# SAFETY IN SMALL AND LARGE PASSENGER CARS

- The Compatibility Problem in Head-On Collisions -

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## 1. INTRODUCTION

Road accidents may involve collisions between vehicles of different weights under a variety of circumstances. It is rare for vehicles of equal weight to collide. The range of vehicle curb weights (masses) extends from less than 700 kg (e.g. VW Polo) to over 1,600 kg (e.g. Daimler Benz, S class). In accordance with the impact laws of mechanics, the consequences of collision involving smaller and larger vehicles are mostly more serious for the driver and passengers of the smaller vehicle. In the past, it has not always been possible to completely quantify the seriousness of accidents or the risk of being injured or killed in Germany because there is no direct link between vehicle mass and the seriousness of passenger injuries. All that is available at present is a study by an insurance association [5] based on single accident cases. This analysis covered front-seat passengers using seat belts as well, but not only the drivers.

An American study [7] estimate the risk of being killed in an accident in a small car (subcompact) very generally as being 8 times higher than the risk in a larger vehicle (full-size car). Examining cars of different masses and of equal masses involved in accidents (comparison between vehicles weighing 900 kg and vehicles weighing 1,600 kg), in [4], on the basis of the FARS (Fatal Accident Reporting System), note a ratio of 2:1 for the risk of being fatally injured in a small car as against the risk of being fatally injured in a larger vehicle. However, the results of US studies cannot always be translated to European conditions, since America's car population is quite different from the European on account of the large number of extremely large vehicles on US roads.
A Swedish study by FOLKSAM Insurance - which also included single-car accidents - found that drivers of 800 kg vehicles have an injury frequency twice as high as that of 1,400 kg vehicles [6].

Following an evaluation of the accident data for North-Rhine/Westphalia now available for research purposes and extended to include automotive features, it is now possible to obtain results for the "compatibility" problem in Germany and in the car population involved in accidents here. The study is concerned with the seriousness of injuries focused to car drivers involved in accidents with oncoming traffic.

## 2. PHYSICAL AND AUTOMOTIVE ASPECTS OF THE "COMPATIBILITY" PROBLEM

The seriousness of accidents can be described using the impact laws of mechanics; one measure is the "change of velocity" in the accident.

In the standard impact test against a rigid barrier, the deformation behaviour of the vehicle front is examined, and the protection afforded against serious injuries measured. Still, although impact against the rigid barrier is a well established testing procedure, it

does constitute a special case in the real accident world. Where a vehicle drives into a rigid barrier at e.g. 50 km/h, kinetic energy is transformed to deformation of the vehicle front. The vehicle undergoes a 50 km/h change of velocity.

To ensure optimal transformation of impact energy into work of deformation, the stiffness of the front is designed in such a way that, to meet the safety standard FMVSS 208, which provides for an impact at 30 mph (48 km/h) against a rigid barrier, advantage is taken of the max. deformation path of approx. 50 to 60 cm of the vehicle front, and also that the survival area in the vehicle cell is not destroyed. The vehicle structure, i.e. primarily the stiffness of the front side member, is optimated to this standard. This keeps the mean deceleration of the vehicle and its passengers (using seat belts) within limits. Where a large vehicle has, e.g., double the mass of a smaller vehicle, double the kinetic energy must be destroyed. This means - assuming the same front length (deformation distance) - double hardness for the front structure (stiffness), or - assuming the same stiffness of the front (force level) - double the length of front (or a combination of these two options).

Where two vehicles are involved in a head-on crash - for the sake of clarity, only head-on collisions are considered here - the change of velocity in the two vehicles results from the law of conservation of momentum applying to a plastic impact. This means - to remain with this example - in the case of an impact of 30 mph per vehicle and an assumed ratio between large vehicle mass and small vehicle mass of $m_L:m_S=2:1$, that the large vehicle continues driving in its direction at 10 mph, while the smaller car is reversed and is pushed back by the larger vehicle at a speed of 10 mph. The large vehicle undergoes a 20 mph change of velocity, the small vehicle one of 40 mph. We have a double change of speed in the smaller vehicle, whose normally softer structure must absorb double the energy.[1)]

Now, it is also possible to optimize vehicle fronts for a collision involving two moving vehicles, i.e. not a wall crash (self-protection) but a collision between vehicles of different size (partner protection). The collision tolerance involved here is called compatibility. The design for the fronts of "compatible" vehicles would have to look as follows:

The small car must share the deformation of the larger vehicle. This can be done by choosing different stiffness characteristics (soft, medium, hard) or a linear increase in the stiffness characteristic for the front of the larger car, at the same time taking advantage of what will normally be greater front length and also a stiffer design in the front of the smaller car.

