PERFORMANCE OF RESTRAINT SYSTEMS IN ACCIDENTS – DOES EVERY OCCUPANT BENEFIT EQUALLY FROM THE MEASURES?

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ABSTRACT

In the light of more active safety systems and autonomous driving controversial discussions are going on about the role of restraint systems. Although current belt and airbag systems reach a good safety level, many challenges were generated by consumer tests, legislation, and urban vehicles but also by the occupant's diversity in terms of age and anatomy. Thus, passive safety measures will not only remain necessary, they have to be further improved. To derive appropriate future measures the following research questions have to be answered:
- Which effect do current restraint systems show in real accidents?
- Do all car occupants equally benefit from available systems independent of their individual characteristics?
- Which actions are necessary to address severely injured occupants in the future?

For the analyses, data from GIDAS is used. The database contains approximately 30.000 accidents from on-scene investigations. Every accident is reconstructed and besides numerous technical parameters, the database contains detailed medical and personal data. To get an impression of accidents in other countries, additional data of the IGLAD database is used. At first, the current situation is analysed based on descriptive statistics. The influence of several restraint systems (e.g. belts with and without pretensioners and load limiters) on the occupant's injury severity is analysed. As the injury severity of car occupants is influenced by many parameters, multivariate logistic regressions are used to identify their relevance and to point out differences between several restraint systems.

The analysis shows that, besides others, the occupant's age has an effect on the injury severity. The demographic change in many countries will put an even higher emphasis on elderly people in accidents. In general, the benefit of load limiters and pretensioners can be proved. However, not every person will equally benefit from these measures. The study reveals differences between several age groups as well as between front and rear seat occupants.

The study shows how current restraint systems perform in actual accidents and which benefits have been achieved by recent developments. The performance is not obtained from dummy tests but from real accidents with real persons. A strong need for adaptive systems is deduced from the analysis. A good performance in dummy tests is not necessarily linked to a high benefit in the real world. Especially elderly people tend to be more severely injured even in less severe crashes. Here, adaptive restraint systems may help, especially by using the available space for the occupant's forward displacement to reduce loads on the thorax and abdomen. Furthermore, reversible systems will become more important when AEB systems become a standard in future vehicles.
One limitation is the use of GIDAS data that only reflects the German situation. The use of the IGLAD database leads to a higher number of countries, but the case numbers are smaller here.

INTRODUCTION – ACCIDENT SCENARIO

Road traffic accidents is one of the leading cause of death for people around the globe. According to estimations of the WHO, 1.250.000 people are killed in road traffic accidents every year. Although safety is a major field in the development of passenger cars since decades, nearly half of all global traffic fatalities are occupants of these vehicles.

This is also true for Europe. Although the fatalitity risk (fatalities per 100.000 population) is the lowest here (compared to all other continents), around 26.000 people die every year and car occupants are by far the biggest group (see Figure 1). Fortunately, the trend is positive and latest figures from the EU prove that in 2016 25.500 people died on EU roads which is the lowest number since many decades.

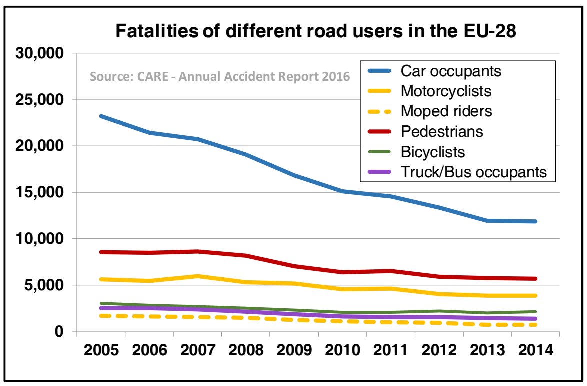

Figure 1. Fatalities of different road users in the EU-28 (2005 – 2014)

This development goes in parallel with increasing fleets and mileage in most of the countries. So, the safety level is increasing steadily even though there are large differences between single countries.

In Germany, which is – together with France and Italy – responsible for the highest absolute numbers of road fatalities in Europe, the situation is similar to the European one. The numbers of killed and injured persons is generally decreasing since 1990, just interrupted by some smaller increases in the years 2011, 2013, and 2014. However, the overall trend will probably continue although the gradients of all curves decrease. Germany already reached a high level in traffic safety and further improvements demand great efforts. The focus must be on more than one road user category as there are four relevant groups: car occupants, motorcyclists, bicyclists, and pedestrians.

Figure 2 shows in detail how these four road user categories contribute to the different injury severity levels in Germany (year 2015).

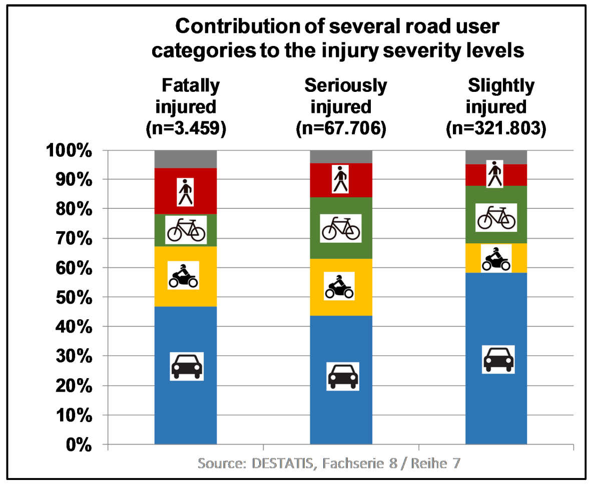

Figure 2. Share of different road user categories for several injury severity levels

Occupants of passenger cars still represent the biggest group of fatalities, seriously injured and slightly injured persons.

