BENEFIT ESTIMATION OF THE EURO NCAP PEDESTRIAN RATING CONCERNING REAL WORLD PEDESTRIAN SAFETY

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ABSTRACT

In 2009, Euro NCAP intends to change its rating system. The new rating will put a greater emphasis on the pedestrian protection potential. Therefore, Euro NCAP endeavours to assess the vehicle's overall safety performance and communicate it simply to consumers using a single star rating.

This study aims to estimate, how well the pedestrian rating system matches the expected real-world benefit. Furthermore, the benefit range achieved for different Euro NCAP pedestrian protection scores is determined. The vehicle impact zones and their related NCAP points are also evaluated for their actual effectiveness.

The analysis bases on the German In-depth Accident Study (GIDAS) database. A case-by-case analysis was carried out for 667 frontal pedestrian accidents where the vehicle speed was 40kph or less. More than 500 AIS2+ injuries are analysed regarding severity, affected body region, impact point on the vehicle, and the particular NCAP zone. An injury shift method was then used to determine the benefit derived from each testing zone.

One result of the study is a detailed impact distribution for AIS2+ injuries across the vehicle front. The rating colour code distributions for different vehicles with various higher point levels were compared to the original dataset and to the current standard in pedestrian protection. In order to estimate the overall benefit range, the analyses used optimistic and pessimistic approaches.

It is shown that current vehicles already exhibit significant real-world benefits. Furthermore, the additional benefit for vehicles achieving various point scores were estimated although the calculated benefits are mostly over-estimations due to missing test results for older vehicles and conservative assumptions.

This is the first detailed analysis of injury causation in NCAP zones and has been made possible by high accident numbers. Thus, the expected real-world benefits of any vehicles can be compared to their Euro NCAP test results.

INTRODUCTION

The present study deals with frontal pedestrian accidents under participation of M1 vehicles and collision speeds up to 40 kph. Basing on in-depth accident data, a detailed distribution of pedestrian impact points in Euro NCAP test zones is created. The data is then used for the evaluation of the Euro NCAP pedestrian rating method. Furthermore, the expected real-world benefit of different Euro NCAP colour distributions is estimated.

DATASET

This chapter deals with the data source which is used for the analysis. The sample criteria as well as the creation of the master-dataset are described. To get an overview of the pedestrian accident scenarios some statistical information is provided.

Data source

For the present study accident data from GIDAS (German In-Depth Accident Study) is 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 Hanover and Dresden. GIDAS collects data from accidents of all kinds. Due to the on-scene investigation and the full reconstruction of each accident, it gives a comprehensive view on the individual accident sequences and the accident 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). Use of the data is restricted to the participants of the project. However, to allow interested parties the direct use of the GIDAS data, several models of participation exist. Further information can be found at http://www.gidas.org.

Sample criteria and master-dataset

The study is carried out on the basis of the current GIDAS dataset, effective July 2008. Out of all 17052 cases in the database only the 13653 reconstructed accidents are used as only these do include information regarding the collision speed.

For the creation of the master-dataset only accidents with at least one involved pedestrian are chosen. Only the first pedestrian hit by the vehicle is considered in the few cases with two or more pedestrians. 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, 1284 accidents meet this condition, making up 70,5%.

In the next step, only accidents with a frontal impact of the pedestrian are taken into account. This criterion is defined on the basis of the Collision Deformation Classification (CDC, according to the SAE J224). 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

Using the second digit of the CDC (impacted vehicle side) and filtering for frontal accidents will lead to a number of 856 accidents.

At last, the accidents are grouped by the collision speed. The impactor velocity in Euro NCAP tests and in the test definitions of the Directive 2003/102/EC is 40kph. Above this velocity, there is only a very limited potential for passive 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 40kph and the ones above.

The following figure shows the accident numbers within the two groups and the resulting injury severity distribution (Figure 1).

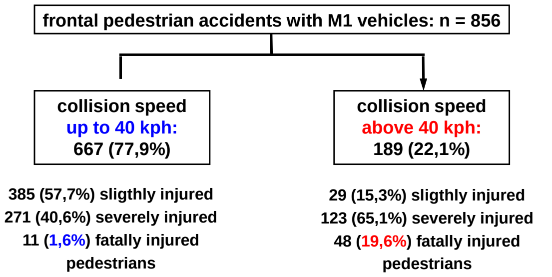

Figure 1. Distinction of accidents with collision speeds up to 40kph and above.

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

The accident site and accident scene – are considered first. (Figure 2). More than 98% of all pedestrian accidents in the dataset happened in town. 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 up to 40kph within the present study.

Looking at the distribution of accident scenes, it can be seen 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 right of way to the pedestrian.