If these two vehicles - now designed for compatibility - collide, first of all the stiff front of the smaller vehicle crushes the soft section of the front of the larger vehicle. In the process, the kinetic energy of the small vehicle is absorbed by the large vehicle. After that there is an even deformation of both vehicles.

Now, however, there are drawbacks in the 30 mph impact test against the rigid barrier described earlier for both vehicles. The small vehicle has been given a stiffer front design; as a result, the entire possible deformation path is no longer deformed; the mean deceleration and, hence, the strains on the occupants are higher. The large vehicle "gives away" opportunities for intaking energy. And although the choice of different degrees of stiffness can deal with the impact of 30 mph against the rigid wall thanks to the longer front, a constant choice of stiffness and optimation of stiffness to cope with the barrier impact might have allowed the occupants to survive an impact involving a speed of perhaps 35 mph without serious injuries. So far, vehicle stiffnesses have not yet been optimized for the protection of people. However, there are approaches to solutions, e.g. in [3].

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1) A double change of velocity normally means quadrupling the kinetic energy to be absorbed. However, this value is halved again, since the distribution of masses is 2:1 as indicated above.

## 3. EMPIRICAL ANALYSES

### 3.1 Data base

In 1985, there were 77,009 accidents involving personal injuries between two cars in the Federal Republic of Germany. Out of these, 15,207 accidents with a total 28,757 casualties were accounted for by accident type "Collision with an oncoming vehicle". 686 of a total of 4,182 killed car occupants lost their lives in this accident type.

This analyses are based on data for accidents involving personal injuries and serious car damage for the State of North-Rhine/Westphalia, supplemented by automotive technology data available at the Federal Road Traffic Agency (Kraftfahrt-Bundesamt) [1]. Attention was paid in particular to the consequences of accidents for **car drivers** in accidents involving two passenger cars (station wagons excluded) with an car age of less than 10 years.

The risk of injury for car occupants depends very much on whether seat belts were used. The rate of seat belt use on front seats of cars averaged 60 % until the introduction of fines in August 1984, since when, the rate has been over 90 %. In order to rule out possible distortions owing to the different rates, this study is confined to accidents occurring between August 1984 and December 1988.

In order to target the problem of compatibility with the available data, the following remarks only concern accidents of type "Collision with an oncoming vehicle". By definition, therefore, the accidents to be considered here are collisions involving oncoming traffic without, e.g., one party intending to turn off to the left.
In the period under review the accidents of this type in North-Rhine/Westphalia totalled 17,612.

### 3.2 Study hypotheses

Compatibility problems always occur when large vehicles collide with smaller vehicles. The two main factors are:
- different vehicle structure optimized for self-protection
- different "mass aggressiveness" of vehicles of different weights.

This gives us the following two hypotheses:

**Hypothesis 1:** Differences in vehicle structure and "mass aggressiveness" mean that the consequences of an accident are **less favourable** for the occupants of the **smaller** and correspondingly **more favourable** for those in the **larger vehicle.**

**Hypothesis 2:** Where the vehicles have the same structure and "mass aggressiveness", this means that a head-on collision involving **two small vehicles** may be expected to have the **same consequences** as a head-on collision involving two **large vehicles.**

### 3.3 Characteristics for assessing the seriousness of injuries

The central question concerns the extent to which the probability of serious consequences for the car occupants depends on vehicle size. Since considerable variations are possible in the number and seating position of co-driver and passengers, our study is confined only to drivers and to the consequences for them.

