

# Comparative Assessment of the Passive Safety of Passenger Cars

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**Abstract** - One goal of the assessment of the crashworthiness of passenger cars is to characterize the potential of injury outcome to occupants of cars involved in an accident. This can be achieved by the help of an index that puts the number of injured occupants of passenger cars in relation to the number of cars involved in an accident. As a consequence, this index decreases with a lower potential of injury and rises with a higher number of injuries while assuming a fixed number of accidents. Another index is introduced that uses an economical weighting of each injury level. The consequential injury costs are calculated using the average economical costs for lightly, severely and fatally injured persons. The calculation of the safety indices is based on an anonymized sample of accident data provided by the Federal Statistical Office. An index of Mercedes passenger car drivers depending on the year of registration between 1991 and 2006 is compared to the index of drivers of cars of other makes within the same range of registration years.

## NOTATION

*ESiX* economic safety index  
*SiX* safety index  
*VL* number of seriously and fatally injured persons  
*VLFK* consequential injury costs  
*VLFK<sub>i</sub>* consequential injury costs of slightly, seriously and fatally injured persons  
*GVWR* gross vehicle weight rating

## ACCIDENT DATA

The basis of the assessment of crashworthiness is an analysis of an anonymized 50%-sample of accident data from the years 2002 to 2006 provided by the Federal Statistical Office. “Light”, “severe” and “fatal” injuries of the drivers of passenger cars which are registered in between 1991 and 2006 are selected. These injury numbers are separated into drivers of Mercedes passenger cars (in total 143,800) and drivers of passenger cars of other makes (in total 1,762,000). By using the indices *SiX* and *ESiX* that serve as an indicator of crashworthiness, trends are shown and comparisons between certain vehicle groups are made.

## INDICES FOR ASSESSMENT OF PASSIVE SAFETY

### Safety Index *SiX*

The Safety Index *SiX* is a measure for the passive safety of a vehicle in terms of protection of the occupants against consequential injuries in a road accident. *SiX* stands for “Safety Index” and denotes the number of at least severely injured drivers per 1,000 vehicles involved in an accident. If the following holds for severely and fatally injured persons

$$VL = \sum_{i=1}^2 n_i \quad (1)$$

with  $i = 1$ : severely injured and  
 $i = 2$ : fatally injured,

then

$$SiX = \frac{VL}{\text{vehicles involved in accident}} \cdot 1.000 \quad (2)$$

SiX is a value that measures solely the outcome of an accident. One main influence factor is the number of slightly injured and uninjured drivers, as the set of all vehicles involved in an accident can be divided into the four groups of slightly, severely, fatally injured, and uninjured drivers. If all drivers of a certain group of vehicles would only be slightly injured or not injured at all, SiX would have a value of zero, and the target of protecting the vehicle occupants (here the drivers), would essentially be achieved. Other occupants than the driver are not considered here because of the following reasons:

- The index is independent from the number of passengers in the vehicle.
- The occupant rate in passenger cars in Germany is approximately 1.4 occupants per vehicle. The main focus should therefore initially lie on the driver.
- The design of passive safety systems with respect to the driver (because of the steering column and pedals) is considered to be more challenging than protecting for example an adult front passenger.