The collision speed – is one of the most important parameter in frontal pedestrian accidents, due to the large influence on the injury severity outcome of the pedestrian. As mentioned above, the study deals with frontal pedestrian accidents with collision speeds up to 40kph. The following chart shows the distribution of the collision speed for all accidents in the master-dataset (Figure 2).

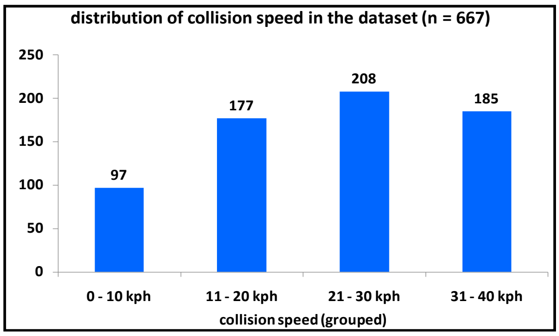

Figure 2. Distribution of collision speed.

<u>The vehicle age</u> – is closely linked to the shape of the vehicle front because the steady development progress as well as the statutory provisions always influences the design of vehicles. It is well known that the front shape is decisive for the pedestrian kinematics and injury causation in case of a frontal impact. The front design of passenger cars changes over time and thus, it is important for the benefit estimation to know how old the vehicles in the dataset are. Thus, the year of market introduction is considered for all vehicles (Figure 3).

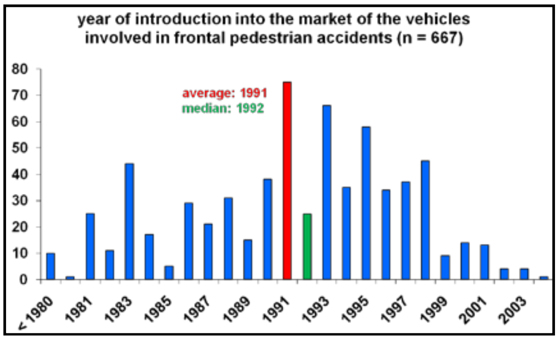

Figure 3. Year of market introduction of the 667 vehicles in the master-dataset.

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

The vehicle age should be considered during the benefit estimation because most of the vehicles did not have to comply with the current legislation concerning pedestrian protection. The vehicles in the dataset do not completely reflect the current vehicle fleet and most of them did not benefit from recently achieved progresses in pedestrian safety.

<u>The age of the involved pedestrians</u> – has a large influence on the injury severity outcome, beside the collision speed and the impacted part of the vehicle. Due to the human physiological properties, elderly 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 graph, the age distribution of the pedestrians in the master-dataset is compared to the distribution within the German pedestrian accident scenario of the year 2006 (Figure 4).

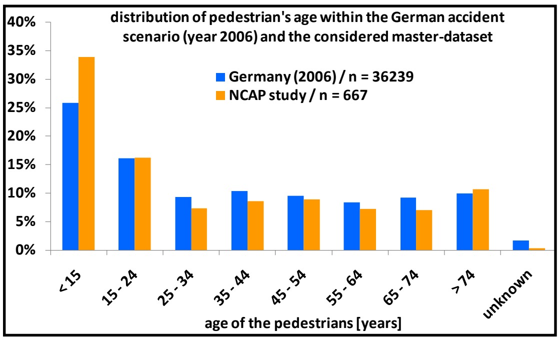

Figure 4. Distribution of the age of the involved pedestrians (master-dataset vs. Germany).

There are some 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 German accident scenario includes all types of pedestrian accidents. This may result in small variations within the distribution. However, the number of involved children (226 persons below 15 years) seems to be sufficient for an estimation of the child head test.

<u>Injury data</u> – are coded in the GIDAS database for every single injury. Pedestrians mostly suffer different injuries. Looking at all injuries in the 667 accidents, 2045 single injuries can be found in the master-dataset. As shown in Figure 6, the majority of these 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.

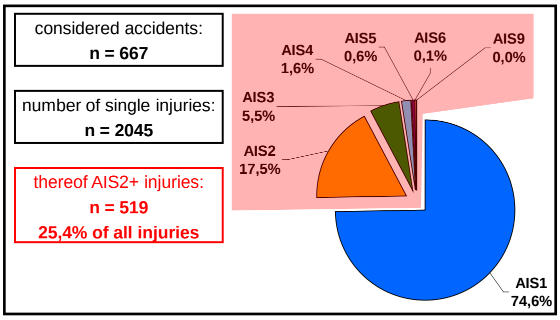

Figure 5. Distribution of injury severity in the master-dataset (n=2045 single injuries).

METHODOLOGY

This chapter describes the methods used in the study. Furthermore, all definitions as well as the assumptions made for the analysis are explained.