For this study, the characteristic to indicate the mean seriousness of injuries to drivers involved in head-on collisions between two cars is the share of fatalities and serious

casualties among all drivers involved in accidents with personal injuries and serious material damage is chosen:

$$AS = \frac{\text{number of fatalities + seriously injured drivers}}{\text{number of drivers in AI and AD}}$$

AI = accidents with personal injuries
AD = accidents with serious material damage

With regard to this specific characteristic the statistically significant variable of whether the driver felt "guilty" or "not guilty" does not have to be taken into account in the statistical analysis (cf. [2]).

### 3.4 Classification by weight classes

For the purposes of the present analysis, the vehicle population is subdivided by curb weight into four weight classes and the distribution is shown in Table 1.

Class 1: car with an curb weight of 600 to 799 kg,
Class 2: car with an curb weight of 800 to 999 kg,
Class 3: car with an curb weight of 1,000 to 1,199 kg,
Class 4: car with an curb weight of 1,200 to 1,599 kg.

Table 1: Cars involved in head-on collision between two cars in North-Rhine/Westphalia in the period 1 Aug. 1984 to 31 Dec. 1988, classified by curb weight (accidents with personal injuries and serious material damage)

| Curb weight [kg] | Cars involved | |
|---|---|---|
| | Number | % |
| 600 to 799 | 3,076 | 8.9 |
| 800 to 999 | 14,037 | 40.6 |
| 1000 to 1199 | 9,795 | 28.3 |
| 1200 to 1599 | 7,683 | 22.2 |
| Total | 34,591 | 100.0 |
| up to 599 / 1600 and more | 615 | |
| not known | 18 | |

### 3.5 Other determinants

Alongside the vehicle features "vehicle structure" and "mass aggressiveness", there are other important factors - e.g. velocity, age of occupants, etc. - which may have a more or less favourable impact on the consequences of the accident for the occupants.

One factor of special importance for the consequences as they affect the occupants involved in a head-on collision is the speed at which the vehicles collide. The data material available for the present analysis does not explicitly include this feature, although we do know that the permissible max. speed and the mean speeds actually driven "inside built-up areas" are definitely below the values "outside built-up areas without autobahns"

(rural roads). Alternatively, therefore, the factor "speed" is considered as explanatory variable via the feature "locality".

Also included in the analysis as a further explanatory variable is "driver age", since the seriousness of injuries under the same arcumstance is, greater in the case of elderly people. On the other hand, accidents involving younger drivers tend to correlate with excessive speeding.

In a consideration of collision compatibility, vehicle age is important for two reasons:
- old vehicles tend to be heavier and stiffer, which leads to special problems when a "light new" vehicle collides with an "old heavy" vehicle;
- older vehicles have, normally a higher degree of corrosion than newer vehicles, so that the accident may have different consequences for the occupants.

This was the reason to include only accidents with passenge cars of less than 10 years age.

### 3.6 Variables used in the study

In line with the remarks contained in Sections 3.2 to 3.5, the analysis uses the following features as independent variables (for dependent variables, see Section 3.3):

Curb weight class of the car under consideration (CAR1) or the other car (CAR2)

(1) 600 to 799 kg
(2) 800 to 999 kg
(3) 1,000 to 1,199 kg
(4) 1,200 to 1,599 kg

Locality (L)

(1) inside built-up area
(2) outside built-up area without autobahn (rural roads)

Age of driver in car under consideration (A)

(1) under 25 years
(2) 25 to 59 years
(3) 60 years and older

## 4. THE STATISTICAL ANALYSIS METHOD

The counting of the fatalities and serious casualties for car drivers involved in head-on car crashes according to two or more variables produces a multi-dimensional matrix. The more variables are considered and the more categories the variables have, the more difficult it is - without adequate analytical procedures - to identify the relevant structures and to distinguish essential influences from the inessential. This is specially true where the occupation of the cells in the multi-dimensional matrix shows considerable variation, i.e. if the matrix has cells with a high as well as cells with a very low occupation frequency.

Statistical procedures based on logit models enable essential determinants to be identified using a multi-dimensional matrix; distinctions can be made between significant and non-significant determinants. Non-significant determinants can be excluded from the analysis, i.e. unlike a "conventional" evaluation involving a splitting up into multidimensional matrices, the use of logit models allows parameters to be excluded wherever they are not statistically significant on the basis of empirical data [2].

