Evaluation of the Euro NCAP Pedestrian Rating on the basis of real-world pedestrian accidents

Dr.-Ing. Lars Hannawald, Verkehrsunfallforschung an der TU Dresden GmbH
Dipl.-Ing. Henrik Liers, Verkehrsunfallforschung an der TU Dresden GmbH

1 Introduction

The aim of this study was the evaluation of the new Euro NCAP pedestrian rating system on the basis of real world pedestrian accidents. Therefore a method for the evaluation of passive safety ratings 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.

2 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.

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2.1 Sample criteria and Master-dataset

The present 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 involved pedestrian are chosen. In the few cases with two or more pedestrians, only the first pedestrian hit by the vehicle is considered. For this reason, every 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 passive safety measures. Furthermore, there are hardly any impacts on the bonnet expected. Thus, a distinction is drawn between accidents with a collision speed of up to 40km/h and above.

Due to the above mentioned facts, the study considers only accidents with a collision speed of up to 40km/h. This leads to the final master-dataset which consists of 667 frontal pedestrian accidents with M1 vehicles and collision speeds of 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.

2.2 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.

2.2.1 Accident site and accident scene

At first, the accidents are considered regarding the accident site and the accident scene (figure 1). As expected, the majority of the considered pedestrian accidents happened in towns. The already large proportion of in-town accidents in the German pedestrian accident scenario (94% in 2006) is thereby further increased by the restriction to accidents with collision speeds of up to 40km/h within the present study.

The distribution of 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.

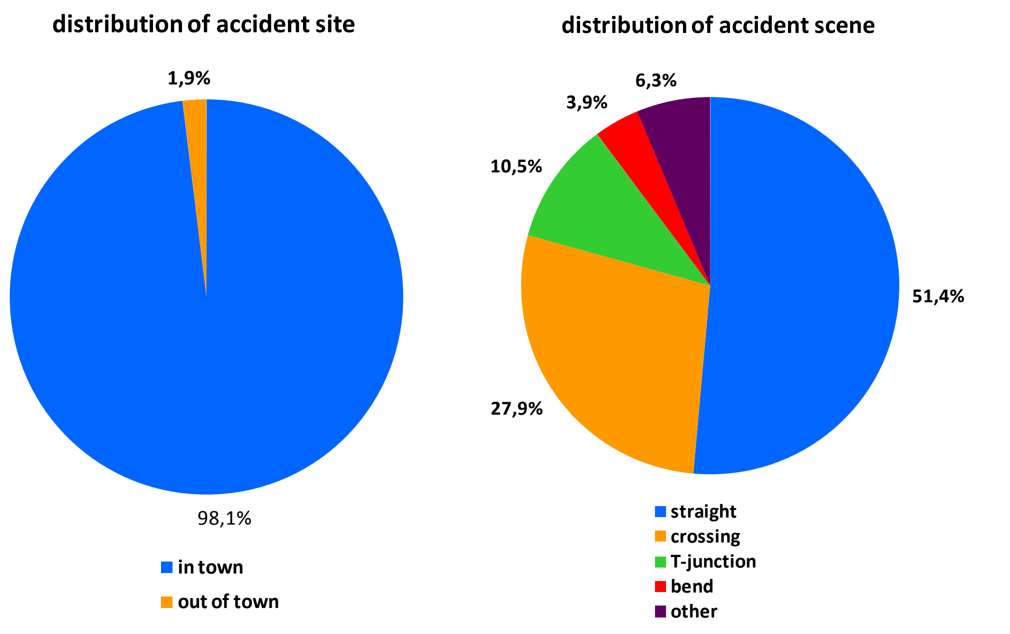

figure 1: Distribution of accident site and accident scene (n = 667)

2.2.2 Collision speed

As mentioned above, the study deals with frontal pedestrian accidents with collision speeds of up to 40km/h. The following chart shows the distribution of collision speed for all accidents in the master-dataset (figure 2).

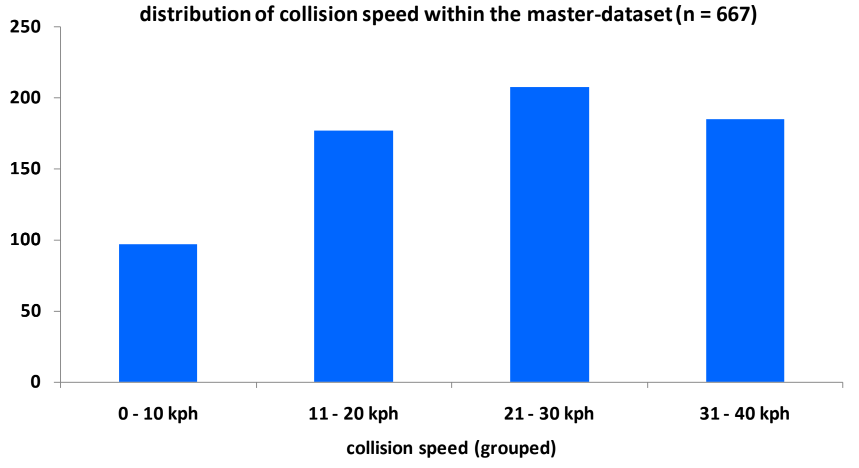

figure 2: Distribution of collision speed (n = 667)

2.2.3 Vehicle data - Year of market introduction

As is well known, the front design of vehicles is decisive for the pedestrian kinematics and injury causation in case of an impact towards the vehicle front. Furthermore, the front design of passenger cars is always changing over time and thus, it is important for the intended benefit estimation to know how old the vehicles in the dataset are. Thus, the year of market introduction is shown for all 667 vehicles (figure 3).