Estimation of the 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 head impact zones – are determined exactly according to the Euro NCAP testing protocol. There are 24 test zones for the child headform test and 24 test zones for the adult headform test. 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.

The resulting grid of testing zones is shown in Figure 6. The example vehicle is taken from a real-world accident out of the master-dataset and is hereafter used for the explanation of the method.

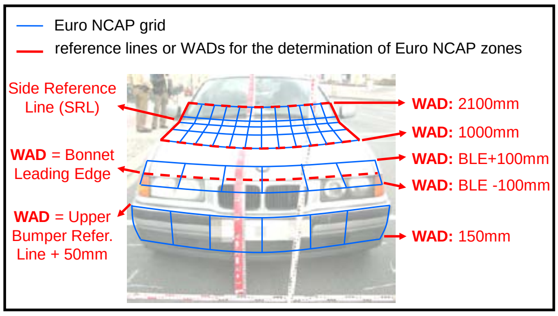

Figure 6. Distribution of injury severity in the master-dataset (n=2045 single injuries).

The upper leg test zones – are primarily defined by the Bonnet Leading Edge Reference Line (BLERL) 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, as shown in Figure 6.

The lower leg test zones – are also determined according to the Euro NCAP testing protocol. The impact zones of the lower legform test are determined by the Upper Bumper Reference Line. 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 (see Figure 6).

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 is the merging of impact data and injury data. The steps of the case-by-case analysis are again illustrated on the basis of the shown real-world accident.

At first, detailed injury information is extracted from the GIDAS database. The following variables, encoded for every single injury, are used:

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

As shown in Figure 8, 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.

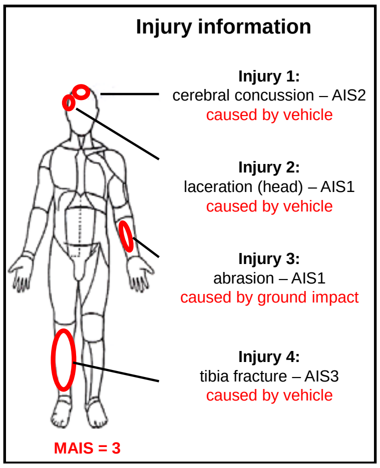

Figure 7. Injury information (example case).

In addition to the medical information, a lot of vehicle data and impact data are investigated at the accident scene for every accident. Chiefly, the impact points on the vehicle are important for the injury causation and the reconstruction. Therefore, every impact point 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 beside.

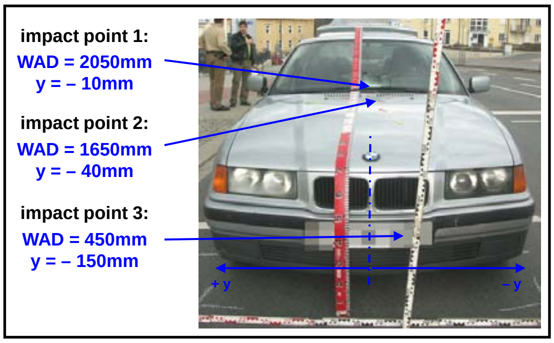

Figure 8. Involved vehicle and documented impact points (example case).

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

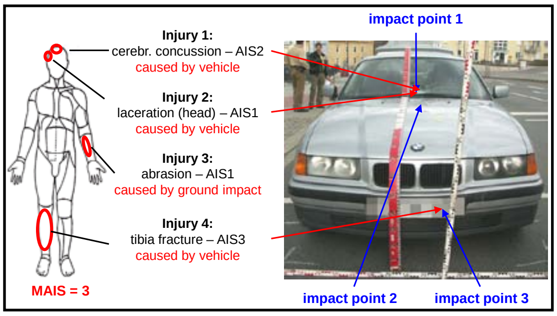

Figure 9. Allocation of single injuries and impact points (example case).

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 on the vehicle. The fourth injury is allocated to the impact point 3 at the bumper. 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, even though the pedestrian did not sustain any injuries in this body region.

In the next step the injuries are allocated to the Euro NCAP test zones. As described above, the 60 test zones are determined separately for every vehicle model, using WAD and y-values. As seen, 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.

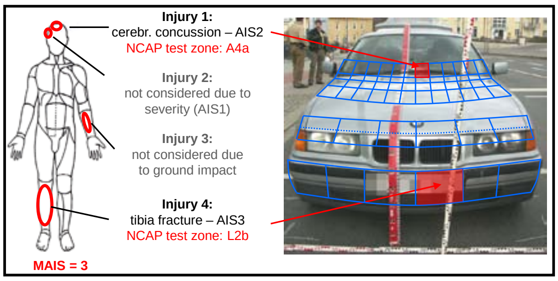

Figure 10. Allocation of single injuries to the Euro NCAP test zones (example case).