## 5. RESULTS

### 5.1 Influence of "locality"

The variable "locality" has, as expected, a very great influence on the mean seriousness of injuries to drivers involved in head-on collisions between two cars.
The percentage of fatalities and serious casualties among drivers (relative to all drivers involved in accidents with personal injuries and serious material damage) is about three times higher in the case of head-on collisions between two cars on rural roads than in built-up areas.
The inference is that the high mean seriousness of injuries on rural roads is basically statisticaly independent of the curb weight of one's own car and of the curb weight of the other car. Thus, the variable "locality" acts as a constant factor on the mean seriousness of injuries; the relative increase in the percentage of fatalities and serious casualties among drivers is equally high for all "curb weight classes".
In view of the high explanatory value of the variable "locality" accounting for the percentage of serious consequences, this variable is further considered again in the model.

### 5.2 Influence of driver age

The independent variable "driver age" has only a comparatively slight imfluence on the mean seriousness of injuries from head-on collisions. Of the three categories of the main effect, only the third category "drivers aged 60 years and more" is significantly different from 0 ($\alpha < 0.05$) and has a positive sign. This means that the percentage of fatalities or serious casualties among "old" drivers involved in head-on collisions is higher than the percentage of young drivers or middle-aged drivers. The absolute amount of this estimated value is small, however, relative to the values of the other parameters in the model, especially the "locality" variable.

Since no interactive effects significantly different from 0 occur between the three categories of the feature "driver age" in the car under consideration and the other parameters contained in the model, the inference is that a higher mean seriousness of injuries can only be established for older drivers, regardless of locality and the weight of one's own car and the weight of the other car.

An additional study of the connection between car driver age and car weight has shown that the percentage of older drivers increases markedly with the curb weight. In order to avoid any distortions to the results from a correlation between these two variables, the analyses in the following Sections ignore drivers aged 60 and older.

As was already established, the same accident consequences can be expected for young and middle-aged drivers involved in head-on collisions between two cars. Thus, if we ignore older drivers, the feature "age of driver of car considered" need no longer be considered in the analysis.

## 5.3 Seriousness of head-on crashes involving two cars as a function of weight

Before dealing with the question of the collision compatibility of cars in the following Sections, the present Section examines the mean seriousness of injuries to drivers involved in head-on crashes between two cars as a function of the weight of one's "own" car; the weight of the "other" car is left out of account in this first analysis.
Fig. 1 shows a curve for the mean seriousness of injuries to drivers involved in head-on crashes between two cars that falls with the curb weight of the car. The seriousness of the consequences fall substantially with the rise in the weight of the car under consideration. The percentage of fatalities and serious casualties among drivers of cars with 600 kg curb weight is 14.2 %; and that for drivers in cars with an curb weight of 1,500 kg is 4.8 %.

