BENEFIT ESTIMATION OF SECONDARY SAFETY MEASURES IN REAL-WORLD PEDESTRIAN ACCIDENTS

Henrik Liers
Lars Hannawald
Verkehrsunfallforschung an der TU Dresden GmbH (VUFO)
Germany
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ABSTRACT

Pedestrian accidents play an important role in the area of traffic accident research. Especially in Asia, pedestrians account for large numbers of accident involvements. However, even in the US 12% of the traffic accident fatalities are pedestrians (FARS, 2008) and in Europe, every fifth person, which died in a traffic accident, is a pedestrian (EU-27, 2008).

For that reason, a study was carried out, dealing with the potential benefit of secondary safety measures for pedestrians. Thus, 669 real-world pedestrian accidents out of GIDAS (German In-Depth Accident Study) have been analyzed. The study considered the exact vehicle impact zones,the affected body regions and the injury causing parts of about 850 AIS2+ injuries. Furthermore, the relevance of the ground impact is estimated, which provides an indication about the possible benefit of primary and secondary safety systems.

On the basis of the detailed impact distribution and by using the developed injury shift method, several secondary safety measures can be estimated concerning their effectiveness. In this paper, the results for measures related to the Euro NCAP pedestrian rating tests are presented. It is calculated how well current vehicles perform in pedestrian protection. The benefit of different Euro NCAP point levels is estimated, including the limit value of 36 Euro NCAP. Furthermore, a correlation between the achieved number of Euro NCAP points and the expected real-world benefit is calculated. By using this correlation, the effect of improved secondary safety measures (e.g. due to increased requirements) can be projected to the future pedestrian accident scenario.

The analysis of injury causation in Euro NCAP test zones bases on a high number of real-world pedestrian accidents. The analysis focused on secondary safety measures which are necessary to meet the requirements of the Euro NCAP rating tests. The developed methodology further allows the evaluation of secondary safety systems like the pop-up bonnet or a pedestrian airbag. Furthermore, the results can be later compared to the benefit of primary safety systems like a brake assistant or sensor-based forward-looking systems.

INTRODUCTION

The study generally deals with the analyses of real-world pedestrian accidents involving M1 vehicles. The aim of the study was the benefit calculation of secondary safety measures for the protection of pedestrians with a focus on the Euro NCAP tests concerning pedestrian safety. The study is a part of a larger research project dealing with the benefit estimation of primary safety systems and secondary safety measures. This paper describes the methods and some results of the analysis of secondary safety measures. Most of the results are currently used in the "vFSS" project ("vorausschauende Frontschutz-systeme") dealing with the development of test procedures for and the benefit estimation of advanced forward looking safety measures.

DATASET

The following chapter deals with the data source that was 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 study accident data from GIDAS (German In-Depth Accident Study) is used. GIDAS is the largest in-depth accident study in Germany and the data collected in the project is very extensive.

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 more than 20.000 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

The GIDAS database currently consists of more than 2.500 accidents involving pedestrians. These are accidents with passenger cars, trucks, trams, motorcycles and bicycles. For the present study, special filter criteria are used not least because of the intended comparison between the benefits of primary and secondary safety measures. Thus, a common dataset (usable for the simulation on the one hand and for the analysis of secondary safety measures on the other hand) has to be created.

First and foremost, only reconstructed accidents are used as only these do include information regarding the initial speed, braking deceleration, collision speed etc. Accidents with unknown parameters (where an exact reconstruction was not possible) are excluded, as well as cases where the pedestrian kinematics is unknown or where no injury information could be investigated due to missing declarations of consent of the involved persons.

The next sample criterion is the vehicle class. The study considers all accidents with passenger cars of the M1 type (according to the UN-ECE definition). Furthermore, only accidents with impacts in zones tested by Euro NCAP are taken into account. These are mostly pure frontal impacts and few lateral impacts. Furthermore, special types of accidents were excluded from the analysis. These are rare cases such as run-over accidents, where the person already laid/sat on the road or accidents where the pedestrian was crushed between two cars.

Descriptive statistics of the master-dataset

The application of all filter criteria to the GIDAS database gives a master-dataset of 669 accidents that can be analysed regarding the benefit of primary and secondary safety measures.