Thus, the present study is focussing on car occupants and their current situation in terms of passive safety measures. Most of the analyses are done with in-depth data of the GIDAS project which allows a detailed look into the technical and medical aspects of accidents with injured car occupants.

DATASET

GIDAS (German In-Depth Accident Study)

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 statistical sampling plan, representative statements for the German accident scenarion are possible. Since mid 1999, the GIDAS project has collected on-scene accident cases in the areas of Hanover and Dresden. GIDAS collects data from all kinds and types of accidents with personal damage. Approx. 3.500 information (about vehicles, persons, injuries, infrastructure, environment etc.) per accident are coded in the database on average. Finally, every accident is reconstructed.

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 www.gidas.org.

The following figures gives an overview about the current contents of the GIDAS database (Figure 3).

GIDAS – December 2016: 30.533 reconstructed accidents		
54.905 vehicles	75.846 persons	40.182 injured persons
35.778 passenger cars	50.747 car occupants	108.069 single injuries
3.561 trucks	6.273 truck/bus tram occupants	29.410 slightly injured persons
1.180 busses & trams	4.132 pedestrians	10.011 seriously injured persons
14.236 two-wheeler	14.694 cyclists	761 fatally injured persons

Figure 3. Content of the GIDAS database (Effective December 2016)

For the present study, several filter criteria are applied to the database. Often, accidents from 2005 to 2016 are considered for the analyses.

Weighting and representativeness
To ensure representative results, the GIDAS dataset is weighted towards the German national statistics. This is necessary due to slightly biased data. The investigation teams are not thoroughly informed about all accidents, information about injuries cannot always be obtained immediately and differences in the investigation areas cannot be excluded. Therefore, it is necessary to weight the data. The derived conclusions out of a study with weighted GIDAS data can be used for statements that can be considered as representative for the German accident scenario.

The GIDAS dataset is usually weighted on the basis of three criteria:

- accident site (urban / rural)
- accident category (accident with slightly / seriously / fatally injured persons)
- type of accident (seven different categories)

Due to the use of weighting factors it is possible that the sum of accidents (or persons, injuries etc.) gives non natural numbers.

Some analyses were made with unweighted data (e.g. all chronological analyses of equipment rates) as the use of weighted data would distort the results. If unweighted data was used this is described in the diagram and/or related text.

CURRENT PASSIVE SAFETY LEVEL

The aim of the chapter is a characterization of the current situation in passive safety in Germany. The GIDAS dataset is used to describe the passenger car fleet in terms of safety equipment. Furthermore, the occupant population is analysed briefly.

Current vehicle fleet
The passive safety level of a country's car fleet depends on several aspects. Important ones are the vehicle age, the distribution of vehicle segments, the legal requirements, and the influence of further stakeholders like NCAPs or insurance institutes.

Age of the vehicles The passenger car fleet of Germany is becoming older and older. Figure 4 shows this fact based on two different data sources. The average age of all registered cars (red line) increased by nearly 2.5 years within 15 years. In 2000, the average age was 6.8 years and on January 1st, 2016 the age was already 9.2 years. The latest publication of KBA from March 2017 proves that this trend is still true as the average age on January 1st, 2017 was 9.3 years.

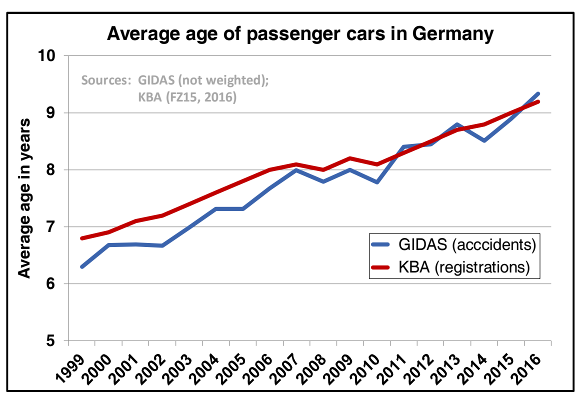

Figure 4. Age of passenger cars in Germany

The blue curve shows the average age of cars based on accident data (out of GIDAS). The figures verify the trend of an aging car fleet.

On the one hand side this trend is a positive one in terms of sustainability, as current vehicles seem to have longer life circles. However, the replacement of older cars by newer ones slows down. That delays the wide distribution of beneficial active and passive safety systems.

Airbag equipment Figure 5 displays equipment rates for several airbag types in passenger cars. The analysis was done with all passenger cars in GIDAS that did not cause the accident as it can be assumed that non-causers are involved in accidents coincidentally. Thus, they represent the fleet average quite well. The time scale on the x-axis uses the accident year and not the year of first registration. So, the diagram represents the current equipment situation of the whole fleet.