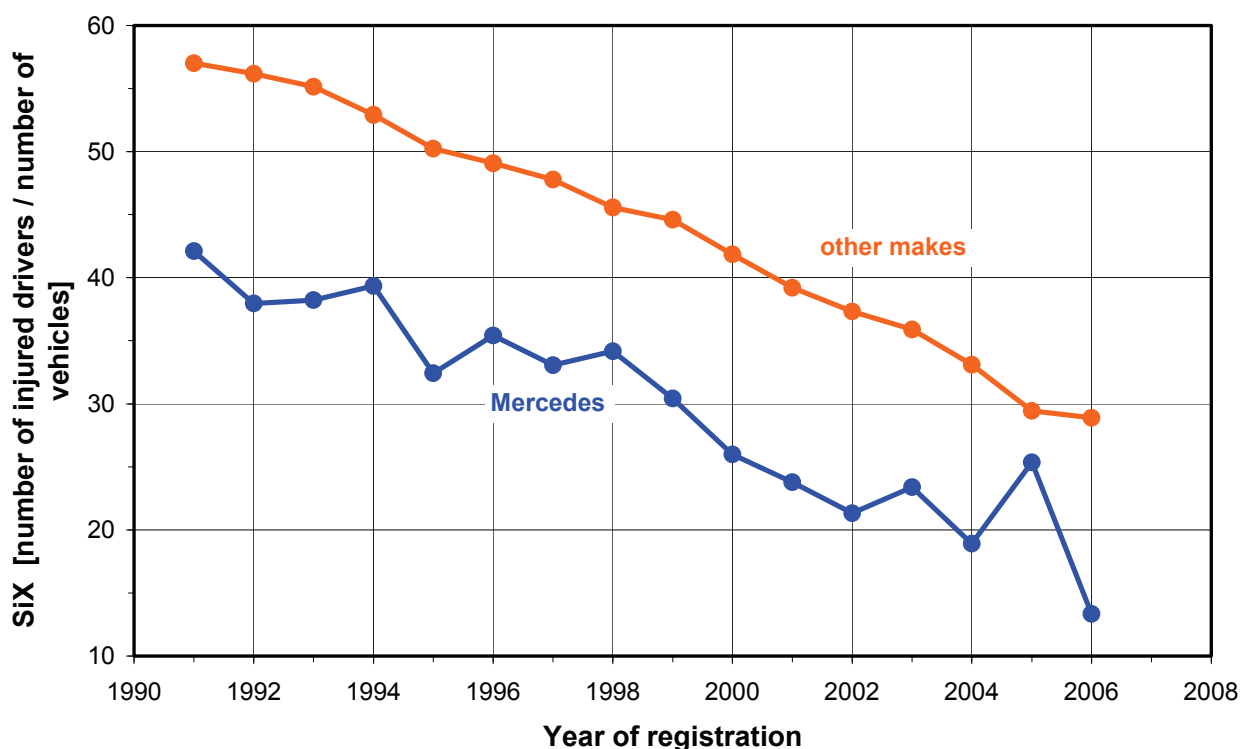


Figure 1: Safety index SiX for passenger cars from Mercedes and other makes depending on year of registration

By means of the safety index SiX we can compare the passive safety of different groups of vehicles. Based on the number of drivers of passenger cars from Mercedes and other makes that have a different injury severity, the SiX depending on the year of registration is shown in figure 1.

### Consequential Injury Costs

The next step is to treat the different levels of injury severity differently by weighting each level with a factor and to include the lowest injury severity into the index. An economical assessment fits nicely in this approach by using consequential injury costs as weighting factors. Consequential injury costs denotes the average economical loss caused by slightly, severely, and fatally injured persons involved in a road accident. Using the instruments of consequential injury costs we gain the ability to assess the benefit of safety measures for example by setting up a cost/benefit analysis. By introducing new findings from an economical and medical point of view, calculations could be

updated in the end of the 1980ies that lead to a consistent monetary assessment. More specifically, these improvements were:

- revision of the earning rate of children and young persons,
- introduction of a lethality rate,
- replacement of the initial value by the earning rate,
- integration of new economic developments: increasing unemployment and rising of the so called hidden economy [1].

In a first step, the resulting consequential injury costs (rounded to the nearest €) were defined for each level of injury severity [MAIS] and averaged over gender, constitution and age of all road users.

By means of the yearly growth rate of the net national product that is highly correlating to the medical care costs, the consequential injury costs are calculated for each year [2]. By leveraging a proper distribution model the costs were transformed into the injury scale “slight”, “severe”, “fatal” used in the federal statistics data.

**Tab. 1:** Consequential injury costs for the year 2005

Injury Severity	Consequential Injury Costs VLFK [ € ]
slight	20.000
severe	164.000
fatal	989.000

Now, consequential injury costs can be calculated for a given period of time:

$$VLFK = \sum_{i=1}^3 n_i \cdot VLFK_i \quad (3)$$

with  $i = 1$ : slightly injured,  
 $i = 2$ : severely injured and  
 $i = 3$ : fatally injured

In this study the consequential injury cost values shown in table 1 for the year 2005 are used for all calculations.