The large majority (97%) of these accidents occur in urban areas. Looking on the accident types, the following results can be derived from the data:

- 85% of the cases are crossing accidents
- 9% of the cases are turning accidents
- 6% of the cases are other accidents (loss of control, longitudinal traffic, resting traffic)
- in 58% of the crossing accidents the pedestrian is not obstructed
- in 60% (crossing accidents) the pedestrian crosses the road from the right to the left.

Considering the collision speeds (figure 1) it can be seen, that approximately 80% of the accidents occur at speeds up to 40kph. Half of the pedestrians are hit with speeds between 11 and 30 kph.

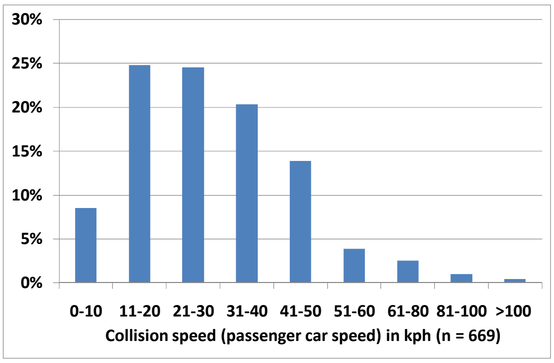

Figure 1. Distribution of collision speed (speed of the passenger car).

Another important parameter is the age of the pedestrian as it is known that the age 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.

The following graph shows the distribution of the pedestrian's age in the master-dataset (figure 2).

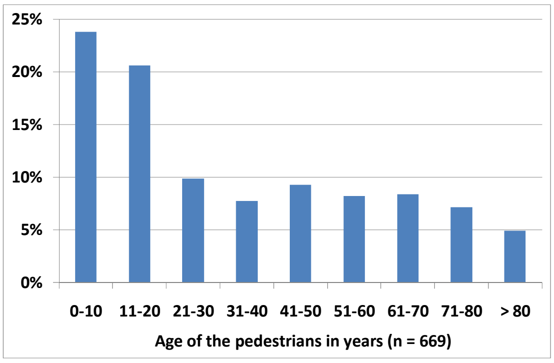

Figure 2. Distribution of pedestrian age.

Every third injured pedestrian is aged up to 14.

Finally, the injury severity is analysed. According to the official definition, the dataset contains:

- 321 slightly injured pedestrians (48,0%)
- 319 seriously injured pedestrians (47,7%)
- 29 fatally injured pedestrians (4,3%)

Furthermore, the distribution of the MAIS is shown in figure 3. The present study is consistently done on the basis of the AIS edition 2005.

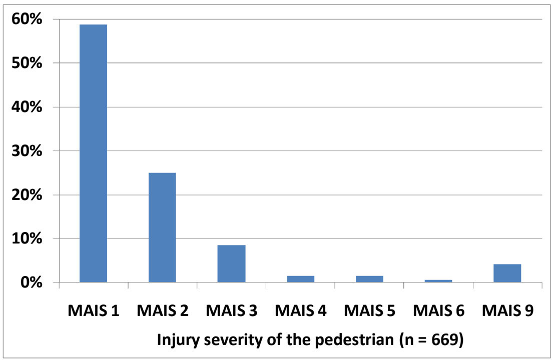

Figure 3. Injury severity distribution (MAIS).

As seen in the figure, approximately 40% of the pedestrians have been MAIS2+ injured. Following many other studies, this group of seriously and fatally injured persons is the interesting group for the development and improvement of safety systems. The analyses within the present study also focus on AIS2+ injuries respectively MAIS2+ injured pedestrians. All in all, the dataset contains 276 MAIS2+ injured pedestrians that sustained about 850 AIS2+ injuries.

METHODOLOGY

This chapter describes the used methods for the benefit estimation. It concentrates on the more sophisticated methodologies basing on the methods published in previous studies.

Summary of known methodologies

As mentioned the aim of the study is the benefit estimation of secondary safety measures on the basis of single injuries sustained in real-world pedestrian accidents. For the intended evaluation of different secondary safety measures resulting in different Euro NCAP test results, a detailed impact distribution of AIS2+ injuries is necessary. To derive this basic information, the following steps have to be done.