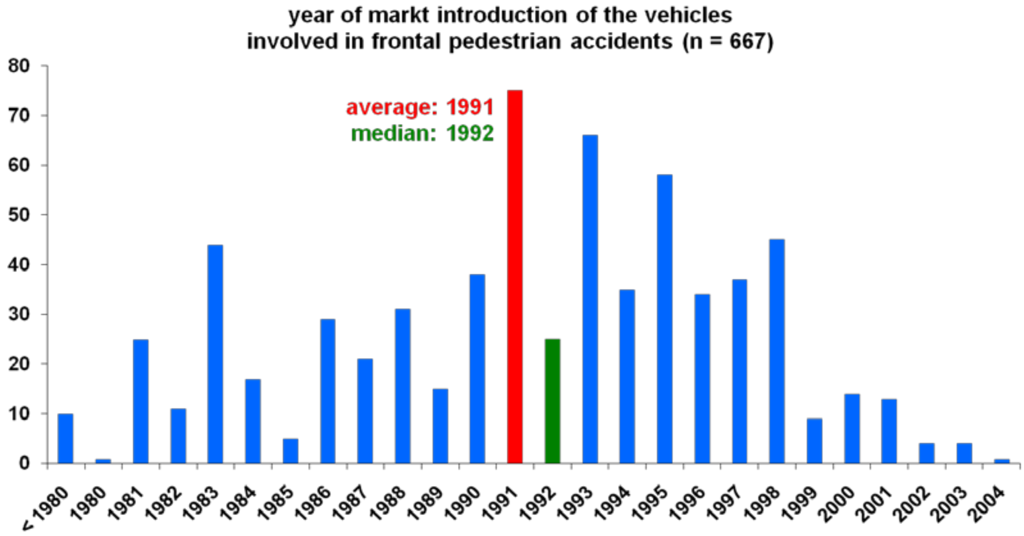

figure 3: Year of market introduction of all 667 vehicles in the master-dataset

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.

2.2.4 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 often hit by other vehicle parts than adults due to their smaller body height. Especially the head impact areas of children differ substantially from the impact zones of adults.

In the following illustration (figure 4), the distribution of the age of the pedestrians within the current master-dataset is compared to the distribution within the German pedestrian accident scenario (year 2006).

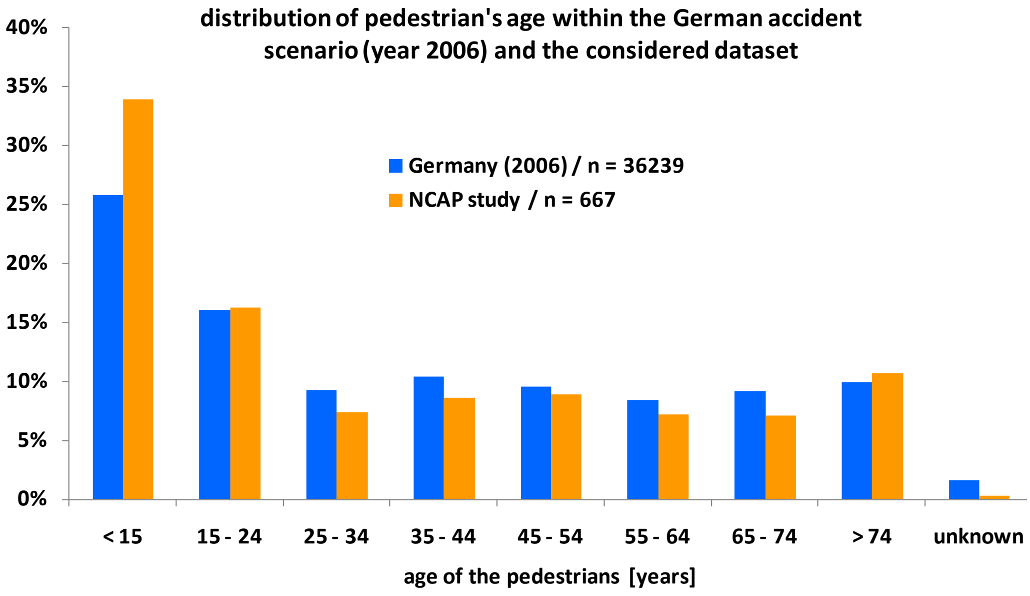

figure 4: Distribution of age of the involved pedestrians

There are small differences between the distributions, especially in the proportion of children. It has to be considered that the master-dataset only consists of frontal pedestrian accidents with M1 vehicles, whereas the entire German pedestrian accident scenario includes all types of pedestrian accidents. This may result in small variations regarding the distribution.

However, the number of involved children (226 persons below 15 years) seems to be high enough for the intended estimation of the Child Headform test.

2.2.5 Injury data

As mentioned above, there are 667 accidents in the master-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.

