAP point score correlates with the pedestrian protection potential in real-world accidents. For the paper, the latest 53 tested vehicles (derived from www.euroncap.com) have been evaluated. The achieved Euro NCAP points of the vehicles range from 9 to 27 points with an average of 17,3 points. The following figure shows the reduction of MAIS2+ injured pedestrians for these vehicles. In addition, two points which are derived from theoretical colour distributions are displayed in the figure. The square at six Euro NCAP points represents an optimised lower leg test row (shown left in figure 16). Most of the considered vehicles achieve at least this performance. The right point (at 36 Euro NCAP points) shows the maximum possible reduction of MAIS2+ injured pedestrians, assuming that all vehicles in the dataset have a completely green Euro NCAP colour distribution.

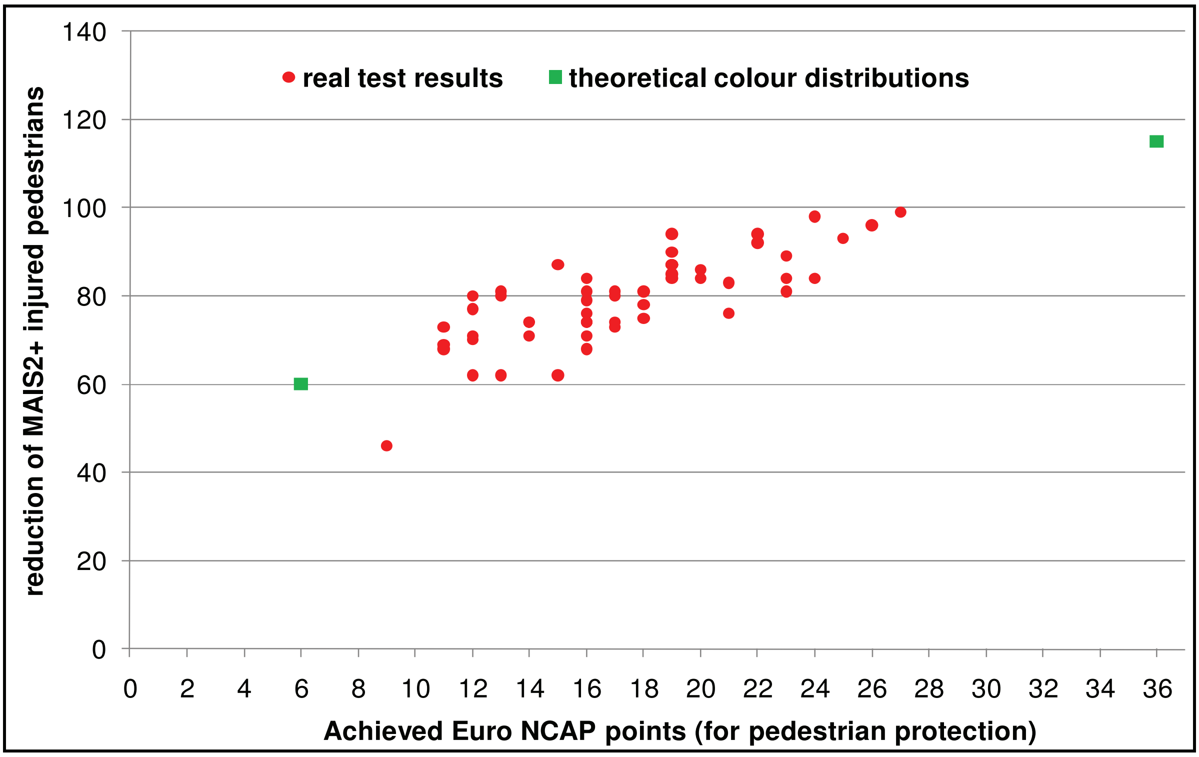

Figure 17. Reduction of MAIS2+ injured pedestrians for 53 real test results

It can be seen that there is a rather good correlation between the number of achieved Euro NCAP points and the calculated benefit for the real-world pedestrian accident scenario. The benefit within one Euro NCAP point level differs slightly which results from the distribution of green, yellow and red test zones across the vehicle front. Furthermore, it can be seen that an optimised lower leg test zone already leads to a considerable benefit (compared to the original GIDAS vehicle fleet and assuming that the vehicles in GIDAS achieve zero points, which is an underestimation!). Except for one vehicle all other vehicles have a benefit of at least 60 reduced MAIS2+ injured pedestrians which is the result of an optimised lower leg zone.

Estimation of other secondary safety measures for pedestrians

If the above presented methodology is modified slightly, it can also be used for the estimation of other secondary safety measures in the field of pedestrian safety. One advantage of the methodology is that not only existing systems can be evaluated but also ideas for future safety systems.

An already existing secondary safety system for pedestrians that can be evaluated is the pedestrian airbag. Its effectiveness can be estimated by considering only AIS2+ injuries that have been caused by the rear edge of the bonnet, the A-pillars, the lower windscreen areas and the windscreen areas next to A-pillars. By assuming an injury shift to all these injuries and by calculating new MAIS values for all pedestrians, the overall effectiveness of such a system can be evaluated on the basis of the real world accident scenario.
Another appraisable system might be the active bonnet (pop-up bonnet). Again, only the addressed injuries (bonnet as injury causing part) are taken into account and the effectiveness for the real world pedestrian accident scenario can be evaluated.

Beyond the mentioned possibilities of benefit estimation, the methodology and the dataset can also be applied to AIS3+ injuries respectively MAIS3+ injured pedestrians. Although the average injury severity of head injuries is higher than the average injury severity of injuries on lower extremities, the above shown effect of secondary safety measures in the lower leg test areas is comparably the same for AIS3+ injuries than for AIS2+ injuries. On the one hand, there is a rather big number of AIS3 injuries on lower extremities which further result in a considerably high benefit. On the other hand, many AIS3+ injuries are caused by the ground impact which nearly leads to the same proportion of pedestrians with an unchanged injury severity.

SUMMARY

Primary and secondary vehicle safety should still be optimised to the highest effects on road safety. For that reason it is very important to analyse the real-world accident scenario and to develop safety systems and/or consumer ratings on the basis of the expected benefit.
Within the present study, a methodology for the benefit estimation of secondary safety systems based on the GIDAS database was presented. The method was explained on the basis of a real-world accident. The results of the case-by-case analysis give an overview on the impact distribution of pedestrians in frontal accidents with passenger cars and show the proportion of vehicle impacts and ground impacts. Using the presented methodology, different secondary safety measures or ideas of future secondary safety measures can be evaluated. Within this paper, the effects of optimised Euro NCAP test zones on the real-world accident scenario are presented. Furthermore, the evaluation of 53 real test results show a correlation between the Euro NCAP point score and the expected real-world benefit.