The estimation of the Euro NCAP test zones is done for every vehicle model that was involved in one of the 276 accidents with an MAIS2+ injured pedestrian. The determination of the 60 single test zones is done on the basis of CAD models, according to the Euro NCAP testing protocol [2]. After that, every actually sustained injury in the 669 real-world accidents can be allocated to a particular Euro NCAP test zone if it occurred in such an area.

A case-by-case analysis is necessary to link impact data (Wrap Around Distance and lateral distance from the vehicle mid of every AIS2+ injury) with injury data such as the type of injury, the injury severity value (AIS), the injury location (exact body region) and the injury causing part. As shown in figure 4 all relevant data is combined to derive the required impact distribution.

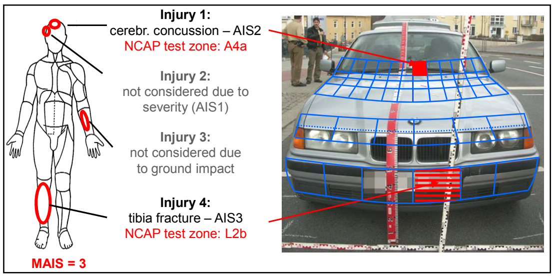

Figure 4. Combination of injury data, measured impact points and the Euro NCAP test zones.

This is done for all 276 accidents with an MAIS2+ injured pedestrian. As a result, the injury causation of pedestrian's AIS2+ injuries in Euro NCAP test zones, in other vehicle zones or due to the ground impact can be displayed.

Improved injury shift method

Previous studies dealing with secondary safety measures for pedestrians vary in relation to the question as to whether all injuries (in all body regions) benefit from improvements that were made to pass a special (body region related) test or if only the injuries in addressed body regions may be affected from secondary safety measures.

For the study, all injuries in all body regions are taken into account. Child head injuries for instance are also considered if they are caused by the bonnet leading edge, although this part is essentially addressed by a test covering 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. Although this assumption is an optimistic one and may lead to an overestimation of the benefit it can be expected that an optimised impact zone will even have a positive effect on injuries of other body regions. An optimised head test zone on the bonnet will surely mitigate injuries to the thorax or abdomen, too.

Contrary to that, the next step of the benefit estimation, the injury shift method, is intentionally done with a pessimistic approach. The aim is the performance estimation of particular Euro NCAP test zones. 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 or lower leg acceleration, the evaluation cannot directly be done on the basis of these parameters. Thus, the Euro NCAP test zones are estimated on the basis of their colour [1].

The performance of all 60 Euro NCAP test zones is judged on the basis of physical parameters. Depending on the results in the test, a characteristic colour is assigned to every zone, namely green for a good pedestrian protection, yellow for an adequate pedestrian protection and red for a marginal one. This colour code was here used for the estimation of effectiveness of single test zones. It is assumed that the original injury severity 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 green or yellow Euro NCAP zone. Figure 5 shows the extent of the injury severity reduction depending on the colour of the particular test zone.

One of the most important assumptions within the entire study is that the injury shift method is only applied to AIS2+ injuries if they were sustained in accidents with collision speeds up to 40kph. It is assumed that there is hardly any potential of secondary safety measures for the reduction or mitigation of injuries. That means that about 500 AIS2+ injuries are not considered by the injury shift.

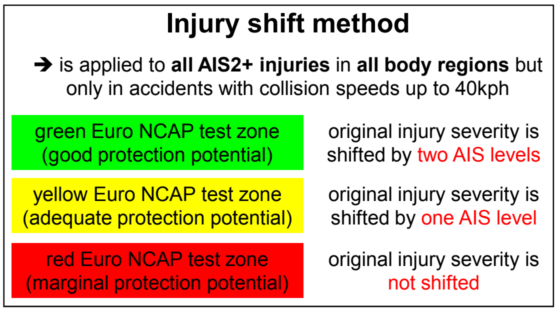

Figure 5. Injury shift method (assumptions).

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 never shifted. Generally, the injury severity can be shifted towards AIS1 at the maximum. It is assumed that no injury is entirely avoided (AIS0).