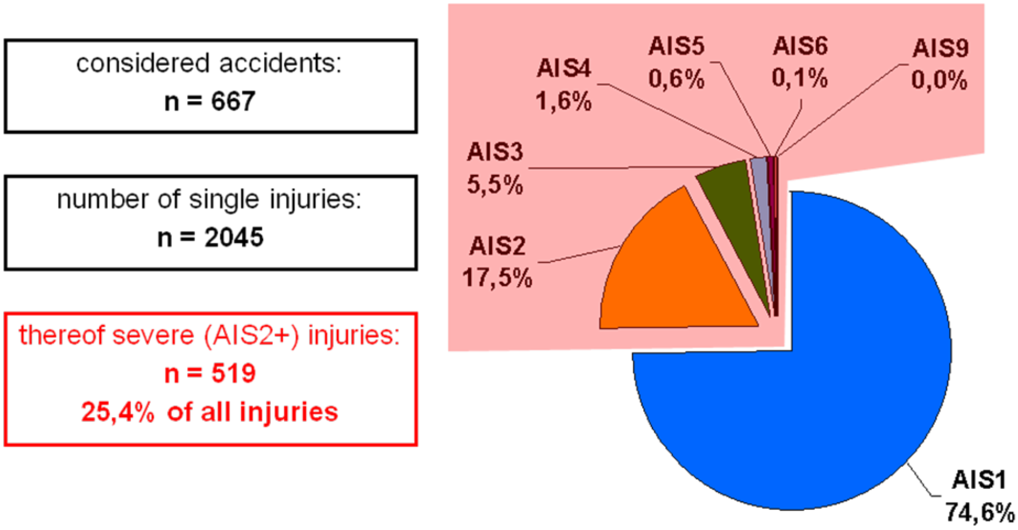

figure 5: Distribution of injury severity in the master-dataset (n = 2045)

3. 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.

3.1 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.

3.1.1 Head impact zones

There are 24 single impact zones for the Child Headform test and 24 single impact zones for the Adult Headform test. Generally, there are four longitudinal rows (two Child Headform test rows and two Adult Headform test rows), which are defined by different Wrap Around Distances (WAD). The lateral borders are the Side Reference Lines. Between these two Side Reference Lines, the rows are divided into 12 equal width areas which finally lead to 48 head impact zones (see figure 6).

3.1.2 Upper Leg test zones

The Upper Leg test zones are primarily defined by the Bonnet Leading Edge (BLE) Reference Line which is determined according to the Euro NCAP testing protocol. Basically, the vehicle is laterally divided into six equal test zones. For the determination of the longitudinal boundaries, the WAD is used. In the study, all injuries are considered to be in the Upper Leg test zone when they have a WAD of ±100mm around the BLE (figure 6).

3.1.3 Lower Leg test zones

According to the Euro NCAP testing protocol, the impact zones of the Lower Legform test are determined by the Upper Bumper Reference Line (UBRL). Again, the vehicle is laterally divided into six equal test zones. In the study, the lower boundary of the test zones is determined for every vehicle model by the constant WAD value of 150mm. The upper boundary is defined as the Upper Bumper Reference Line plus 50mm.

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

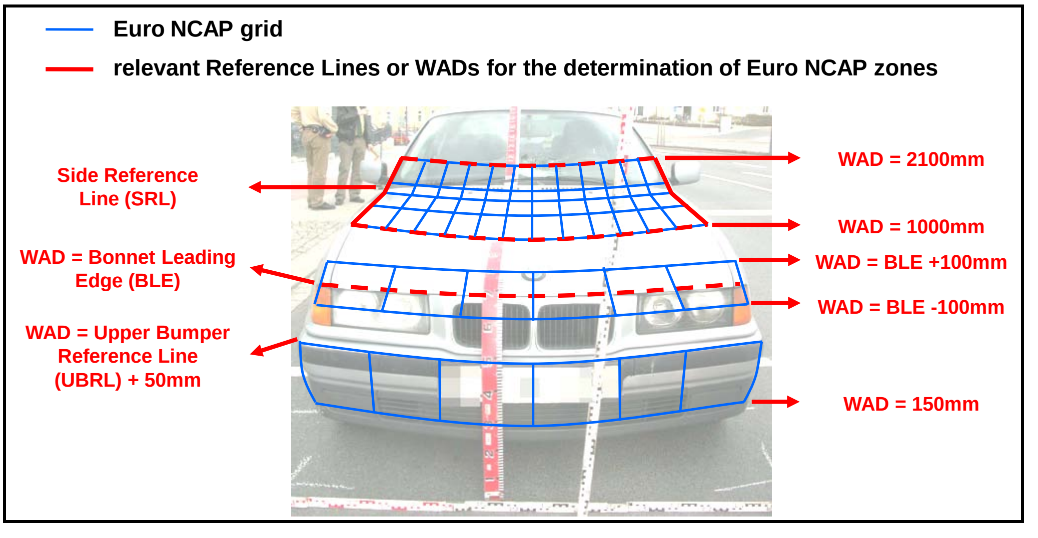

figure 6: Determination of the Euro NCAP zones

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

3.2 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.

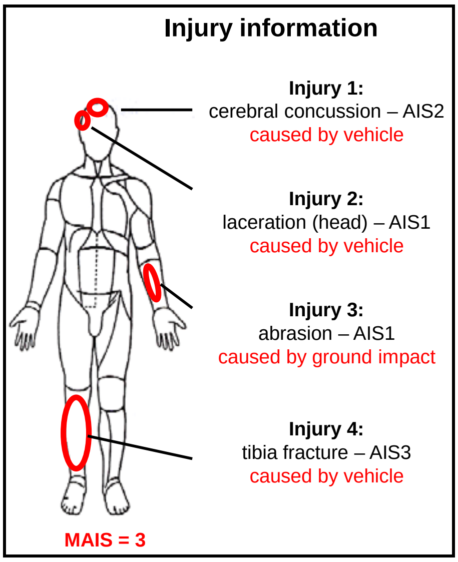

figure 7: Injury information (example case)

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.