As mentioned, only AIS2+ 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 its 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. The consequent distribution is shown later.

Optimistic and pessimistic approach

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

The first approach uses all injuries which are sustained in all test areas. 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 probably overestimates 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. So, 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 an optimised impact zone will even have a positive effect on injuries in other body regions. An optimised head impact zone on the bonnet, for instance, could mitigate injuries to the thorax or abdomen, too. Thus, the pessimistic approach underestimates 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 lies somewhere between.

Injury Shift Method

For the intended evaluation of the Euro NCAP pedestrian rating method and the benefit calculation of different rating results, the performance of particular Euro NCAP test zones has to be estimated. 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 cannot directly 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, representing these parameters.

Within the Euro NCAP pedestrian rating, all 60 test zones are judged on the basis of physical parameters. 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. It is assumed that the original severity of an injury could be reduced by a green or yellow test zone. That means the AIS value 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.

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

Optimistic Approach **Every injury** in an NCAP test zone is shifted (independent of the body region and impacted NCAP zone)		Pessimistic Approach Only injuries in **addressed body regions** are shifted, if they were caused by a **related NCAP** zone)
injury severity is shifted to AIS1	injuries, caused in a zone with **good** pedestrian protection potential **(green)**	**injury severity is shifted by two AIS levels***
injury severity is shifted by two AIS levels*	injuries, caused in a zone with **adequate** pedestrian protection potential **(yellow)**	**injury severity is shifted by one AIS level***
injury severity is not shifted	injuries, caused in a zone with **marginal** pedestrian protection potential **(red)**	**injury severity is not shifted**

*** maximum shift to AIS1 (no reduction of complete injuries / no shift to AIS0)**

Figure 11. Assumptions (Injury shift method).

The injury shift method considers the idea of using an optimistic and a pessimistic approach. As 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 conservatively.

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

Benefit estimation

For every real-world accident in the dataset it is known which injuries the pedestrian has sustained and which impact zones were responsible for them. Along with the measured Euro NCAP test zones for every vehicle model it is now possible to evaluate any Euro NCAP colour distribution regarding its actual real-world benefit. In Figure 12, an example for such a colour distribution (left side) as it may result from a Euro NCAP rating test is shown.

This colour distribution is then assumed for all vehicles in the dataset. Using the injury shift method, it is calculated how the injury severity outcome will be if all M1 vehicles in pedestrian accidents would have this Euro NCAP distribution. For this purpose, an assumption has to be made concerning the original pedestrian safety performance of the vehicles in the 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).

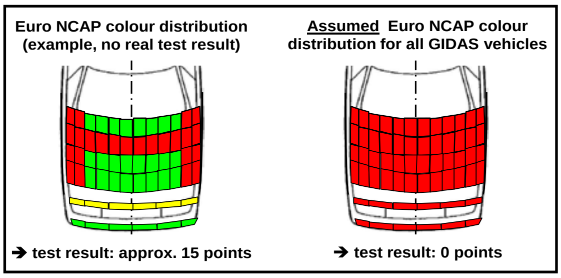

Figure 12. Euro NCAP colour distribution (example) / Assumed GIDAS distribution.

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, 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 overestimation of the benefit.

Keeping this in mind, the benefit is calculated. As described, the severity of all AIS2+ injuries in green or yellow test zones is shifted downwards according to the assumptions in Figure 11. Then, the injury severity (represented by the MAIS) is re-calculated, resulting from the maximum AIS value of all injuries. Depending on the number, the severity and the causation of the injuries, the MAIS of a pedestrian is reduced or remains constant.

The following illustration shows the methodology in an example (Figure 13). On the basis of the example accident, two different Euro NCAP colour distributions are evaluated (pessimistic approach). The distributions are chosen in a way to show different resulting MAIS values for the pedestrian.

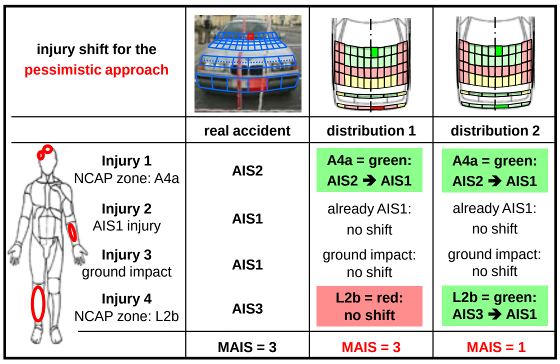

Figure 13. Evaluation of Euro NCAP colour distributions (injury shift method).

As seen 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 two different Euro NCAP colour distributions are assumed for 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 or MAIS1.