Benefit estimation

Out of the case-by-case analysis it is known which injuries have been sustained by the pedestrian and which impact zones were responsible for them. Along with the measured Euro NCAP test zones for every vehicle model it is possible to evaluate any Euro NCAP colour distribution regarding its expected real-world benefit; theoretical distributions as well as real test results.

The colour distribution that has to be evaluated is assumed to all vehicles in the dataset. Using the injury shift method, it is calculated how the injury severity outcome will be if all vehicles in the dataset would have this Euro NCAP distribution.

One important thing that has to be assumed is that the vehicles in the original GIDAS dataset have zero Euro NCAP points. Due to the fact that most of the vehicles in the GIDAS dataset are rather old, this assumption seems to be suitable. However, the actual pedestrian protection performance is unknown for the majority of the vehicles, due to missing Euro NCAP test results for older vehicles.

Keeping this in mind, the benefit can be calculated. The injury severity (represented by the MAIS) is re-calculated for every pedestrian, using the maximum AIS value of all single injuries. Depending on the number, the severity and the causation of the injuries, the MAIS of a pedestrian is reduced or remains constant.

Analysis of real Euro NCAP test results

The central aim of the study is the evaluation of measures related to the Euro NCAP pedestrian tests. It is intended to evaluate all currently tested vehicles concerning their real-world effectiveness in pedestrian accidents. Furthermore the state of the art as well as the minimum expectable safety level of recently introduced vehicles is considered.

For that reason, the real test results of all vehicles tested by Euro NCAP according to the 2010 rating method are derived from the official homepage [3]. Finally, 66 different vehicle models (tested between January 2010 and February 2011) are used for the analysis. The performances of these vehicles range between 9 and 28 Euro NCAP points with an average of 17,9 points and a median of 18 points.

The colour distributions of these vehicles are then used for the characterisation of the state of the art, representing the pedestrian protection potential of currently tested vehicles. Therefore, the proportion of green, yellow and red test zones within the 66 vehicle models is calculated. Figure 6, for instance, shows the proportions of green test results for every zone each. Zones where the proportion is clearly above the half (≥ 55%) are coloured green.

AH	0%	6%	33%	36%	41%	39%	41%	39%	39%	36%	8%	0%
	3%	8%	32%	41%	42%	42%	41%	42%	41%	29%	6%	3%
CH	9%	23%	48%	64%	73%	74%	79%	77%	65%	53%	20%	5%
	11%	15%	42%	48%	65%	64%	64%	64%	50%	39%	15%	8%
UL	14%		12%		12%		14%		12%		14%	
LL	79%		88%		95%		94%		88%		77%	

Figure 6. Proportion of green tested Euro NCAP zones (66 currently tested vehicles).

It can clearly be seen that the vast majority of currently tested vehicles achieve good test results in the lower leg test areas. Furthermore, the child head impactor test zones in the vehicle mid perform relatively well. Contrary to that, the tested vehicles show worse results in nearly all other head impactor test zones, especially in the outermost test zones. Looking on the upper leg test zones it can be derived from the figures that only every sixth vehicle achieves a "green" result on average.

Figure 7 shows the proportion of red tested zones. Again, zones with a proportion above 55% are coloured. As expected, the distribution is inverted compared to the green one; leading to the same conclusions as mentioned in the paragraph above.

AH	100%	88%	56%	47%	44%	47%	48%	48%	50%	52%	86%	100%
	94%	82%	56%	42%	39%	39%	38%	36%	42%	56%	83%	94%
CH	77%	58%	18%	9%	11%	9%	2%	3%	11%	20%	61%	80%
	77%	59%	26%	24%	17%	20%	18%	15%	26%	32%	58%	80%
UL	62%		70%		62%		65%		73%		64%	
LL	9%		0%		0%		0%		0%		9%	

Figure 7. Proportion of red tested Euro NCAP zones (66 currently tested vehicles).

Finally, the proportions of yellow tested Euro NCAP zones are shown, including the remaining percentages per test zone (figure 8).