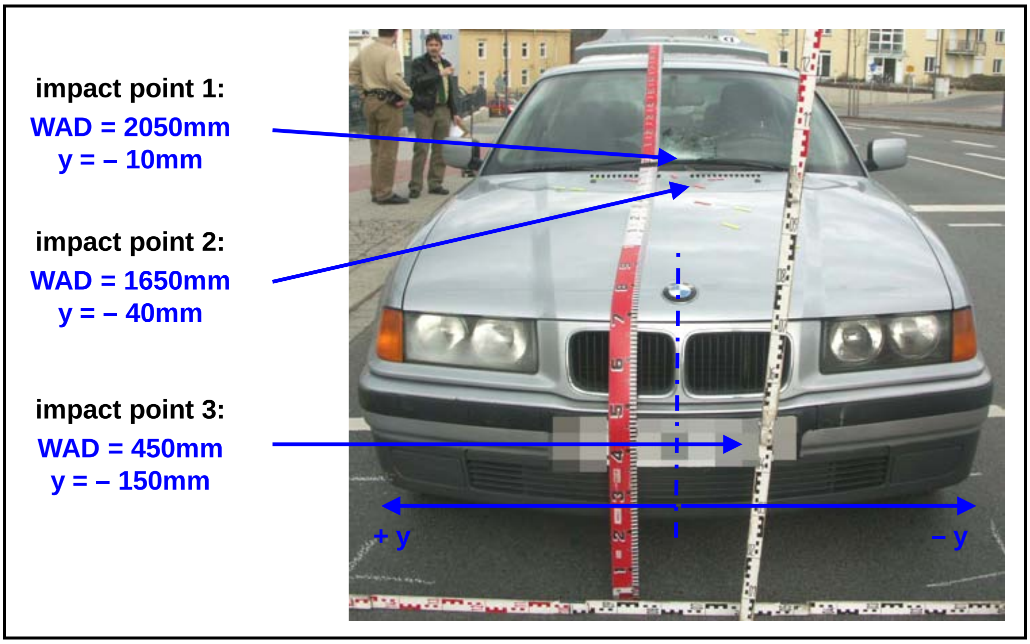

figure 8: Involved vehicle and investigated impact points (example case)

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.

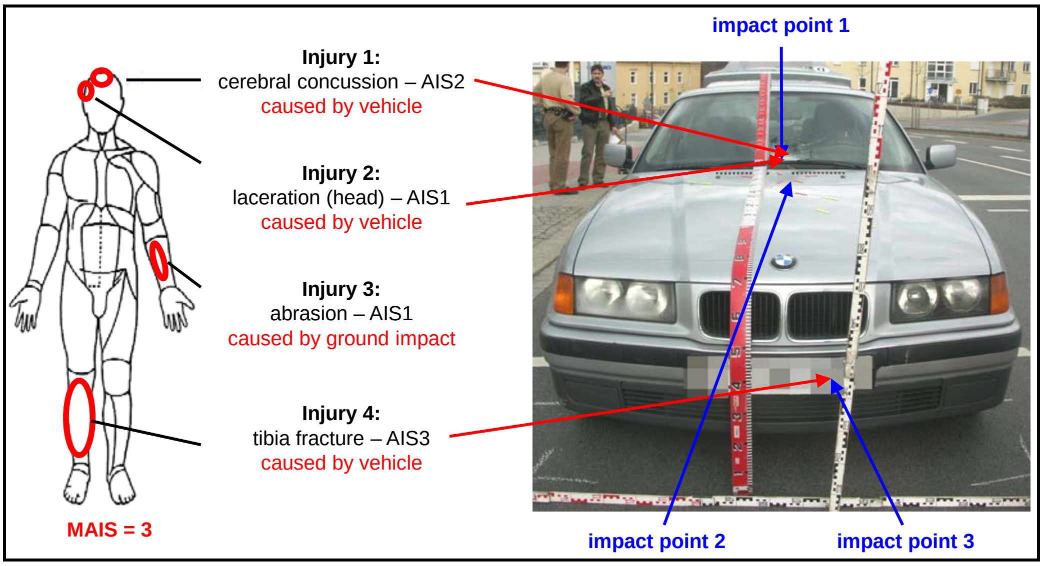

figure 9: Allocation of single injuries and impact points (example case)

As illustrated in figure 9, the two head injuries in the example case can be allocated to the *impact point 1*. The third injury was caused by the ground impact. It is therefore not assignable to an impact point. The fourth injury is allocated to the *impact point 3* at the bumper. Moreover, it can be seen, that an impact point at the vehicle must not necessarily lead to an injury. *Impact point 2*, for instance, results from an impact of the shoulder, whereas the pedestrian did not sustain any injuries in this body region.

In the next step the single injuries are allocated to the Euro NCAP test zones. As described in chapter 0, the 60 Euro NCAP test zones are determined separately for every vehicle model, using WAD and y-values. As described above, all single injuries have been allocated to an impact point and thus, they also have individual WAD and y-values now. Hence, every single injury can be assigned to a Euro NCAP test zone.

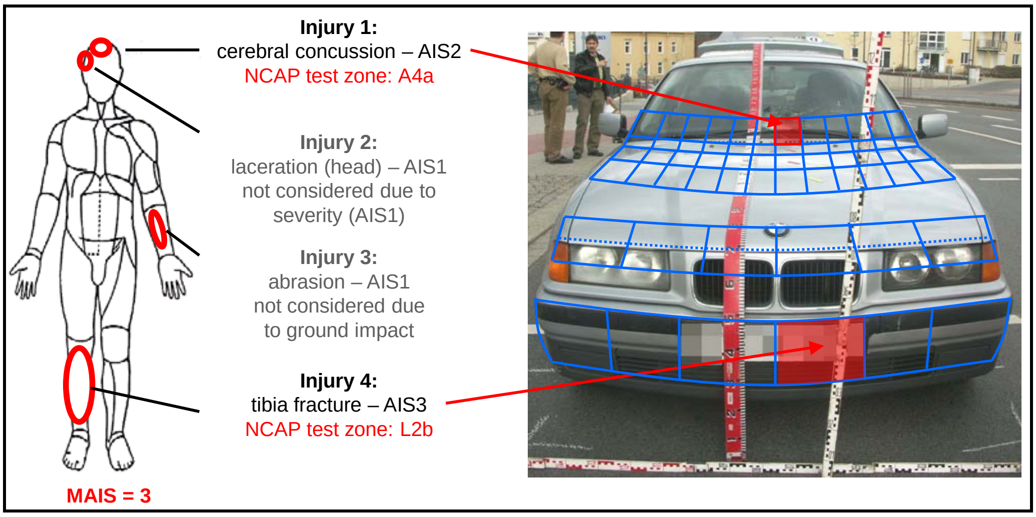

figure 10: Allocation of single injuries to the Euro NCAP test zones (example case)