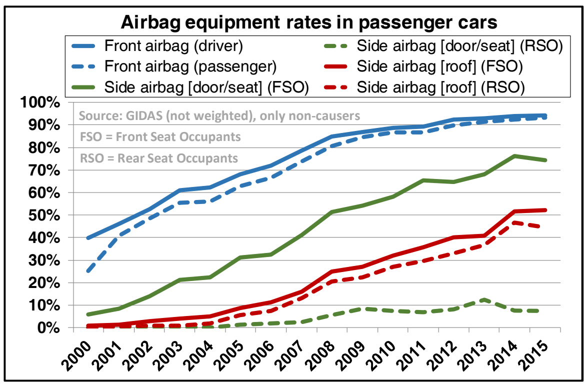

Figure 5. Airbag equipment rates in passenger cars per accident year

The diagram shows that nearly all current passenger cars are equipped with front airbags for drivers and front passengers (blue lines). The former gap between the equipment rates on driver and passenger seats (resulting from cars with driver airbags only; mostly first registered in the early 1990s) is nearly closed. Furthermore, it can be seen that door/seat mounted side airbags (mostly addressing the thorax, abdomen and/or pelvis) are available for front seat occupants (FSO) in about three quarters of current passenger cars. However, there are hardly any thorax/pelvis airbags available for rear seat occupants (RSO; considering the outer seats in the second row).

The third group of airbags - namely head airbags (usually curtain airbags) - show similar equipment rates for front and rear seat occupants. Unfortunately, the rate is still low with 52% (FSO) respectively 44% (RSO) in the year 2015.

The actual benefit of door/seat mounted side airbags is subject of controversial discussions. However, the potential of curtain airbags for the reduction of severe head injuries - especially in lateral pole collisions - is proven. High equipment rates are one key factor for the further reduction of seriously or even fatally injured occupants.

Equipment with belt systems The development of advanced belt systems for passenger cars is still in progress. Remarkable changes took place since the introduction of static 2-point-belts in the mid of the last century. Nowadays there are many technical solutions available for car occupants. The state-of-the-art are dynamic 3-point-belts with load limiters and pre-tensioners on front seats. Rear seats are often equipped with less advanced belt systems.
Figure 6 shows the current situation for the German car fleet based on GIDAS data. Again, all non-causers were used for the analysis and on the x-axis the accident year (not registration year) is given. It can be seen that 90% of the driver seats are already equipped with 3-point-belts with pretensioners. In nearly 80% of the cars a load limiter is available for the driver. Usually, both systems are combined. Today, there are only very few models that offer a load limiter but no pretensioner and vice versa.
The situation of rear seat occupants is comparable to the airbag aspect. In the 2000's the equipment rates of load limiters and pretensioners for rear seats delayed behind the front seats. The curves (red, green) even show that the equipment rates obviously stagnate since 2010 on a level of around 30%. How often occupants do or do not benefit from these systems is shown later in the paper.

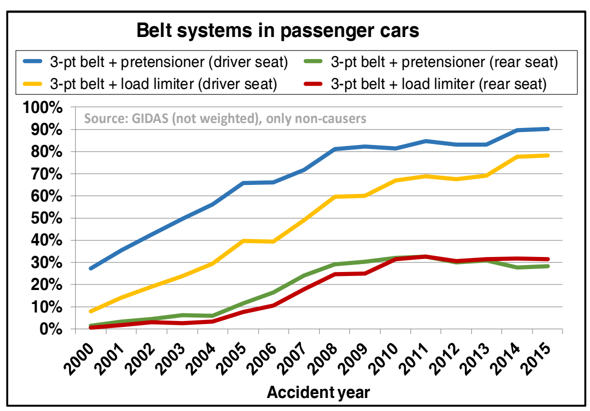

Figure 6. Equipment rates of several belt systems in passenger cars

Occupant population
In this chapter, the current occupant population is characterized in terms of individual parameters like age, gender, height, and weight. Furthermore, the occupation rates are analysed to check if less advanced belt systems (see last chapter) for rear seats will have remarkable consequences at all.

The following analyses were done again with unweighted GIDAS data to see chronological effects.

Age of car occupants The study has already shown that passenger cars in the German fleet have become older and older in recent years. Figure 7 shows the same aspect for the occupants. Again, only occupants of non-causing parties are used to avoid a bias that may arise from causers in certain risk groups (e.g. novice drivers, elderly drivers). Using unweighted data for the age distribution may also lead to another bias, as older people are more vulnerable than younger ones, which will increase their chance of getting documented by GIDAS. However, this bias is disregarded here, as the focus is more on major current trends.

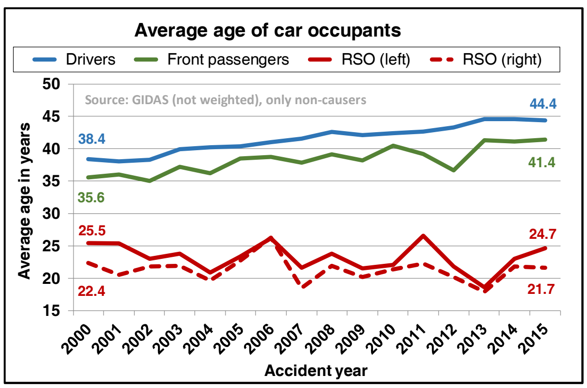

Figure 7. Average age of car occupants in Germany (based on GIDAS data)

The most important information in the figure is the continuous increase in driver age. In 2000, the average age of car drivers was 38.4 years. 15 years later this value increased by full six years to 44.4 years. In parallel, the average age of front passengers also increased by nearly six years. Front passengers are three years younger on average. Rear seat occupants show a different picture. Here, the average age is nearly constant over time (the variations in the red curves result from the small case numbers of around 110-130 RSO with known age per year).

There are several reasons for this development. One main reason for the aging driver population is the fact that nowadays nearly every person has a driving license and makes use of it. One or two decades ago (and especially in the former GDR), there were hardly elderly women with a driving license. Furthermore, life expectancy is increasing and the healthiness of elderly people is higher than some years ago. Together with the demographic change in Germany, these facts are responsible for the increasing average age.
In most of the cases with two occupants (driver and front passenger), the front passenger is the female partner of the driver. Therefore, both age curves are parallel to each other. Front passengers are slightly younger as German car drivers have to be at least 17 years old.