This procedure is done for all 667 pedestrians. The overall benefit of a Euro NCAP colour distribution is then calculated. Thereby, the benefit is defined as the number of reduced MAIS2+ injured pedestrians. In the above given example, only the second distribution (rightmost column) will achieve a reduction from MAIS2+ injured MAIS1 injured.

ANALYSES AND RESULTS

This chapter contains information about the single steps of the analysis and the related results. At first, the detailed impact distributions are considered. Afterwards, the estimation of different Euro NCAP rating results is done.

Impact distribution

At first, the results of the case-by-case analysis are presented. As described above, all AIS2+ injuries are either allocated to a Euro NCAP test zone or to another (non-tested) vehicle zone or to the ground impact. Using this data, a detailed analysis concerning single Euro NCAP test zones is done.

The optimistic approach – uses all injuries of the pedestrian, independent from the body region. For this reason, all injuries in Euro NCAP test zones are considered for the impact distribution. Figure 14 gives an overview of the general impact location for the 519 AIS2+ injuries in the dataset.

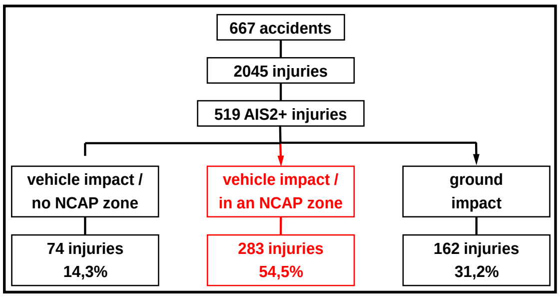

Figure 14. Type (location) of impacts (AIS2+ injuries, optimistic approach).

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.

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

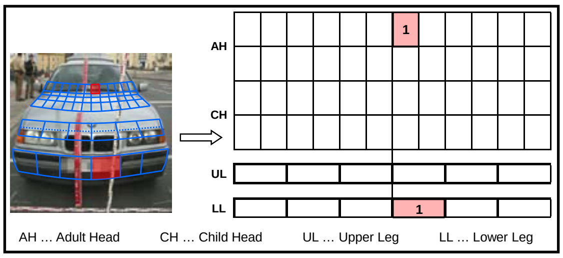

Figure 15. Transfer of impact zones (example).

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).

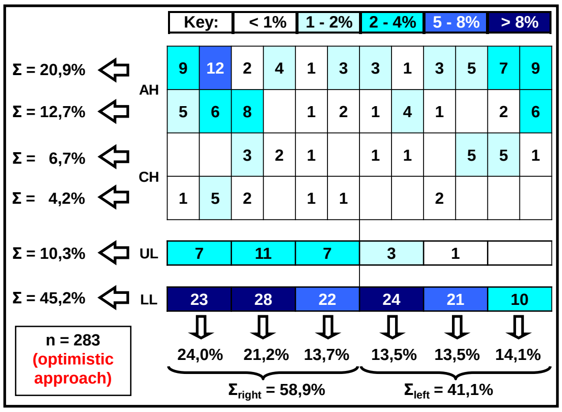

Figure 16. Distribution of impact zones (AIS2+ injuries, optimistic approach).

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

It can be seen that the pedestrian impacts, which caused AIS2+ injuries, are not symmetrically distributed. The majority (59%) of the pedestrians are hit by the right side of the vehicle which seems to be 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 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 on the vehicle.

Another third of the impact points is 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%. 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 decreases in accidents with younger vehicles. Not more than three out of the 29 injuries in the upper leg area were caused by vehicles introduced 1997 or later.

<u>The pessimistic approach</u> – only bases on injuries within the three addressed body regions. 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 directly addressed by the specific tests. However, 212 AIS2+ injuries remain for the analysis of impact distribution, representing 41% of all AIS2+ injuries in the dataset.

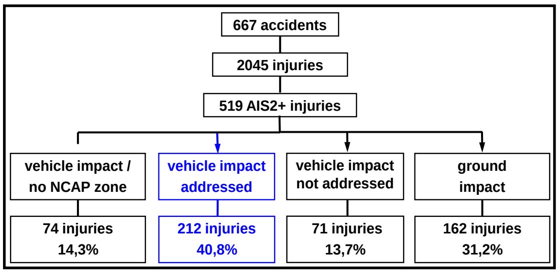

Figure 17. Type (location) of impacts (AIS2+ injuries, pessimistic approach).

The impact zones of the relevant AIS2+ injuries are summed up for all 667 accidents which finally lead to the distribution shown in 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 vehicle side.