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 thus, it 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.

3.3 Optimistic and pessimistic approach

Over time, some studies concerning the evaluation of passive pedestrian safety measures have been carried out. The underlying amount of injuries which are used for the benefit estimation often is the decisive point. There are two different possibilities to evaluate passive safety measures.

The first approach uses all injuries which are sustained in all areas of the vehicle front. For example 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 passive safety measures. For this reason the approach is called *optimistic approach*. This method will probably over-estimate the benefit of passive safety measures.

In contrast, the *pessimistic approach* only uses injuries which are sustained in addressed areas of the vehicle. That means that only injuries are considered in the three body regions which are addressed by Euro NCAP tests: head, lower leg and upper leg/pelvis. Consequently, all injuries to the upper extremities, thorax, abdomen, and spine are left out because they are not directly addressed by legislation and Euro NCAP tests. Furthermore, the above mentioned child head injury, which was caused by the bonnet leading edge, is not considered within this approach.

However, it can be expected that optimized impact zones will even have a positive effect on injuries in all body regions. An optimized head impact zone on the bonnet, for instance, could mitigate injuries to the thorax or abdomen. For this reason, the pessimistic approach will under-estimate the benefit of passive safety measures.

It is difficult to decide which of the two approaches is more realistic. Hence, the study uses both approaches in order to estimate the benefit range. The actual benefit is somewhere between.

3.4 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.

Furthermore, the injury shift method considers the idea of using an optimistic and a pessimistic approach. As it can be seen in figure 11, the injury severity shift is bigger within the optimistic approach which finally leads to a greater benefit. Within the pessimistic approach, the injury severity shift is done more conservative.

Generally, the severity of an injury can be shifted towards AIS1 at the maximum. It is assumed that no injury is entirely avoided (AIS0).

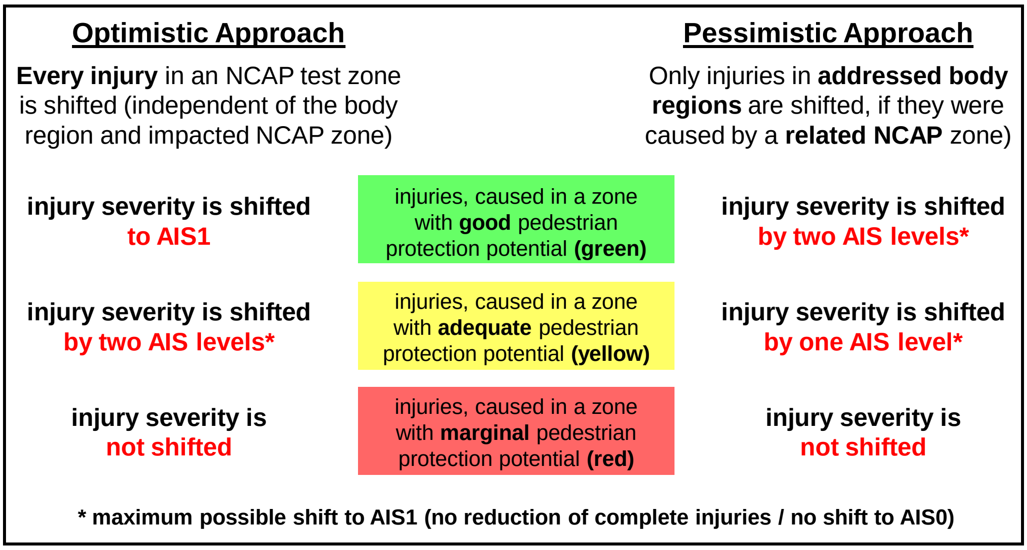

figure 11: Assumptions of the injury shift method

It can be derived from the figure that injuries in red Euro NCAP test zones are neither shifted within the optimistic approach nor in the pessimistic one. It is assumed that red test zones will have no injury reduction potential.

The methodology of the injury shift method is explained on the basis of an example within the following chapter.

3.5 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 above-mentioned 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 important 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).