AH	0%	6%	13%	21%	15%	13%	11%	13%	13%	15%	6%	0%
	2%	9%	15%	21%	17%	17%	21%	21%	17%	15%	11%	2%
CH	6%	17%	42%	32%	21%	21%	25%	25%	25%	30%	17%	8%
	6%	21%	36%	32%	23%	19%	23%	26%	25%	28%	25%	6%
UL	25%		19%		23%		21%		15%		23%	
LL	9%		13%		6%		8%		13%		11%	

Figure 8. Proportion of yellow tested Euro NCAP zones (66 currently tested vehicles).

In the upper leg test zones, about every fifth tested vehicle achieves "yellow" test results on average. The lower leg test areas of few vehicles also show yellow zones and some head impactor test areas are covered with yellow test fields, too.

These three distributions represent the state of the art of current vehicles (model years 2009 and 2010). In the next step, a "minimum expectable safety level" is derived from this information. Therefore, all zones with frequencies of at least 55% of one colour automatically get this colour in the "basic shape". Furthermore, the colour distribution has to be symmetrical. That means, for instance, if the test zone on the left vehicle side is already red, the related test zone on the right vehicle side is also defined as red. Zones with high frequencies of yellow test zones and/or similar proportions of red and green zones are defined as yellow. In doing so, the following Euro NCAP colour distribution was created (figure 9).

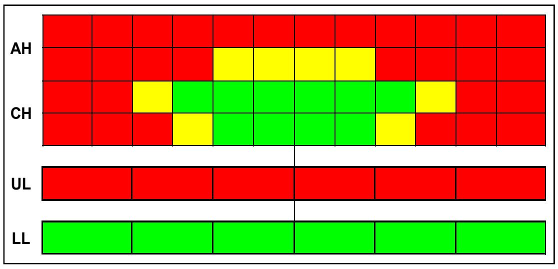

Figure 9. "Basic Euro NCAP shape" (Current minimum expectable safety level).

The following points are assumed per zone:

- lower/upper leg: green = 1.0 point
- head test zones: green = 0.5 points
  yellow = 0.25 points
  red = 0 points

Applying these scores to the above shown distribution leads to an overall rating result of 13 Euro NCAP points. This can be assumed to be the minimum expectable safety level of recently introduced vehicle models. Compared to the single test results, 86% of the tested vehicles achieve this result. Furthermore, it has to be mentioned that the test results now (June 2011) are on average already one year old and it can be expected that the "basic pedestrian protection level" increases steadily.

ANALYSES AND RESULTS

This chapter gives a summary about some results of the study. At first, the impact distribution is shown. Afterwards, the results of the benefit estimation for different Euro NCAP rating results are described. In addition, the performance of the above shown "basic Euro NCAP distribution" and some theoretical shapes is compared to real vehicles.

Impact distribution

At first, the results of the case-by-case analysis are presented. All AIS2+ injuries have been either allocated to a Euro NCAP test zone, to another (not tested) vehicle zone or to the ground impact. Figure 10 shows the general areas of injury causation for all AIS2+ injuries. In addition, the numbers for accidents up to 40kph are given in brackets.

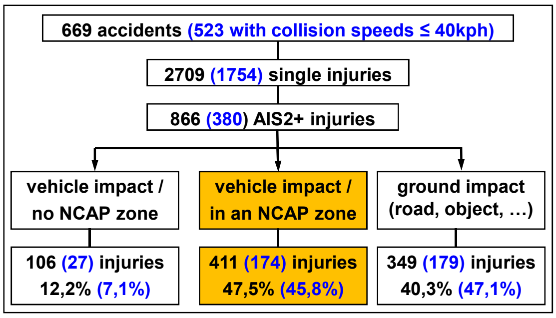

Figure 10. Injury causation of AIS2+ injuries.

The first conclusion that can be drawn from the figures is that about every second AIS2+ injury occurs in a Euro NCAP test zone. The ground (= secondary) impact plays a very important role, especially in low speed accidents. The relevance of other vehicle parts (not tested) obviously increases with the collision speed. This is caused by more impacts in areas with a WAD above 2100mm.