The reason for the constant age of rear seat occupants is the high proportion of children on these seats. Additionally, the red curves show that children (especially in Child Restraint Systems) are usually secured on the right rear seat as this seat is supposed to be the safest one (in countries with right hand traffic).

The following figure shows the age distribution of the four occupant groups with data from GIDAS accidents of the years 2014 and 2015. Here, causers and non-causers are considered.

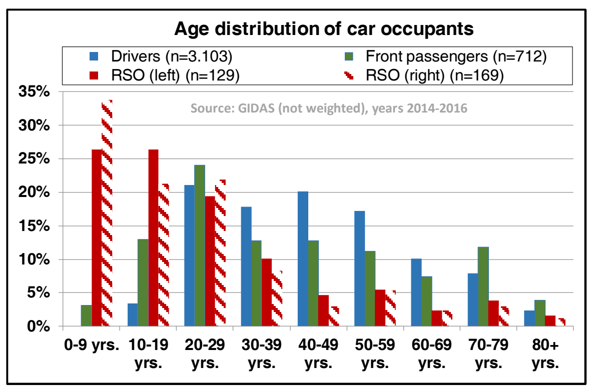

Figure 8. Age distribution of car occupants in Germany (based on GIDAS data)

The distributions prove that children dominate the group of rear seat occupants. The driver age is nearly equally distributed between 20 and 60 years. It should be also considered that 10% of drivers and 16% of front passengers are already aged 70 or more. In the years 1999-2001 these age group made up only 4% resp. 6%.

Gender and height The occupant height is one of the most influencing parameters for the performance of passive safety measures. It is not for nothing that airbags and belt systems are developed based on several dummies, which are defined by heights (and masses). One major requirement for restraint systems is to provide sufficient protection for all kinds of occupants, namely for the wide range of persons between the smallest women to the tallest men.

Here, the height of occupants is not analysed for the last 15 years, as the German population did not change substantially in terms of height within this period. As height is significantly depending on the gender, a differentiation between male and female occupants is done. Children up to an age of 15 are excluded, as they will lead to a strong bias in the height distributions.

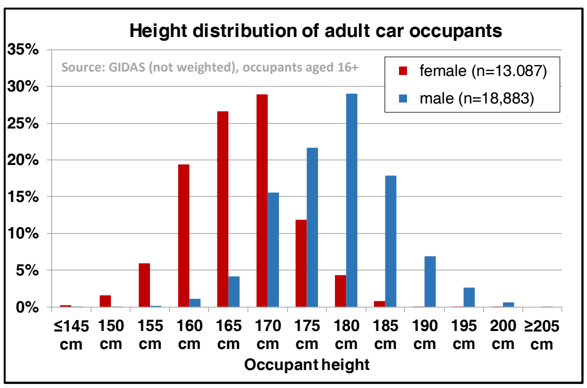

Figure 9. Height distribution of car occupants in Germany (based on GIDAS data)

The diagram shows that males are significantly taller than females. The overall case numbers state that men are more often involved in accidents with personal damage than women are, which is mostly caused by the large differences in the number of rides and mileage.
Although it cannot be ruled out that the use of accident data may lead to a small bias, the distribution can be used for a judgement if the used dummies still cover the actual size of occupants in Germany. Table 1 shows the compared values:

Table 1.
Height of occupants and HIII dummies

Height in cm	Occupants	HIII Dummy
female, 5th percentile	156 cm	152 cm
male, 50th percentile	178 cm	175 cm
male, 95th percentile	190 cm	188 cm

The current German population (derived from accident data of the years 1999 – 2016) is slightly taller. It is well known that people in most of the high-income countries become taller and taller over time. This is not a big problem for the small dummy (5% female) which is now the 2% percentile and thus, covers more smaller people. However, maybe the tall persons will run out of scope in the future.

Weight The weight distributions of male and female car occupants (adults aged 16+ years) is shown in Figure 10.

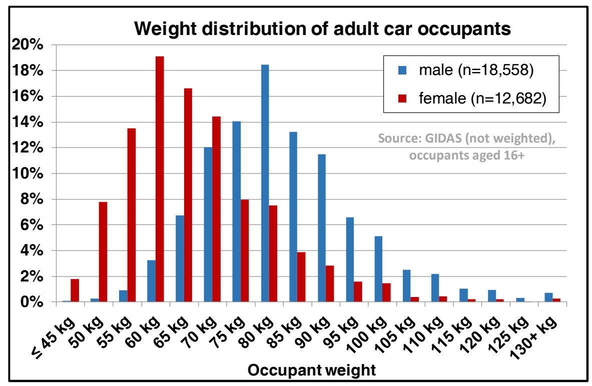

Figure 10. Weight distribution of car occupants in Germany (based on GIDAS data)

Again, the difference between the gender groups is significant. 1.4% of the women were pregnant which may result in a small, but not remarkable shift.
Again, the values of the occupant population and the Hybrid-III dummy family are compared:

Table 2.
Weight of occupants and HIII dummies

Weight in kg	Occupants	HIII Dummy
female, 5th percentile	50 kg	54 kg
male, 50th percentile	80 kg	78 kg
male, 95th percentile	108 kg	101 kg

It can be seen that the occupant population is slightly different from the dummy family in terms of weight. Male occupants in the German accident scenario are heavier than their dummy eqivalents whilst 5% of the female occupants have a weight up to 50kg. In general, the German population is becoming heavier over time, so that the Hybrid III dummies will not cover exactly the actual population.