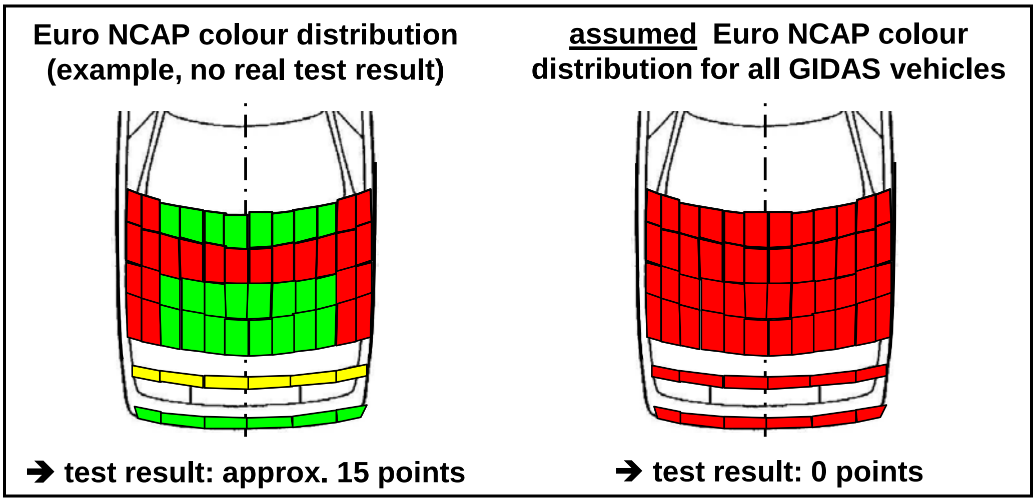

figure 12: Euro NCAP colour distribution (example) / Assumed GIDAS distribution

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 above, 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, resulting from the maximum AIS value of all single injuries. 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 (using the pessimistic approach). The distributions are chosen in such a way as to show different resulting MAIS values for the pedestrian.

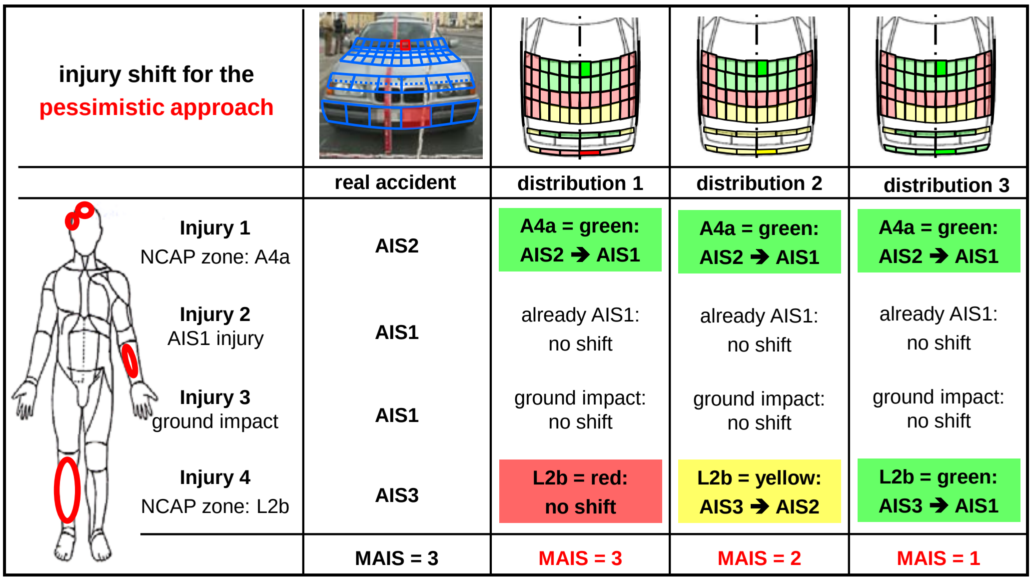

figure 13: Evaluation of Euro NCAP colour distributions (injury shift method)

As already described above, 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, which are highlighted by intense colours, 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. Thereby, the benefit is defined as the number (or proportion) of reduced severely injured pedestrians which is comparable with the reduction of MAIS2+ injured pedestrians. In the above given example, only the third distribution (rightmost column) will achieve a reduction from *severely injured* to *slightly injured*.

4 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. Furthermore, the relevance of several injury causing parts is checked for the three body regions that are addressed by legislation and Euro NCAP tests.

4.1 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. The following chapters deal with the impact distribution, separated by the optimistic and pessimistic approach.

4.1.1 Optimistic approach

At first the distribution of all 519 AIS2+ injuries is shown for the optimistic approach. 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.

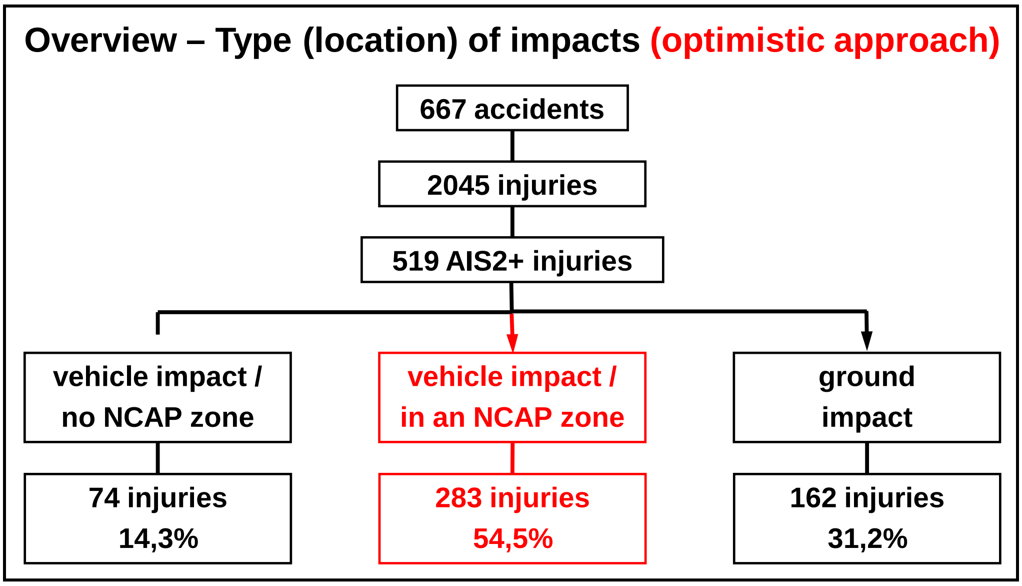

figure 14: Type (location) of impact (AIS2+ injuries, optimistic approach)

In the next step, a detailed distribution is generated for all 60 Euro NCAP test zones. As seen in figure 13, two of the considered injuries result from the example case. Thus, they are recorded in their specific test zones as follows (figure 15).