### Safety Index ESiX

ESiX denotes the „Economic Safety Index“, and is calculated as follows:

$$ESiX = \frac{VLFK [Tsd. \text{ €}]}{\text{vehicles involved in accident}} \quad (4)$$

It corresponds to the consequential injury costs of the driver in thousand € per vehicle involved in an accident. Obviously, the ESiX increases with rising consequential injury costs or with a lower

number of involved vehicles and therefore expresses a lower level of safety, while with a low number of injured or a higher number of involved vehicles it shows a higher safety potential.

Figure 2 shows the safety index ESiX for each year of registration in order to compare crashworthiness of two different groups of vehicles. It is based on the consequential injury costs for drivers of passenger cars from Mercedes and other makes related to the number of vehicles involved in an accident.

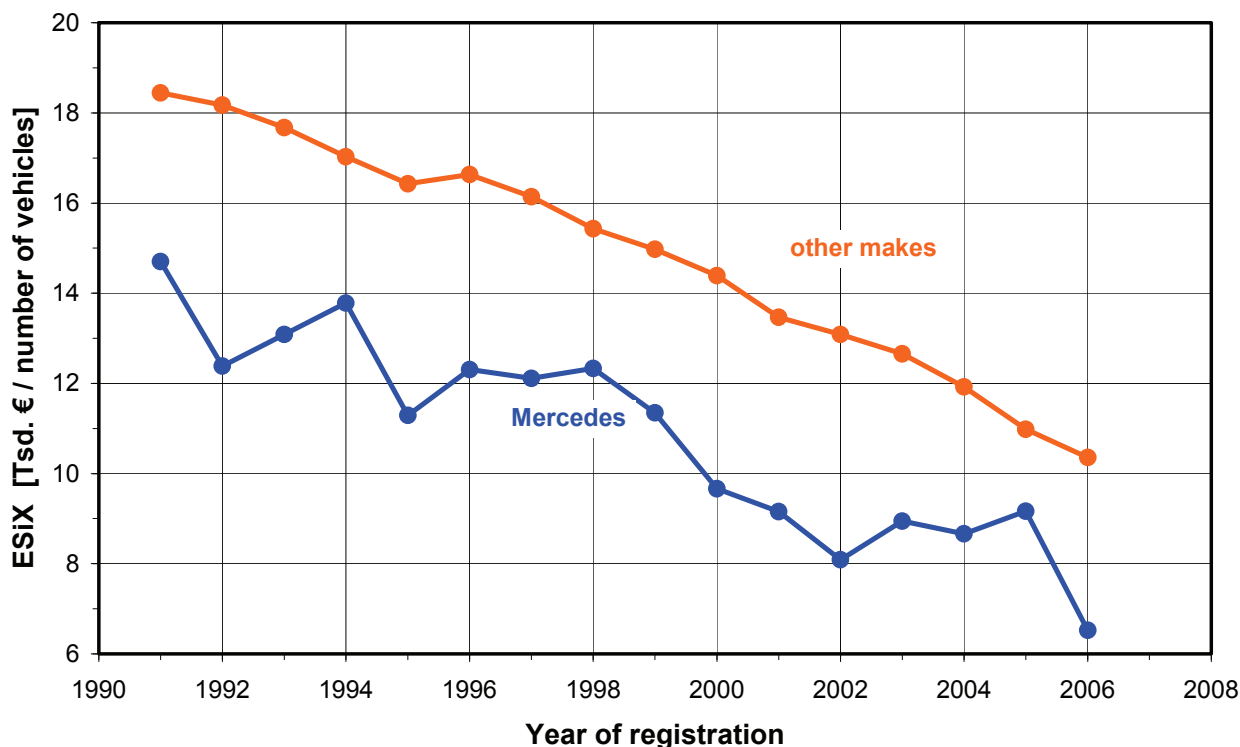


Figure 2: Safety index ESiX for passenger cars from Mercedes and other makes depending on year of registration.