It can be further seen from the figure that the majority (56,1%) of all severe injuries in the dataset occurred in accidents with collision speeds above 40kph although they make up only 22% of all accidents. Another important fact is that pedestrians in accidents with high collision speeds often suffer more than one severe injury. Especially fatally injured pedestrians can have up to 70 single injuries (given that the information from the autopsy is very detailed). As a consequence, one pedestrian can be responsible for more than one AIS2+ injury in one Euro NCAP zone.

This is confirmed by figure 11 that shows the distribution of all AIS2+ injuries in Euro NCAP zones. The majority of the pedestrians account for one or two AIS2+ injuries per test zone, but there are two (fatally injured) pedestrians who suffered about 10 thorax injuries in one Euro NCAP zone, leading to a small bias in the shown distribution. However, the impact distribution leads to clear conclusions concerning the occurrence of AIS2+ injuries. The majority of these injuries are sustained in the lower leg test zones, followed by the rearmost und outermost head impact test zones.

	right vehicle side						left vehicle side					
AH	4%	7%	1%	-	0%	-	1%	-	-	-	4%	3%
AH	2%	2%	1%	0%	2%	1%	1%	0%	-	-	1%	1%
CH	1%	-	2%	1%	-	0%	0%	-	-	-	-	1%
CH	1%	1%	2%	-	-	-	-	-	0%	-	-	2%
UL	2%		2%		2%		2%		1%		3%	
LL	6%		8%		6%		7%		9%		7%	

Figure 11. Distribution of AIS2+ injuries in Euro NCAP zones (all collision speeds / n=411).

Figure 12 shows the same distribution for accidents with collision speeds up to 40kph. As described above, the injury shift method is only applied to these 174 AIS2+ injuries.

	right vehicle side						left vehicle side					
AH	6%	4%	-	-	1%	-	-	-	-	-	1%	5%
AH	3%	3%	-	-	-	-	-	1%	-	-	2%	1%
CH	-	-	5%	1%	-	-	1%	-	-	-	-	1%
CH	-	-	1%	-	-	-	-	-	-	-	-	1%
UL	3%		5%		3%		1%		1%		3%	
LL	6%		11%		8%		10%		10%		3%	

Figure 12. Distribution of AIS2+ injuries in Euro NCAP zones (coll. speed ≤40kph / n=174).

As expected, the proportions in accidents with smaller collision speeds are slightly shifted towards the lower leg test zones. This is especially a result of fewer thoracic and abdominal injuries.

Evaluation of real Euro NCAP test results

On the basis of the case-by-case analysis and the detailed impact distribution, various analyses can be done with the available data. On the one hand it is possible to directly estimate the benefit of existing secondary safety measures (like an active bonnet or an external pedestrian airbag). On the other hand, the safety performance of single vehicles models can be estimated if their Euro NCAP test results are available. It can be analysed how the pedestrian accident scenario would be if all vehicles would feature the given Euro NCAP colour distribution.

Furthermore, the impact distribution can be inverted to conclude which zones/parts of the vehicle should be better addressed or improved by secondary safety measures. In doing so, all pedestrian impact points should be considered, not only the ones tested by Euro NCAP.

For the present paper, all 66 real test results are estimated regarding their benefit in the real pedestrian accident scenario. In addition, three theoretical shapes are evaluated. The first one only has optimised lower leg test zones; the second one represents the best possible Euro NCAP test result (upper limit of 36 points) and the last one is the created "basic shape" out of the 66 recently tested vehicle models ((figure 13).

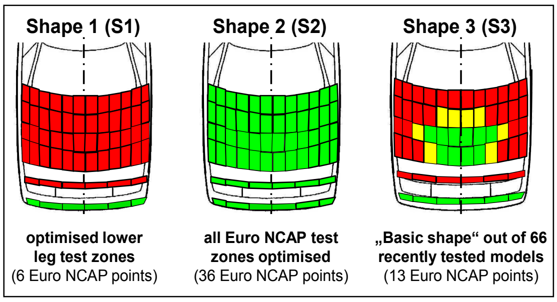

Figure 13. Evaluated theoretical shapes.