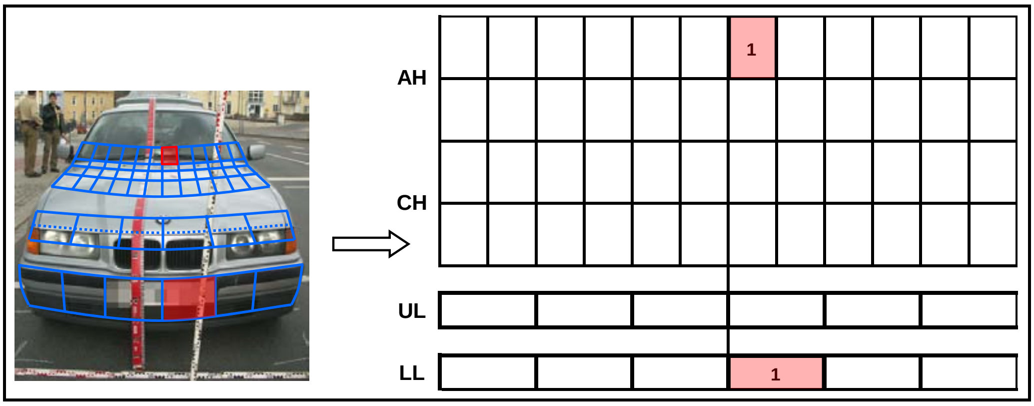

figure 15: Transfer of impact zones (example case)

This procedure is repeated for all 667 accidents respectively for the 283 AIS2+ injuries that occurred in Euro NCAP test zones. The number of impacts in every test zone is added and finally, the following distribution can be derived (figure 16).

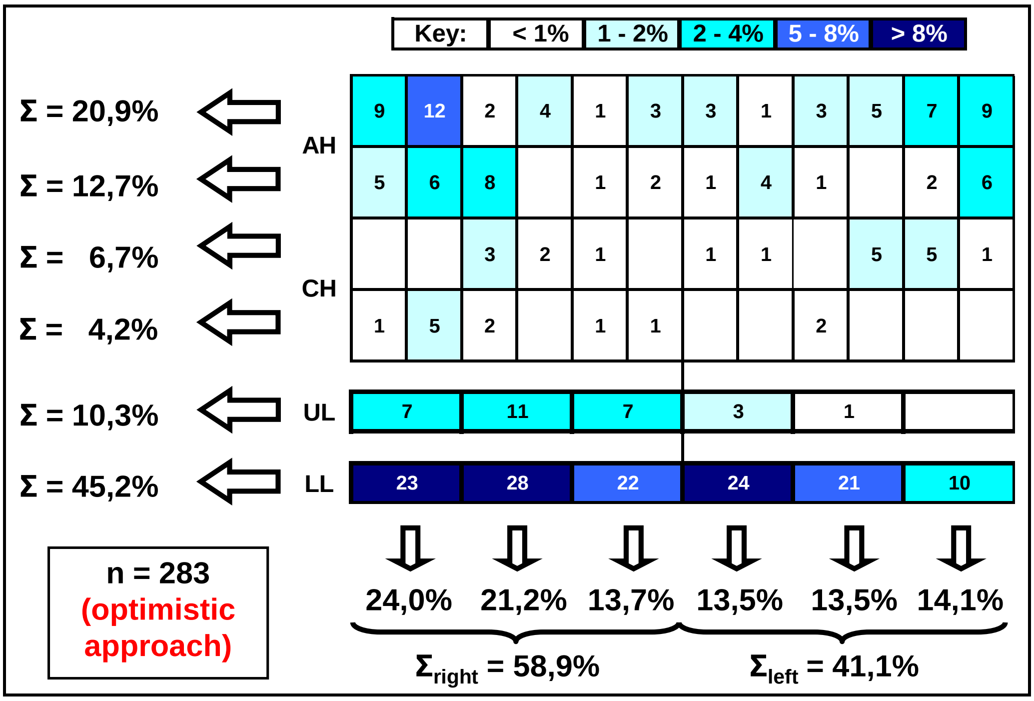

figure 16: Distribution of impact zones (AIS2+ injuries, optimistic approach)

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. Nearly one quarter of the impacts are located rightmost on the vehicle front. The frequency in the rightmost Lower Leg test zone is more than twice as high as the frequency in the leftmost zone.

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 test 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 younger vehicles. Not more than three out of the 29 injuries in the Upper Leg test zone were caused by vehicles introduced 1997 or later.

4.1.2 Pessimistic approach

The analysis of impact zones is done again for the pessimistic approach. As shown in figure 17, the 283 AIS2+ injuries in Euro NCAP test zones are separated into two groups. Out of all injuries in Euro NCAP test zones, one quarter (71 of 283) is not addressed by the specific tests (compare chapter 0). However, 212 AIS2+ injuries remain for the detailed analysis of Euro NCAP test zones which represents 41% of all AIS2+ injuries in the master-dataset.