### Comparison and Discussion of the Safety Indices

Both Indices SiX and ESiX, shown in Figure 1 and 2, are based on a sample of data from the Federal Statistical Office. A clear trend can be derived: Both, SiX and ESiX decrease continuously with growing year of registration. That means newer passenger cars have clearly a higher crashworthiness. Additionally, both safety indices show a noticeable gap between Mercedes passenger cars and other makes where Mercedes cars are below the others.

Both indices show a similar trend, so the question is which one is to be preferred. To find an answer, both indices are compared to each other, which is shown in figure 3 and we can also see that there is a high correlation between the two safety indices SiX and ESiX (see figure 4) which is expressed by the square of the correlation coefficient  $R^2 = 0,995$ .

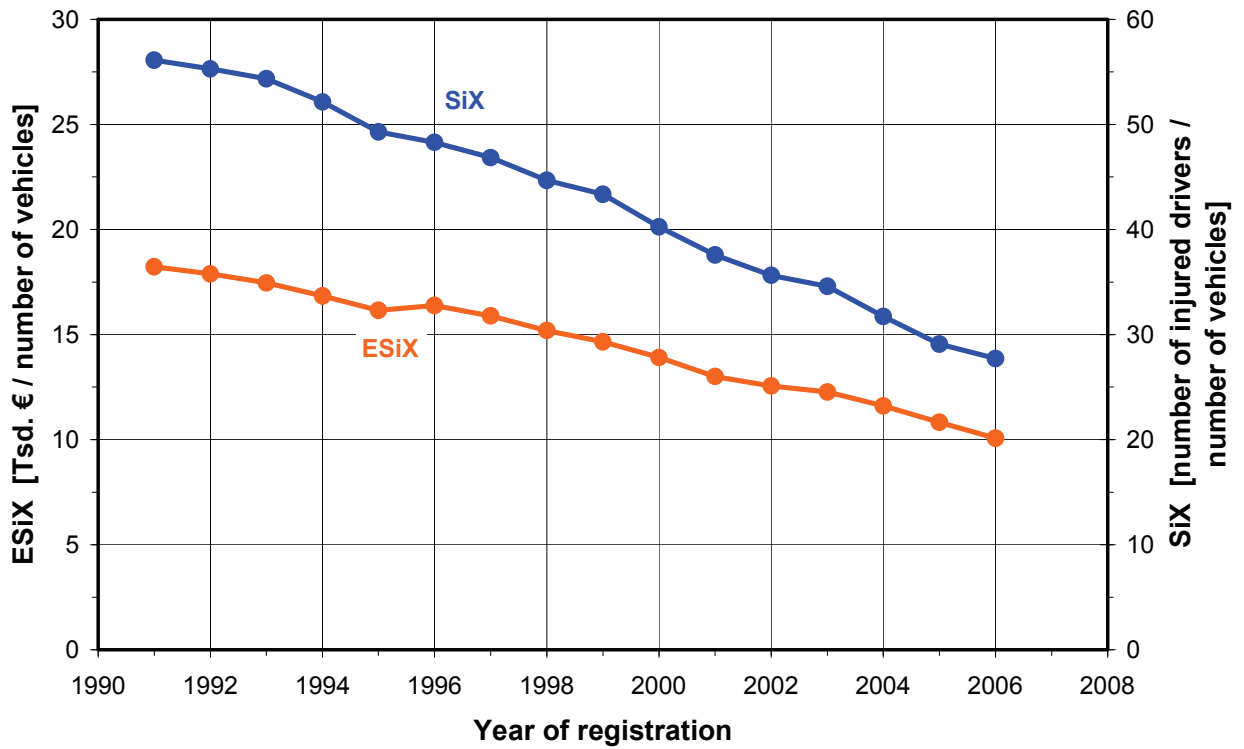


Figure 3: Safety indices SiX and ESiX for all passenger cars depending on year of registration