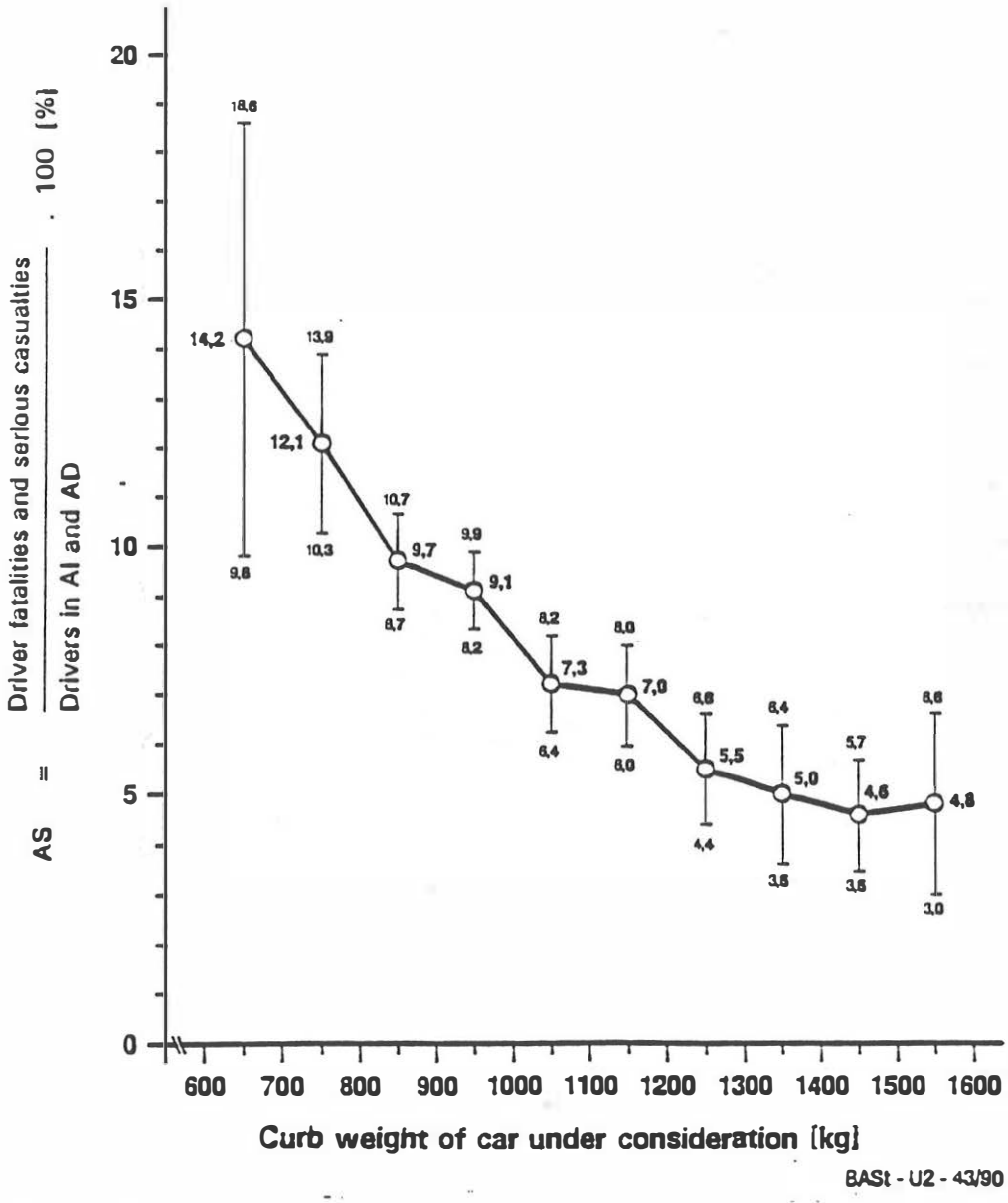


Fig. 1: **Seriousness of head-on crashes involving two cars on rural roads as function of the curb weight of the two cars (driver age up to 59 years)**

## 5.4 Compatibility in a consideration of four weight classes

To describe the collision compatibility of cars, a model is estimated in what follows that takes as independent variables the feature "locality" and the car under consideration and/or the other car (each in four weight classes). The dependent variable considered is the percentage of fatalities and serious casualties among drivers relative to all drivers involved in accidents with personal injuries and serious material damage (AS).
Using this model, we can estimate expected values for the seriousness of accidents and the relevant confidence intervals for all covariable constellations. Fig. 2 shows the results for the rural road sector.
In the following the two hypotheses for the collision compatibility of cars involved in head-on collisions described above were tested (see Annex Table A1 and A2 and Fig. 2):