All in all, the 69 colour distributions each are assumed to all vehicles in the dataset and the new number of MAIS2+ injured pedestrians is calculated following the above mentioned method. Assuming that the vehicles in the original GIDAS dataset have zero Euro NCAP points and that the 669 accidents were responsible for 276 MAIS2+ injured pedestrians, every model or colour distribution will lead to a decreasing number of seriously injured pedestrians.

The following graph shows the calculated reduction of MAIS2+ injured pedestrians for all 69 colour distributions (figure 14).

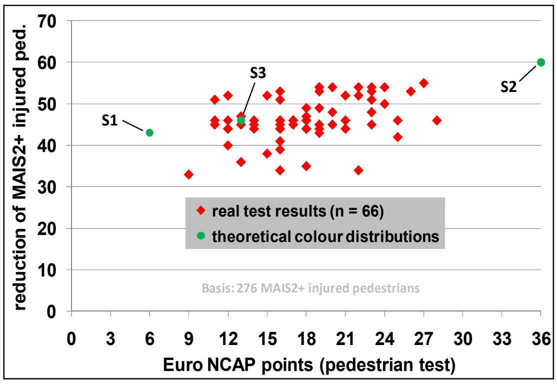

Figure 14. Reduction of the number of MAIS2+ injured pedestrians for 69 colour distributions.

Various conclusions can be derived from the figure.

I) In general, the reduction of MAIS2+ injured pedestrians will increase with an increasing number Euro NCAP points.

II) The maximum possible reduction amounts to 60 MAIS2+ injured pedestrians, assuming that all vehicles achieve 36 Euro NCAP points (shape S2). That means the other way round that 216 (of the original 276) pedestrians remain MAIS2+ injured due to other severe injuries sustained during the ground impact or on other vehicle parts.

III) If all vehicles would feature completely optimized lower leg zones (point S1 in the figure), the number of MAIS2+ injured pedestrians would already decrease by 43 persons.

IV) Although some vehicle models achieve good test results (represented by many Euro NCAP), their benefit in the real-world pedestrian accident scenario is smaller than the benefit of the 6-point-distribution (S1). One vehicle model, for instance, performs worse than the S1 shape.

V) There are partially considerable variations within one point level. In the most frequent group of (16 Euro NCAP points), the reduction varies between 34 and 53 MAIS2+ injured pedestrians.

VI) The result of the "basic shape" S3 (achieving "only" 13 Euro NCAP points) shows a notable reduction of 46 seriously injured pedestrians. That means that the large majority of current vehicle models (which built the colour distribution of the shape) already have acceptable pedestrian safety performances.

SUMMARY AND CONCLUSIONS

In the study 669 real-world pedestrian accidents involving M1 vehicles have been analysed concerning the pedestrian's impact points on the vehicle and the injury causation. More than 850 AIS2+ injuries are analysed with regard to their severity, body region and causation. A detailed impact distribution for injuries in Euro NCAP test zones is generated both for all accidents and only for accidents with collisions speeds up to 40kph.

Various analyses can be done on the basis of this information. It is possible to evaluate secondary safety measures like pop-up bonnets or external pedestrian airbags. Furthermore, the benefit of system ideas or future secondary safety measures can be estimated prospectively. In this study the data is used for the evaluation of different Euro NCAP pedestrian rating results. Therefore, the benefit is defined as the reduction of MAIS2+ injured pedestrians, resulting from single injury severity reductions in yellow and green Euro NCAP test zones.

At first, 66 vehicle models recently tested by Euro NCAP have been used to describe the state of the art and to create a "basic shape". This shape represents the current expectable pedestrian protection performance. Afterwards, these 66 vehicle models and three theoretical shapes have been evaluated concerning their effectiveness in the real-world pedestrian accident scenario. Taking the actual real-world impact points as a basis, different Euro NCAP colour distributions 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 there is a correlation between the number of Euro NCAP points and the reduction of MAIS2+ injured pedestrians. However, the expected real word benefit may vary considerably within one Euro NCAP point level. Another important fact is that even a vehicle achieving 36 Euro NCAP points is incapable to reduce the number of seriously injured pedestrians to an acceptable extent. Therefore, combinations of primary and secondary safety measures will be the number one way to make great progresses in reducing the number of seriously and fatally injured pedestrians.

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