Occupation rates As described above, different safety measures are available for different seats in passenger cars. Today, the equipment is nearly identical for the outermost seats in one row. However, the second (or third) row often shows less advanced belt systems and less airbags (e.g. no front airbags). The interesting question is how often people do or do not benefit from these measures. Therefore, the occupation rates in passenger cars are analysed. Figure 11 shows the frequency of occupied seats when there was a driver (cases without driver were excluded).

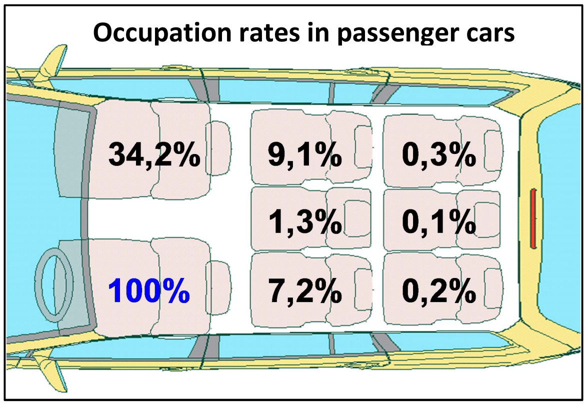

Figure 11. Occupation rates in passenger cars in Germany (based on GIDAS data)

It can be seen that in nearly every third case a front passenger was in the vehicle together with the driver. In about every tenth case the right rear seat (2nd row) was occupied. Left rear seats show slightly smaller occupation rates, which is a result of the right hand traffic in Germany. As there are only few vehicles in the market having three seat rows, the occupation rates are very small there. Additionally, Table 3 shows the common configurations in passenger cars in Germany.

Table 3.
Occupation configurations in passenger cars

Configuration	Occu-pants	Share
Driver only	1	63,2%
Driver + front passenger	2	24,6%
Driver + 1 RSO (rear seat occupant)	2	1,6%
Driver + front passenger + 1 RSO	3	5,7%
Driver + 2-3 RSO	3 - 4	1,0%
Driver + front passenger + 2-3 RSO	4 - 5	3,6%
Other constellations	–	0,3%

The most frequent case is a person driving alone in the car. Traffic surveys show that this fact becomes more and more relevant. In 2002, the passenger rate in cars was around 46%. In 2008, this value decreased to 35%, which correlates very well with the accident data from GIDAS. One possible reason is that many households can afford two cars and so, more people drive alone.

In every fourth case, only a front passenger accompanies the driver. The third most frequent configuration is a driver, a front passenger and one rear seat occupant (e.g. a family with one child). All other configurations are not very relevant.

However, it has to be mentioned that the occupation rates in Germany are slightly biased due to the sampling criteria (accidents with personal damage only). In GIDAS, there is a shift towards more passengers. Consequently, the presented occupations rates may be slightly overestimated.

As a result it can be stated that the occupation rates of rear seats are quite low. Additionally, many of the occupants on rear seats are children having their own additional Child Restraint System (CRS). So, restraint systems for rear seats are not required very often.

Belt use Another important aspect for the evaluation of restraint systems is their use. Belts will have no restraint effect at all if they are not used. The protection potential is also limited if belts are not used correctly (e.g. due to misuse, wrong belt routing, out-of-position etc.). Thus, the first goal must be the increase of belt usage rates to 100%. The traffic surveys that the BASt is doing periodically shows that the belt usage rates in Germany are already on a high level and even increase further. However, there is a difference between several seats – often rear seat passengers show lower belt usage rates.

It has to be mentioned that belt usage rates in accident databases are mostly biased towards lower values than in the overall traffic. This is because accidents are not in these databases if the restraint system was used and managed to avoid all injuries.

However, Figure 12 (made with GIDAS data for adult occupants in several periods in the last 15 years) confirms the general trend in Germany. The overall belt usage rate is still increasing for all occupants (orange bars) and reached around 96%. Rear seat occupants (red bars) show a remarkable increase since the early 2000s. Drivers (blue) and front passengers (green) show very similar rates.

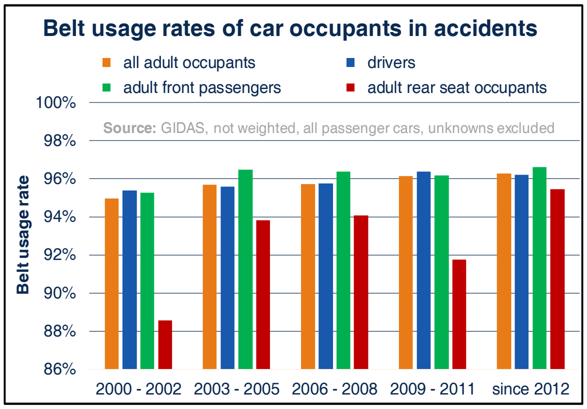

Figure 12. Belt usage rates of car occupants in accidents (based on GIDAS data)

For the analysis, all car occupants with a known belt status were used. This may lead to a slight bias, as the actual belt status could not be investigated for some occupants. Therefore, unknowns were more likely "not belted" persons, as the investigation teams could not find any marks or corresponding injuries.
Independent from this methodical particularity it is clearly visible in the data that unbelted persons show higher injury severities. The comparison of the injury severity of drivers and front passengers in frontal crashes with a delta-v of 15kph or higher shows the following results:

Table 4.
Injury severity vs. belt usage rates (Front crash, PDoF = 10/11/12/1/2, delta-v ≥ 15 kph)

Injury severity	n	Belt usage rate
Not injured	1,683	97.1%
Slightly injured	2,533	91.3%
Seriously injured	874	85.8%
Fatally injured	35	68.6%

INFLUENCING PARAMETERS ON OCCUPANT'S INJURY SEVERITY

The focus of the main part of this study is on influencing parameters that determine the injury severity of car occupants. The experience of many years in research confirms that generally many aspects influence the occupant's injury severity. Figure 13 shows a selection of such parameters.