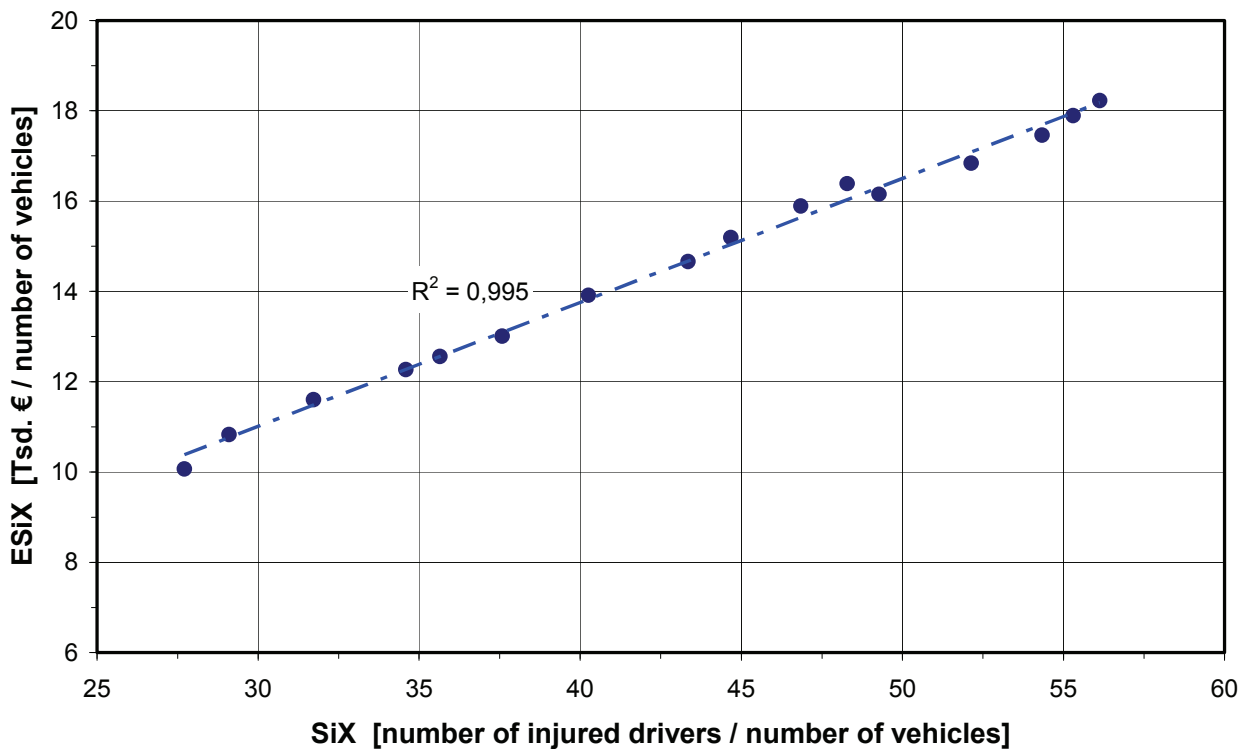


Figure 4: Correlation between the safety indices SiX and ESiX for all passenger cars

The safety indices SiX and ESiX differ in the weighting of the injury severity of vehicle's driver: The index SiX is calculated by the sum of severely and fatally injured casualties in the nominator while the ESiX is made up of slightly, severely, and fatally injured casualties that are weighted by the consequential injury costs. The number of severely and fatally injured casualties is provided by

the federal statistics regularly. Additionally the proportion of the consequential injury costs of slightly injured casualties accounts for only 28.5% (for the year 2005), thus the safety index SiX is preferred in the following discussion. Besides, the slightly injured casualties only have a small influence on the outcome of the ESiX, so they can be neglected.