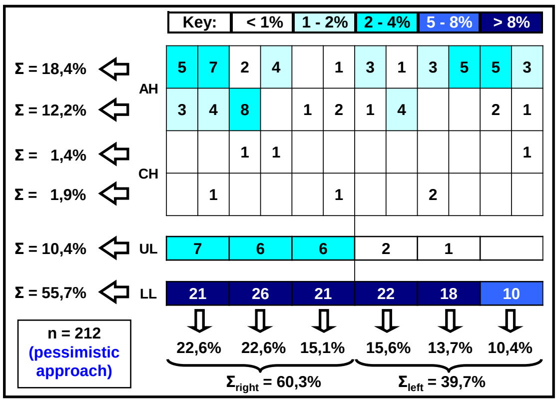

Figure 18. Type (location) of impacts (AIS2+ injuries, pessimistic approach).

In comparison to the results of the optimistic approach, the proportion of impacts in the lower leg test zones increases further to more than 55%. The proportion of impacts in the adult head test zone decreases slightly to 31% whilst the proportion of head impacts in the child head test zone decreases substantially to not more than 3,3%. This implies that this test zone hardly causes severe head injuries but injuries to other body regions, like thorax, abdomen or upper extremities. The proportion of impacts in the upper leg test zones remains constant. Again, the majority of these injuries results from accidents with older vehicles. Two out of the 22 injuries in this zone were caused by vehicles introduced in 1997 or later.

Evaluation of the Euro NCAP pedestrian rating

Using the results of the case-by-case analysis and the detailed impact distribution, various analyses can be carried out with the available data. Two of them are shown hereafter.

At first, the general potential of passive safety measures concerning the Euro NCAP tests is given. Principally, all passenger cars are addressed by the Euro NCAP tests. The test procedures are meant for frontal collisions and, as mentioned above, the potential of passive safety measures is limited to certain collisions speeds. For this reason, the filter criteria for the present study were determined according to these facts.

The following overview, including the numbers of MAIS2+ injured pedestrians, is given to illustrate the possible benefit for the entire pedestrian accident scenario.

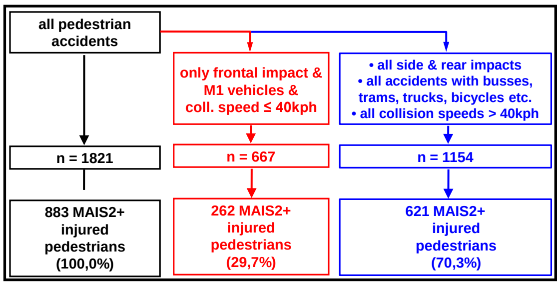

Figure 19. Relevance of accidents addressed by the Euro NCAP pedestrian rating.

It can be derived from the figure, that not more than 30% of all MAIS2+ injured pedestrians are involved in the considered frontal accidents with M1 vehicles and collision speeds up to 40 kph. For this reason, the benefit of passive safety measures in Euro NCAP test zones is generally limited. For the intended analyses, 262 MAIS2+ injured pedestrians are available in the 667 accidents.

The first analysis deals with the allocation of points to the single test zones and the benefit of single areas. The analysis should answer the question, which benefit for the real accident scenario can be expected from the optimisation of single test zones and how the Euro NCAP rating method does factor in the real-world injury causation. For this purpose, seven idealised Euro NCAP colour distributions are generated. Then, their real-world benefit is estimated and compared to the related Euro NCAP rating result. Figure 20 shows the seven colour distributions and their Euro NCAP point scores.

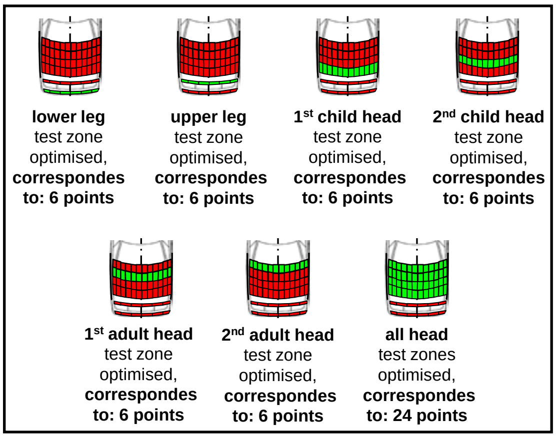

Figure 20. Idealised Euro NCAP shapes.

There are six distributions with one optimised (i.e. green) test row (each corresponding to six Euro NCAP points) and another distribution, where all head impact test zones are optimised (resulting in 24 Euro NCAP points).

Every distribution is then assumed for all vehicles in the dataset and the resulting number of MAIS2+ injured pedestrians is calculated. Using the optimistic as well as the pessimistic approach, the benefit range can be estimated, too. The following graph shows the calculated reduction of MAIS2+ injured pedestrians for the seven idealised Euro NCAP colour distributions.