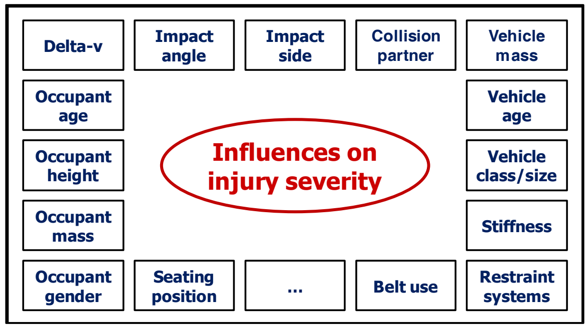

Figure 13. Selection of influence parameters on occupant's injury severity

However, this is by far not the entire list of influencing variables. In general, there are four main groups of parameters:

- crash data
- vehicle characteristics
- individual parameters of the occupant
- situational conditions

A big challenge for researchers is to evaluate and quantify the contribution of every parameter as univariate analyses are out of the question for this really multidimensional aspect. So, only multi-variate methods are useful to address this issue.

The scope of this paper are individual parameters and restraint systems. Thus, not all parameters mentioned in Figure 13 are analysed in detail. For the study, the following three aspects are chosen to address the research questions mentioned in the abstract above:

- influence of different belt systems
- influence of occupant's age
- influence of occupant's height

Multivariate logistic regression models were used. Therefore, GIDAS provides sufficient data, which is one substantial requirement for robust results. For some aspects, additional descriptive statistics with subsamples were created.

Influence of different belt systems

At first, the important question is answered which effect current restraint systems have in real accidents. It was already shown in Table 4 that the use of restraint systems (here: belts) will significantly decrease the chance of being seriously or even fatally injured. This is due to the facts that belted occupants will not be ejected out of the car and will be protected from having substantial impacts with the car's interior.

Another aspect is the performance of different belt systems in terms of injury severity reduction. Therefore, a multivariate logistic regression was done to eliminate the influence of some parameters and to get an impression of the "actual" difference between several systems. The program SPSS® was used to calculate the logistic regression models. The following filters were applied to the data:

- only injured car occupants
- occupant age > 14 years
- belted occupants only

Figure 14 shows the result of the logistic regression. The four curves show the risk of being MAIS2+ injured in a frontal crash for a 40-year-old belted occupant depending on the type of belt system. The highest risk comes from a standard 3-point-belt. Belts with load limiters or pretensioners already reduce the risk of serious injuries. The best performance is derived for 3-point-belts with load limiters and pretensioners. The risk difference between the last mentioned and a standard belt at a delta-v of 50kph is around 10%.

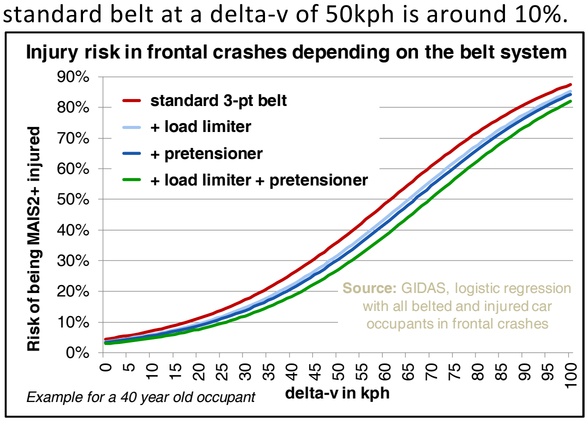

Figure 14. Injury risk in frontal crashes depending on the belt system

The result is admirable as there are so many influencing parameters (see Figure 13) and in the model, only the delta-v, the age, the gender, and the belt system were used. Nevertheless, the influence of several belt systems can be seen and the results are plausible.

Influence of the occupant age

It is well known that the impact severity (e.g. represented by the delta-v) has the highest influence on the outcome in case of a crash. However, another crucial parameter substantially influences the injury severity – the occupant age. The physical constitution of humans is changing over time. The older people become the higher is their vulnerability. This has a big effect in accidents and also for the dimensioning of restraint systems.

Again, multivariate regression models were used to estimate the age influence in frontal crashes. Here, some other filters were applied to the data to create comparable conditions (e.g. only "modern" cars registered in 2000 or later to ensure a similar minimum level of passive safety).

Figure 15 shows the result of the logistic regression based on curves for 30 and 70 year old male occupants. (Age was used as metric variable within the models.) It can be seen that the risk of being at least seriously injured differs between the two age groups. Additionally, the effect of belt use is displayed in the diagram (dotted lines).