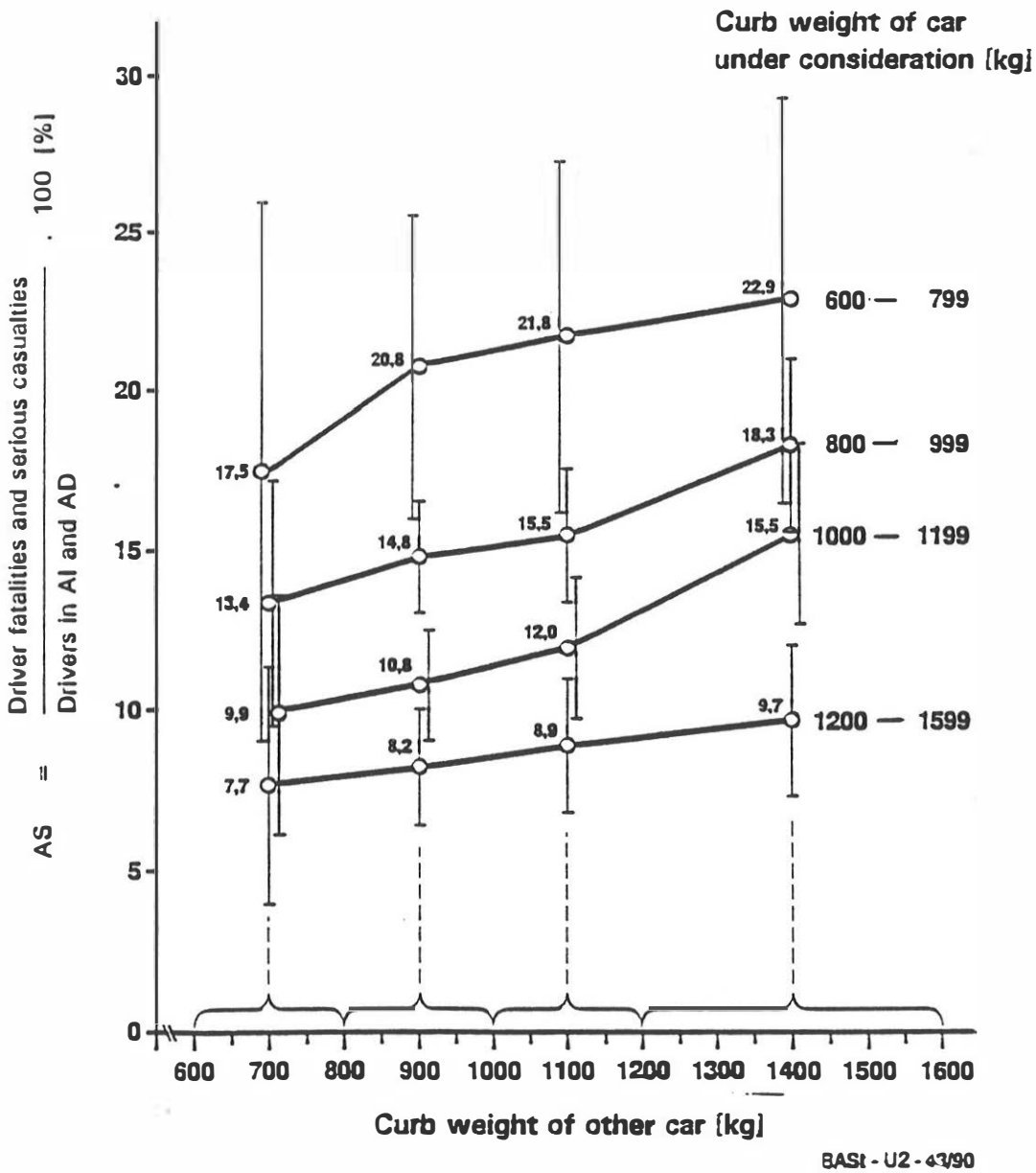


Fig. 2: **Compatibility - expected values for the seriousness of accidents in head-on crashes involving two cars on rural roads, as function of the curb weight of both cars (driver age up to 59 years)**

**Hypothesis 1** says that, in accidents involving cars of different weight, **different "mass aggressiveness"** can lead to more serious consequences of the accident for the occupants of the smaller and correspondingly less serious consequences for those in the larger vehicle.
This hypothesis can only be maintained partly:

- Fig. 2 makes it clear that seriousness of the consequences of the accident for the driver is related quite definitely to the curb weight of his own car. The consequences for drivers in cars with an curb weight of 600 to 799 kg are - regardless of the weight of the other car - some 2.5 times less favourable than for drivers of cars with an curb weight of 1,200 to 1,599 kg.
  On rural roads, for example, the expected value for the percentage of fatalities and serious casualties among drivers in cars with an curb weight of 600 to 799 kg in the case of head-on collisions with a car of 800 to 999 kg curb weight is 20.8 %, with a car of 1,200 to 1,599 kg curb weight 22.9 %; the corresponding expected values for drivers in cars with an curb weight of 1,200 to 1,599 kg, however, are only 8.2 % (weight of other car 800 to 999 kg) and 9.7 % (weight of other car 1,200 to 1,599 kg) resp.
- Within the various curb weight classes, however, hypothesis 1 can be confirmed in principle; it can be seen, e.g., that, in the case of drivers of cars with an curb weight of 800 to 999 kg involved in head-on collisions with a smaller car (600 to 799 kg weight), the consequences for the car with 800 to 999 kg curb weight are much less serious (13.4 %) than in the case of a head-on collision with a heavier car (1,000 to 1,199 kg curb weight 15.5 % and 1,200 to 1,599 kg curb weight 18.3 %).

**Hypothesis 2 - equal "mass aggressiveness"** - viz. that the consequences of a head-on collision between cars of equal weight classes are approx. the same for the occupants, cannot be confirmed. In fact, Fig. 2 shows that the seriousness of the consequences for the driver depends quite substantially on the curb weight of his own car. The values of the characteristic for the seriousness of injuries AS fall strikingly as the weight of the car under consideration increases. The expected value for the percentage of fatalities and serious casualties among drivers in head-on collisions involving two cars with an curb weight of 800 to 999 kg is 14.8 %; in head-on collisions involving two cars with an curb weight of 1,200 to 1,599 kg, the figure is 9.7 %.

## 6. SUMMARY, DISCUSSION OF THE RESULTS

Head-on crashes between cars are particularly serious. Where large and small vehicles collide, physical theory leads to expect compatibility problems. The main factors regarded as underlying the special collision intolerance of vehicles of different sizes are the different vehicle structures optimized for self-protection and the different "mass aggressiveness" of vehicles of different weights.

In 1985, there were 77,009 accidents involving personal injuries between two cars in the Federal Republic of Germany. Out of these, 15,207 accidents with a total 28,757 casualties were accounted for by accident type "Collision with an oncoming vehicle". 686 of a total of 4,182 killed car occupants lost their lives in this accident type.

The analysis undertaken in this report is based on the data for accidents involving personal injuries and serious material damage in the State of North-Rhine/Westphalia, supplemented by automotive data available at the Federal Road Traffic Agency. In order to rule out any distortions due to differences in rates of seat belt use, the study is confined to accidents occurring after August 1984. Since then, the rate of seat belt use in the Federal Republic has averaged well over 90 %.
The vehicle population was broken down by curb weight into four weight classes.

The assessment criterion in the statistical analysis was the mean seriousness of injuries to drivers involved in head-on collisions between two vehicles. The independent variables considered in addition to the features "curb weight class of the car under consideration" or "of the other car" were the features "locality" and "age of the driver of the car under consideration".

The statistical analysis was made using logit models, which enable the key determinants to be identified and their impact quantified within the scope of multi-dimensional analysis.
As expected, the feature "**locality**" has a great impact on the mean seriousness of injuries to car drivers involved in collisions with oncoming cars; regardless of curb weight class of the vehicle, the consequences of accidents for drivers on rural roads are ***about three*** times less favourable than in the case of built-up areas.
The feature "**age of driver in the car under consideration**" has a comparatively slight impact on the mean seriousness of injuries to drivers involved in head-on collisions between two cars. In the case of older drivers, however, there is in fact a higher mean seriousness of injuries, regardless of locality and the curb weight of their own or the other car.

Study hypothesis 1, viz. that **different "mass aggressiveness"** in accidents involving cars of different weights produces more serious consequences for the driver of the smaller car - and correspondingly less serious consequences for the driver of the larger vehicle - were only confirmed with reservations.
Study hypothesis 2, viz. that **equal "mass aggressiveness"** produces approx. the same consequences for car occupants in head-on collisions involving cars of the same weight, was not confirmed.