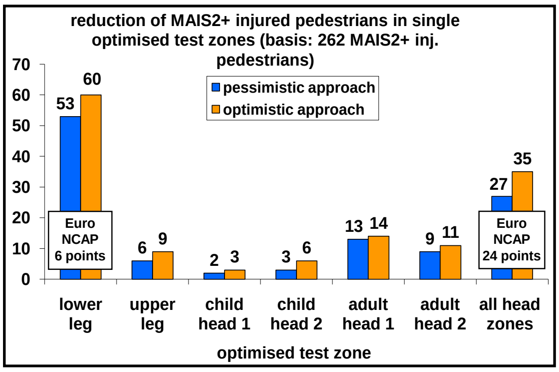

Figure 21. Reduction of MAIS2+ injured pedestrians by single optimised test zones.

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. As illustrated, an optimised lower leg area, which achieves six Euro NCAP points, can save between 53 and 60 pedestrians from being MAIS2+ injured whilst an optimised head impact test area (achieving 24 Euro NCAP points) will save between 27 and 35 of these pedestrians. From this point of view the lower leg test zones seems to be underestimated towards the head impact zones within the Euro NCAP pedestrian rating.

In conclusion, a higher Euro NCAP result is not always linked to a higher benefit. A several times higher Euro NCAP point score must not necessarily be as effective as single optimised test zones.

Benefit estimation of various Euro NCAP point scores

The second analysis deals with the question, which benefit range can be expected from increasing the average pedestrian protection level by six Euro NCAP points. Furthermore, it is estimated how large the benefit range can be between different vehicles achieving the same number of Euro NCAP points. For the study, two Euro NCAP colour distributions achieving 18 points as well as two colour distributions achieving 24 points are generated. The latest Euro NCAP tests show, that these point scores are realistic for currently developed and recently testes vehicles.

On the one hand, the real-world impact distribution is used as a basis for the creation of one "good" and one "bad" Euro NCAP colour distribution. On the other hand, the distributions are generated with regard to current Euro NCAP test results. Thus, nearly all distributions already have green lower leg areas, although they have the greatest effect on the calculated benefit. If one would additionally look for colour distributions with red lower leg areas on purpose, even more wide-spread results could be achieved. In addition, nearly all of the outermost test zones in the head impact areas (near the Side Reference Lines) are coloured red which represents the current technical feasibility.

The used distributions are shown in Figure 22.

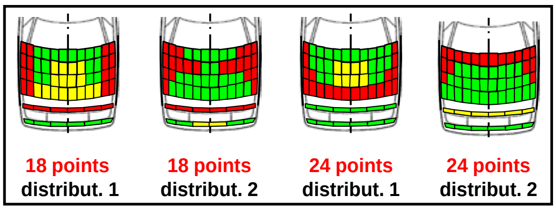

Figure 22. Euro NCAP colour distributions for the estimation of 18 and 24 points vehicles.

The benefits of the four colour distributions are estimated, assuming again that all 667 vehicles in the dataset have the same colour distribution. Then, the results of the four distributions are compared.

The calculated numbers of MAIS2+ injured pedestrians are shown in the following table.

Table 1.
Reduction of MAIS2+ injured pedestrians for the estimated 18 and 24 points vehicles

	NUMBER of MAIS2+ injured pedestrians		**REDUCTION** of MAIS2+ injured pedestrians
	pessi-mistic appr.	**opti-mistic appr.**	**benefit**
basis (master-dataset)	262		---
18 points distribut. 1	**172**	**171**	**90 … 91**
18 points distribut. 2	**188**	**181**	**74 … 81**
24 points distribut. 1	**162**	**158**	**100 … 104**
24 points distribut. 2	**178**	**177**	**84 … 85**

Looking at the 18 points vehicles, it can be derived from the table that the number of reduced MAIS2+ injured pedestrians already differs between the two distributions. The first distribution reduces the number of MAIS2+ injured pedestrians by 74 (pessimistic approach) respectively 81 (optimistic approach) persons. The second distribution leads to a reduction of 90 (91) severely injured pedestrians. The range within the group of 18 points vehicles amounts 10 (16) MAIS2+ injured pedestrians, representing 12,3% for the optimistic approach and even 21,6% within the pessimistic approach.

Similar results can be derived from the two distributions reaching 24 points. The first one will reduce the number of MAIS2+ injured pedestrians by 100 (pessimistic approach) respectively 104 (optimistic approach) persons. The second distribution leads to a reduction of 84 (85) MAIS2+ injured pedestrians. The range between both 24 points distributions again reaches considerably high values of 16 respectively 19 persons, which are 19,0% for the pessimistic approach and 22,4% for the optimistic one.

Figure 23 illustrates the calculated benefit ranges, separated by the two approaches. Every bar is built by the results of the two distributions with the same Euro NCAP point score.