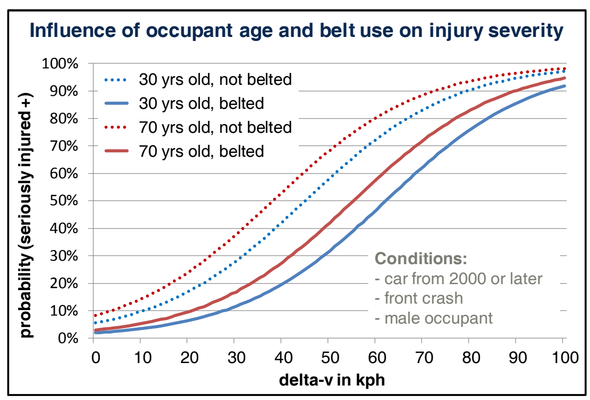

Figure 15. Influence of occupant age and belt use on injury severity

From previous studies the authors know that the age influence is especially relevant in frontal (and side) crashes. In rear crashes, there are other injury mechanisms and the age effect is not that high. Thus, restraint systems play an important role for elderly occupants.

In general, there is a conflict between the necessity of restraining the occupant (preferably high belt forces) and the physical limits of vulnerable elderly occupants (preferably low belt forces). The challenging task is to find a compromise between both aspects. However, a higher age will most likely lead to more severe injuries, especially in the body regions that have contact with the belt (thorax, abdomen).

To prove this, a comparison with GIDAS data is done, analyzing the occurrence of belt-induced injuries. Therefore, the "injury causing/impacted part" is used that is coded for every single injury. It has to be mentioned that the belt as injury causing part means that the injury was caused by the restraint effect whilst the probability of more severe injuries would be higher without a belt.

Figure 16 illustrates the share of occupants that suffered a belt-induced injury for several age groups. The corresponding collisions were frontal crashes with a delta-v of not more than 50 kph (to exclude very severe collisions). The basis are all injured persons (exclusion of uninjured occupants) and the bars show how many percent of these occupants suffered at least one belt-induced injury. (Occupants aged 90 years or older are very seldom so that the case numbers are very low.)

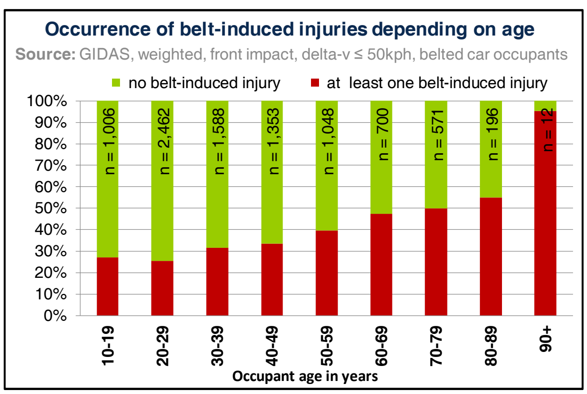

Figure 16. Occurrence of belt-induced injuries depending on the age (AIS1+)

The diagram already shows very clearly how the risk of suffering a belt-induced injury increases with the age. In frontal crashes with a delta-v of up to 50 kph every second elderly (aged 60+) occupant is injured by the restraint system.

Fortunately, most of the relevant injuries are contusions of the thorax and/or abdomen with an AIS1. The next analysis is focusing on more severe injuries to check if this effect is still present.

Figure 17 shows the same issue but for belt-induced injuries of the severity AIS2+.

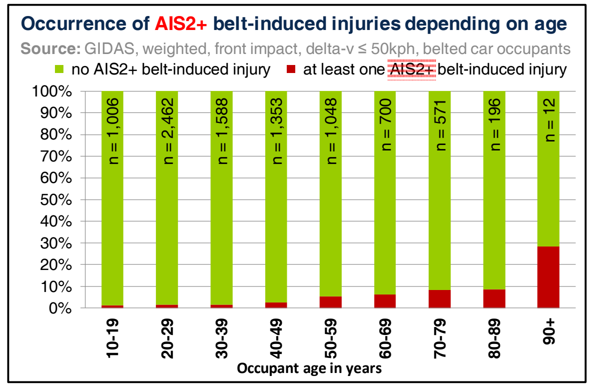

Figure 17. Occurrence of belt-induced injuries depending on the age (AIS2+)

The diagram shows that belt-induced injuries are mostly very slight. The share of persons with an AIS2+ belt-induced injury is very low. However, there is again an increase of this share when the occupant's age increases. Typical AIS2+ injuries are rib fractures, lung contusions, sternal fractures, spleen ruptures or even pneumothoraxes, and haemopneumothoraxes.

Finally, it can be stated that age is one of the most influencing parameters for the injury severity of car occupants. This is especially true for front impacts where restraint systems play an important role.

Influence of the occupant height

One research question in this study was if all car occupants equally benefit from available systems independent of their individual characteristics. The results of the previous chapter already confirm that elderly occupants show higher injury severities than younger persons and that current belt systems are maybe too aggressive.
Now, another individual parameter is analysed with regard to the restraint/protection effect – the occupant's height. Therefore, only drivers are considered, as they are the critical group of occupants in the front crash. Front passengers mostly have enough space between the body and the dashboard as they do not have to adjust the seat. The expectation says that small drivers are sitting closer to the steering wheel and dashboard. Consequently, they will be injured more severe/often in case of a frontal impact.

To check this thesis, descriptive statistics are done with GIDAS data, comparing small (height <170cm) and tall (height ≥ 170cm) drivers.

In the first analysis, the overall injury severity of small and tall persons are compared with each other. To eliminate the influence of the crash severity, the shares of MAIS2+ injured drivers are displayed for several delta-v groups so that both height groups can be easily compared. Unbelted drivers were excluded for the analysis. Figure 18 shows that there are no obvious differences between the injury severity of small and tall drivers of passenger cars. This is true for this kind of analysis when all other influences are left out.