## APPLICATION OF THE SAFETY INDEX SiX

To avoid a comparison of mid- and large-size Mercedes passenger cars with small size vehicles of other makes, only vehicles with a gross vehicle weight rating of 1,65t or above are selected in the following discussion. This guarantees that only vehicles in the same weight class are compared with each other. Due to a low number of cars for the vehicle years 2005 and 2006 in the accident data, this holds especially for cars with fatally injured drivers, these years are left out by now. The safety index SiX is shown for both groups of cars in figure 5. While the curve of the injured drivers in cars of other makes resemble closely a decreasing straight line, the SiX of injured drivers of Mercedes passenger cars shows some variability. The reason for this effect is the (by a factor of about 7) lower number of Mercedes cases per year of registration. Overall the Mercedes curve is considerably below the SiX curve of other makes.

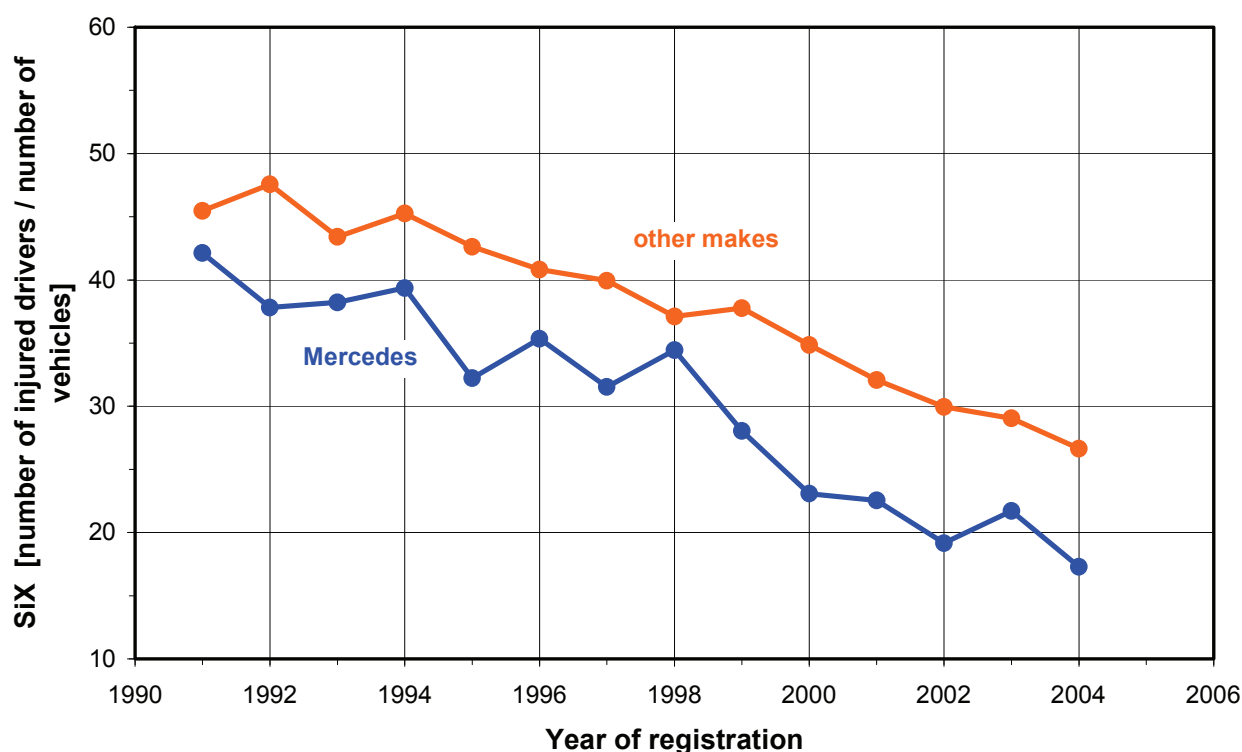


Figure 5: SiX in comparison for passenger cars from Mercedes and other makes with  $GVWR \geq 1.65$  t

Figure 6 shows the quotient of the safety indices of both groups. The average of the quotient has a value of about 1.3 which means that the safety index for the driver of a Mercedes passenger car is by this factor lower than for the drivers of other makes. Additionally, the quotient is above the average value from the year 1999 onwards while it is below the average before. That means the margin of the SiX between Mercedes passenger cars and other makes even broaden with newer vehicles.