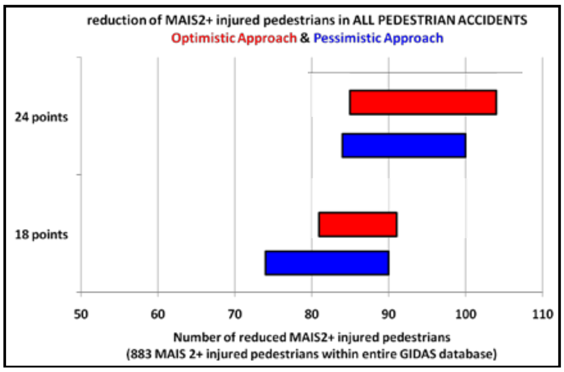

Figure 23. Comparison of calculated benefits (reduction of MAIS2+ injured pedestrians) of 18 and 24 points Euro NCAP colour distributions.

The benefit of the bad 24 points distribution is smaller than the benefit of the good 18 points one. The benefit range within one NCAP level may be greater than the difference between two levels that are six points apart from each other. Comparing the two good distributions with each other as well as the two bad ones with each other shows that the 24 points vehicles will finally have higher benefits.

RESTRICTIONS OF THE STUDY

As mentioned, not all vehicles will actually achieve zero Euro NCAP points. Unfortunately, only ten vehicles (in 667 accidents) have already been tested by Euro NCAP. In these ten accidents, one AIS2 injury is still found that was caused by a green Euro NCAP zone. Thus, the assumption, which says that a green test zone does not cause AIS2+ injuries, is not entirely exact. Furthermore, the assumption that all GIDAS vehicles have zero Euro NCAP points, leads to an over-estimation of the absolute benefit.

Another fact is the use of the Abbreviated Injury Scale (AIS). The process of the injury shift method is not distinguished for different severity levels. An AIS5 injury, for instance, is treated the same way as an AIS2 injury. The severity of both injuries is reduced to AIS1 (optimistic approach) in case of green Euro NCAP test zones. Thus, the maximum injury severity may be reduced to MAIS1 in both cases. However, there is a large difference between an originally MAIS5 injured person and an originally MAIS2 injured one. The effect of the injury severity reduction on the probability of surviving depends substantially on the MAIS level.

SUMMARY AND CONCLUSIONS

The study deals with frontal pedestrian accidents under participation of M1 vehicles and collision speeds up to 40kph. In a case-by-case analysis of 667 accidents, the pedestrian's impact points on the vehicle are measured exactly regarding the WAD and the lateral distance from the vehicle mid. More than 500 AIS2+ injuries are analysed concerning severity, body region and injury causation.

At first, a detailed impact distribution is generated out of the accident data. The front shapes of the involved vehicles are measured and every AIS2+ injury is allocated to the actual Euro NCAP test zone or to other vehicle areas or the ground impact. Nearly half of all AIS2+ injuries occurred in Euro NCAP zones and about one third of the considered injuries were sustained in the ground impact.

Various analyses can be done on the basis of the impact distributions. This study uses the data for the evaluation of the Euro NCAP pedestrian rating and for the benefit estimation of different Euro NCAP colour distributions. Here, the benefit is defined as the reduction of MAIS2+ injured pedestrians, resulting from single injury severity reductions in yellow and green test zones.

At first, some idealised shapes are evaluated to answer the question, which benefit can be expected from the optimisation of single test rows. Finally, it can be stated that an optimised lower leg area could reduce most of the AIS2+ injuries in Euro NCAP test zones, due to the frequent impacts in this zone.

Next, the benefit of different Euro NCAP colour distributions achieving 18 respectively 24 points is estimated. For this purpose, one "good" and one "bad" Euro NCAP colour distribution is generated for each point score and then evaluated concerning the expected real-world benefit. The results show that the benefit range within one Euro NCAP level can be as large as or greater than the difference between an 18 points and 24 points vehicle. This conclusion is derived from the analysis of realistic (feasible) Euro NCAP distributions. Using the real-world impact distribution and disregarding the feasibility, it is even better possible to derive a "most effective" distribution as well as a "hardly effective" one for nearly every Euro NCAP level. The real-world benefit will differ substantially, although the Euro NCAP point score is the same!

Taking the actual real-world impact points as a basis, vehicles with different Euro NCAP colour distributions will achieve different real-world benefits, depending on the individual position of their red, yellow and green fields. Vehicles with equal Euro NCAP pedestrian ratings (point scores) may have great as well as small real-world benefits.

The results of the study show that it is highly recommended to include findings out of real-world accident data and associated effectiveness studies in the development of passive safety measures, legislation tests or ratings like Euro NCAP.