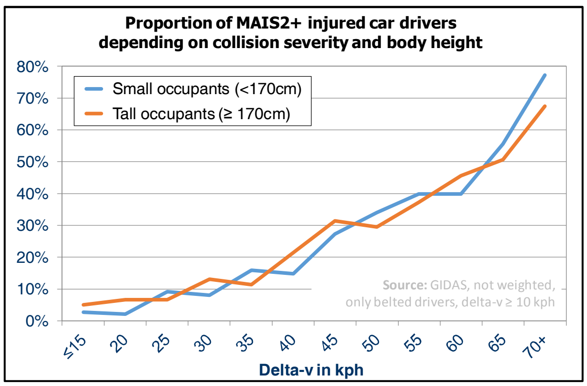

Figure 18. Proportion of MAIS2+ injured car drivers depending on collision severity and height

However, the different seating positions should result in different injury mechanisms. So, the second analysis deals with the frequency of several injury causing parts for AIS2+ injuries. Figure 19 shows the result of a univariate analysis for the body region "lower extremities".

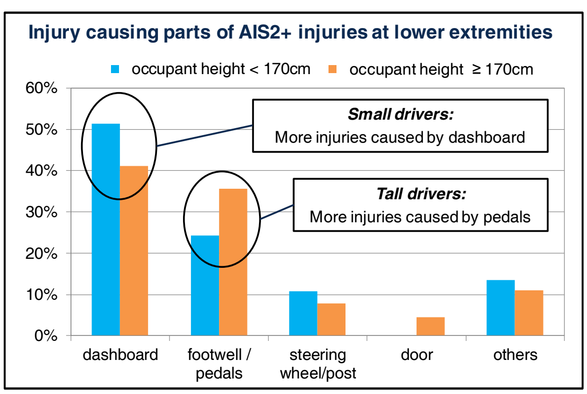

Figure 19. Injury causing parts of AIS2+ injuries at lower extremities

As expected, small drivers suffer more AIS2+ injuries caused by the dashboard and steering wheel (post) whilst taller drivers show higher proportions of injuries caused by the footwell/pedals.

The interpretation of such univariate analyses is difficult, as the body height seems not to be the only influence causing the obtained results. A large interference of many aspects is very likely. One example is the relation between height, gender and vehicle class: Small persons are often females as they are significantly smaller than males. Women often drive in urban areas and less often on highways. Furthermore, they drive in smaller/compact cars whilst men own/drive bigger/heavier cars.

Thus, multivariate methods are necessary. Therefore, logistic regression models are calculated for car drivers in frontal crashes, considering the following parameters:

- delta-v
- age of the driver
- gender of the driver
- height of the occupant
- model year of the car (grouped)
- vehicle class

The logistic regression models show that the parameters have different influences on the injury severity (dependent variable = MAIS2+: yes/no). In table 5 the parameters are sorted by significance, starting with the most influencing variables.

Table 5.
Influence of several parameters on the injury severity of car drivers in frontal crashes

Parameter	Influence
delta-v	yes, highly significant
driver age	yes, significant
vehicle segment	yes, significant
vehicle age	yes, significant
gender	yes, not significant
height	no

It can be seen that the occupant height had no further significant influence on the prediction quality after the other parameters were added to the models.

SUMMARY

At the beginning of the paper, the current situation of restraint systems as described. Then, several influencing parameters on the injury severity of car occupants were listed. Two of them, namely the age and height, were analysed in detail. Additionally, current restraint systems (especially belts) were analysed regarding their effect in real world accidents.

The results for Germany are (in brief):

- The equipment rates with airbags und advanced belt systems (with load limiters and pretensio-ners) are increasing for drivers and front passengers.
- Rear seats are not equally equipped with belts and airbags like front seats.
- The occupation rate on rear seats is quite low and becomes even lower over time.
- Drivers and front seat passengers become older.
- The German passenger car fleet is also ageing and 9.3 years old in 2017.
- The belt usage rates are already on a high level and still slightly increasing.
- Rear seat occupants show slightly lower belt usage rates.
- Belt use is a key factor for the occupant protection. Many seriously and fatally injured persons were not belted.
- The occupant age is – after the crash severity – the most influencing parameter for the injury severity.
- The occurrence of belt-induced injuries is increasing with the occupant’s age.
- The occupant height seems to have no remarkable influence on the injury severity.

OUTLOOK

The analysis shows that current restraint systems are already working well and protect occupants better than previous systems did. Three-point-belts with load limiters and pretensioners show a good performance. However, the strong influence of the occupant age in combination with the demographic change in many countries and the ageing occupant population underline the future necessity of adaptive restraint systems.

In many cases the restraint system seems to be too aggressive which is obviously a consequence of the challenging requirements for restraint systems.

Most of the crashes, which result in at least one injured car occupant, occur at relatively low delta-v values. Around 90% of injured car occupants that suffered a front crash had a delta-v of not more than 50 kph. This is maybe one approach to reduce belt forces by using more available forward displacement of the occupant.

Additionally, the introduction of AEB systems and autonomous driving functions will lead to more situations where the driver and/or passengers are not aware of a sudden braking action by the car. So, more occupants than today will already be in a forward movement at the moment of the crash as long as they are not fixed to the seat by reversible pretensioners. Here, predictive systems are necessary that are able to condition the occupant already before the crash.

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