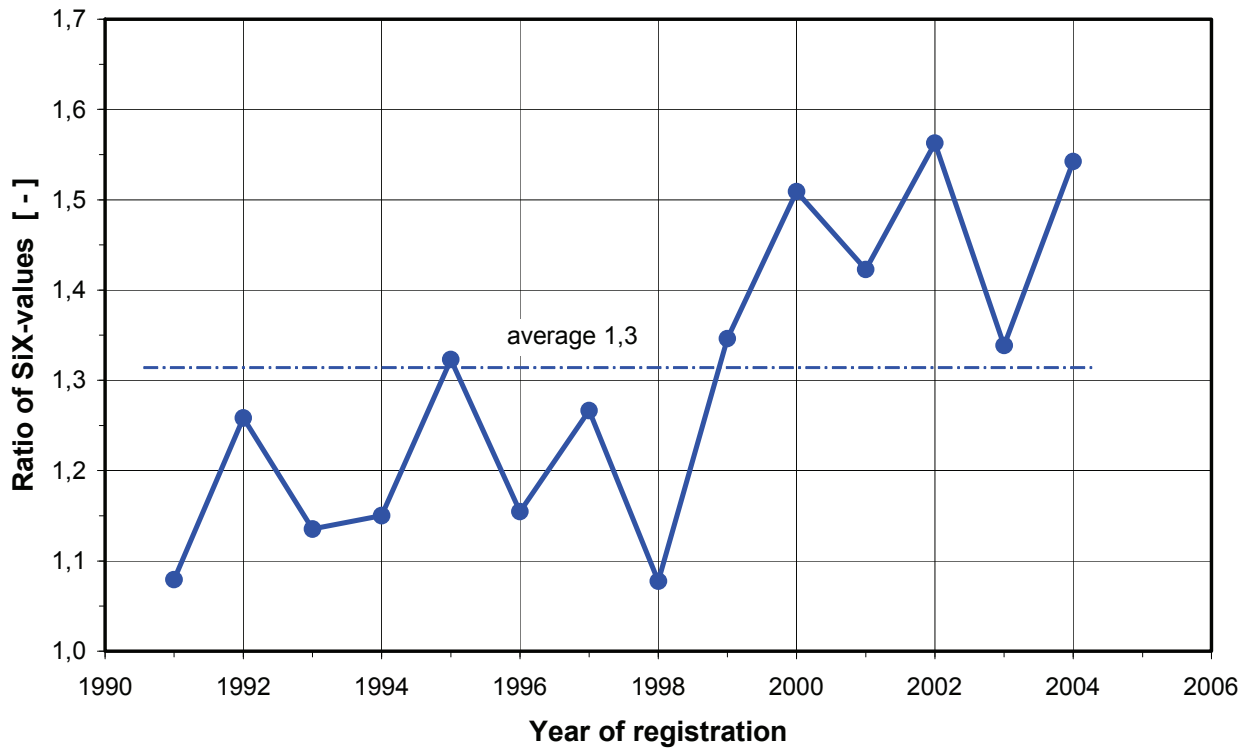


Figure 6: Quotient of SiX values of car drivers from other makes and Mercedes

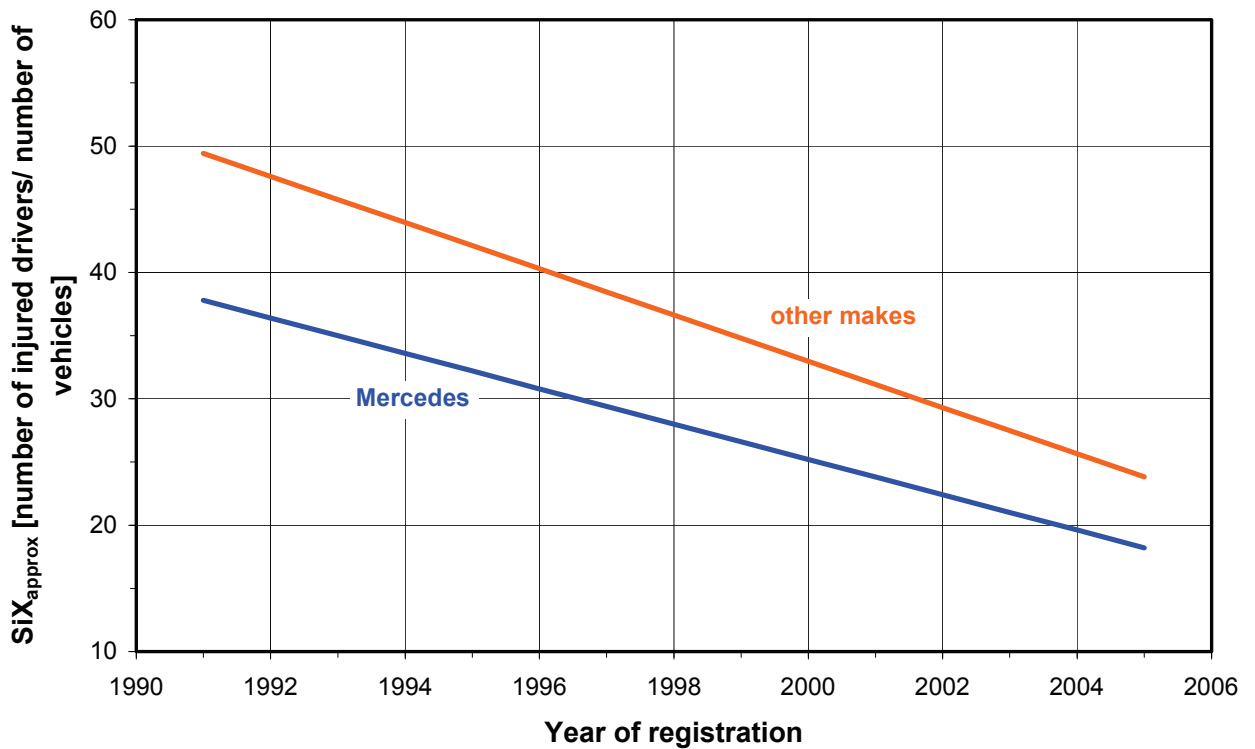


Figure 7: Approximate SiX values of passenger cars from Mercedes compared to other makes with a GVWR  $\geq 1.65$  t

Figure 7 shows the linear approximation of the SiX curves for passenger cars from Mercedes and other makes: The SiX curve for Mercedes passenger cars is considerably below the curve for other

makes. We can conclude that the injury potential for drivers of Mercedes passenger cars is in average about 24% lower than for drivers of cars of other makes.

## **INTERPRETATION OF RESULTS**

The decreasing safety index SiX proves that we have a considerable gain of crashworthiness in passenger cars. Surely, this is due to the continued development of safety measures in passenger cars for protection of the occupants. Especially Mercedes passenger cars show an advantage in this trend. One reason for this is the early introduction of innovations in the field of passive safety in the broad fleet of Mercedes cars. Real-life safety has always been the basis for introduction of these measures and specification of safety systems being built into new car models. For example, the side air bag has been introduced in all models and the window bag in E- and S-Class even before the year 2000. The efficiency of both systems has already been proven in [3].

Moreover, the early introduction of active safety systems in the Mercedes passenger car fleet, for example ESP since year 2000, has also a positive effect on the protection of occupants in a crash. This is because the type of collision is shifted from side collisions in accidents where the car is skidding into a more frontal type of collision and thus increasing the possible protection for the occupants against injuries caused by the crash. Additionally the whole kinetic energy of the collision is reduced by ESP right before the crash which also leads to a lower accident severity.

## **SUMMARY**

The safety indices SiX and ESiX are very well suited for the assessment of crashworthiness of vehicles based on data from real life accidents. Choosing the SiX for the sake of simplicity, the index could deliver a clear first evidence that improvements in the crashworthiness of passenger cars have been made, both, measures improving passive safety as well as by introducing active safety, in the form of driver assistance systems, which have an effect in reducing the severity of accidents.

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