In fact, the empirical analysis showed that the seriousness of the consequences for drivers was associated on average and quite significantly with the **curb weight** of the driver's own car. The mean seriousness of injuries is some ***2.5 times*** as high for small cars or for cars with a weight between 600 and 799 kg - regardless of the weight of the other car - as it is for large cars or for cars with an curb weight between 1,200 and 1,599 kg.

Thus, there must be other factors operating to explain why safety is very much greater for the occupants of large vehicles than it is for small vehicles. One possible explanation is that the interior appointments of large - and hence more expensive - cars offer more scope for the use of safety-enhancing features. For example, the use of energy-absorbing materials in the interior (e.g. dashboard), the installation of safety steering wheels, etc. is easier to implement cost-wise for large cars than it is for small cars.
Differences in car safety for different cars within each weight class cannot be made by means of the data base used for this study.

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# ANNEX

Table A1: Expected value for seriousness of accidents involving car drivers in head-on crashes between two cars **inside built-up areas** as a function of four curb weight classes (Accidents with personal injuries and serious material damage; driver age up to 59 years)

| Curb weight of considered CAR1 | Curb weight of other CAR2: 600 to 799 kg (1) | | 800 to 999 kg (2) | | 1000 to 1199 kg (3) | | 1200 to 1599 kg (4) | |
|---|---|---|---|---|---|---|---|---|
| | AS[1] | confidence-limits[2] | AS[1] | confidence-limits[2] | AS[1] | confidence-limits[2] | AS[1] | confidence-limits[2] |
| 600 to 799 kg (1) | 5.5*) | 8.2<br>2.8 | 6.7 | 8.3<br>5.1 | 7.1 | 8.9<br>5.3 | 7.5 | 9.6<br>5.4 |
| 800 to 999 kg (2) | 4.1 | 5.2<br>2.9 | 4.5 | 5.1<br>3.9 | 4.8 | 5.5<br>4.1 | 5.8 | 6.7<br>4.8 |
| 1000 to 1199 kg (3) | 2.9 | 4.0<br>1.8 | 3.2 | 3.7<br>2.6 | 3.6 | 4.3<br>2.9 | 4.8 | 5.7<br>3.9 |
| 1200 to 1599 kg (4) | 2.2*) | 3.3<br>1.2 | 2.4 | 2.9<br>1.8 | 2.6 | 3.2<br>2.0 | 2.8 | 3.6<br>2.1 |

1) AS = percentage of fatalities and serious casualties relative to all drivers involved in accidents with personal injuries and serious physical damage

2) 95 % confidence interval

*) In the constellation, fewer than 10 fatalities or serious casualties were recorded

Table A2: Expected value for seriousness of accidents involving car drivers in head-on crashes between two cars **on rural roads** as a function of four curb weight (Accidents with personal injury and serious material damage; driver age up to 59 years)

| Curb weight of considered CAR1 | Curb weight of other CAR2: 600 to 799 kg (1) | | 800 to 999 kg (2) | | 1000 to 1199 kg (3) | | 1200 to 1599 kg (4) | |
|---|---|---|---|---|---|---|---|---|
| | AS[1] | confidence-limits[2] | AS[1] | confidence-limits[2] | AS[1] | confidence-limits[2] | AS[1] | confidence-limits[2] |
| 600 to 799 kg (1) | 17.5 | 26.0<br>9.0 | 20.8 | 25.6<br>16.0 | 21.8 | 27.3<br>16.4 | 22.9 | 29.3<br>16.4 |
| 800 to 999 kg (2) | 13.4 | 17.2<br>9.6 | 14.8 | 16.5<br>13.0 | 15.5 | 17.6<br>13.3 | 18.3 | 21.0<br>15.6 |
| 1000 to 1199 kg (3) | 9.9 | 13.6<br>6.3 | 10.8 | 12.5<br>9.0 | 12.0 | 14.2<br>9.9 | 15.5 | 18.3<br>12.7 |
| 1200 to 1599 kg (4) | 7.7 | 11.4<br>4.0 | 8.2 | 10.0<br>6.4 | 8.9 | 11.0<br>6.8 | 9.7 | 12.1<br>7.2 |

1) AS = percentage of fatalities and serious casualties relative to all drivers involved in accidents with personal injuries and serious physical damage

2) 95 % confidence interval