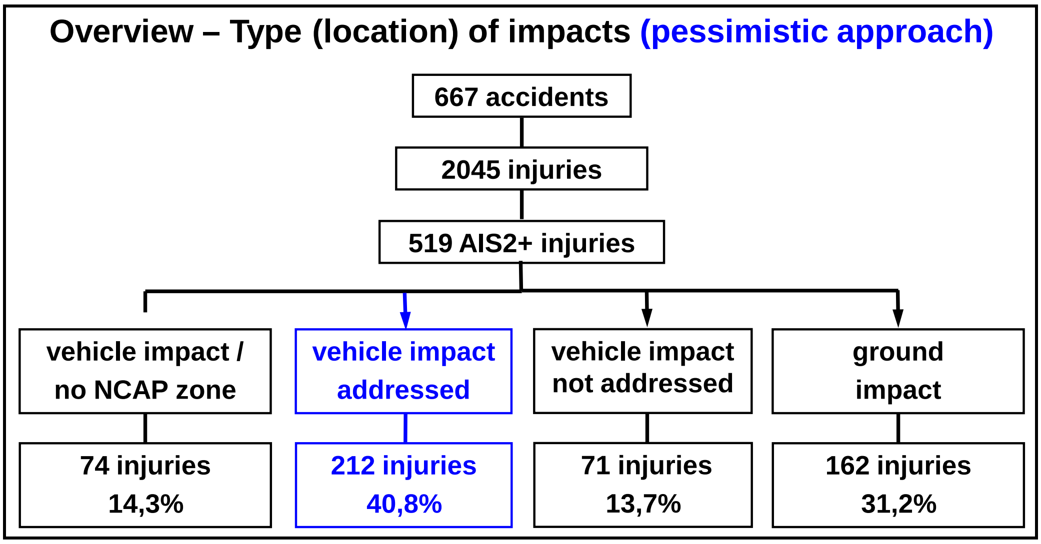

figure 17: Type (location) of impact (AIS2+ injuries, pessimistic approach)

The specific impact zones of the 212 relevant AIS2+ injuries are summed up for all 667 accidents which finally lead to the following distribution (figure 18). Again, an asymmetrical distribution can be derived from the data. About 60% of the impact points were located in Euro NCAP test zones on the right side of the vehicle front.

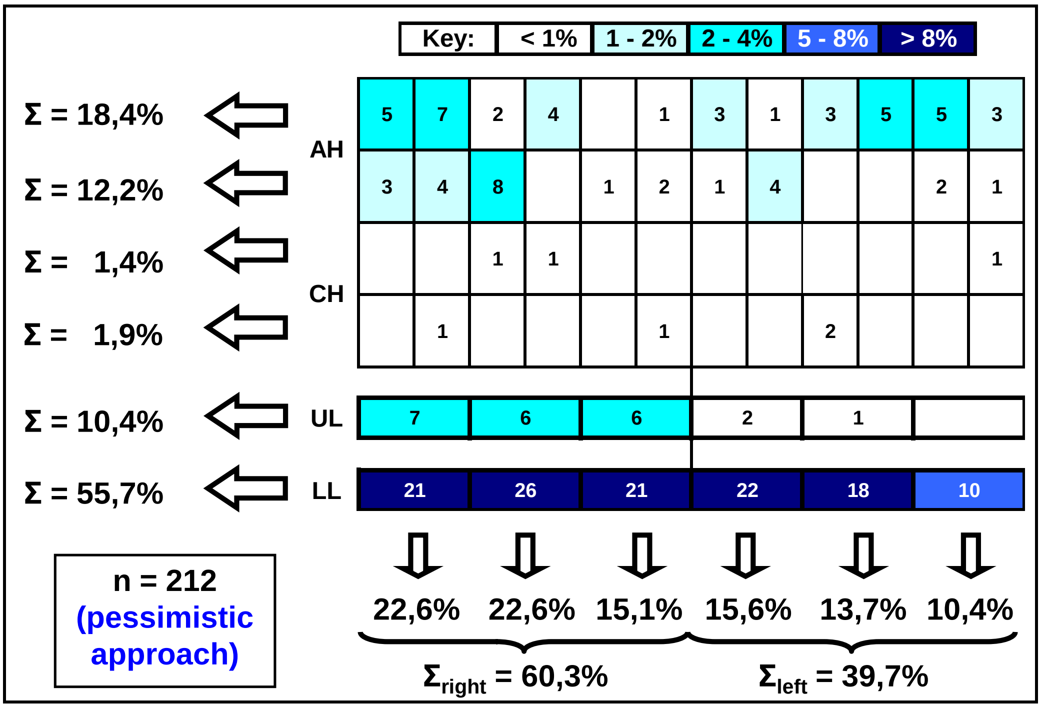

figure 18: Distribution of impact zones (AIS2+ injuries, pessimistic approach)

In comparison to the results of the single test rows of the optimistic approach, it can be stated that the proportion of impacts in the Lower Leg test zones increased further to more than 55%. The proportion of impacts in the Adult Head test zone decreased slightly to 31% whilst the proportion of head impacts in the Child Head test zone decreased substantially to not more than 3,3%. This implies that this test zone hardly causes severe head injuries but injuries to the thorax, abdomen or upper extremities. The proportion of impacts in the Upper Leg test zones remains constantly. Again, the majority of the injuries in this area result from accidents with older vehicles. Two out of the 22 injuries in this zone were caused by vehicles introduced in 1997 or later.

4.1 Impact distribution

5 Summary

Primary and secondary vehicle safety should still be optimised to the highest effects on road safety. With this new developed method it is possible to estimate the effects of optimised test areas based on the new NCAP pedestrian test protocol. In addition to that, also the effects of a combination of primary and secondary safety measures could be estimated, which is getting more and more important in the near future.

The method was described on different examples using optimistic and pessimistic assumptions. Finally the number of impacts resulting to an AIS2+ injury for each NCAP Test zone is shown.