THE EFFECTIVENESS OF PRIMARY SAFETY FEATURES IN PASSENGER CARS IN GERMANY

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ABSTRACT

Based on a large sample of about 690'000 passenger car accidents in Germany for the years 1998-2002 this study investigated in full detail the effectiveness of primary safety features in real world accident behaviour in Germany. In a first part of the paper, a statistically sound methodology for such an investigation is presented, which can be applied to large accident databases. Special emphasis is laid on the question of statistical significance. The main statistical tool to be applied is the method of odds ratios in contingency tables.

After a brief review on existing methods and results in this area in the literature (second part) we apply in a third part the presented methodology to the accident material in order to demonstrate the substantial and statistically significant effectiveness of an Electronic Stabilization Program (ESP) in passenger cars in Germany. These results underline the already available results in the literature and are of great relevance because today already more than 60% of the newly registered passenger vehicles in Germany are equipped with ESP. Additionally to the overall effectiveness of ESP the influence under specific accident situations (like specific road conditions, accidents with fatalities and so on) is going to be investigated.

A further part is devoted to other even more recent primary safety features (like brake assist). Here the situation is much more complicated mainly due to the lack of relevant accident cases, e.g. accidents in which cars with brake assist on board are involved. Especially the car-to-pedestrian accidents are going to be investigated in order to see whether a positive effect of the brake assist can be confirmed.

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INTRODUCTION

The detection and quantification of a possible effect of a primary safety function in the accident behaviour of vehicles is a major area of research in the field of accident analysis. In recent years the possible effect of an Electronic Stabilization Program (abbreviated: ESP) for passenger cars has attracted much attention. ESP aims to prevent a possible instability of a vehicle, when the car does not follow the steering angle. ESP uses single or multiple wheel braking. This forces the car to follow the steering angle as far as possible, due to physical limits. Thus the question is of great importance whether or not ESP is able to prevent to a certain extent the skidding of vehicles and therefore should help the driver not to loose control of the car in critical situations. Even if different manufacturers use different acronyms for their Electronic Stabilization Program, for example Active Stability Control (ASC), Automotive Stability Management System (ASMS), Dynamic Stability Control (DSC), Vehicle Dynamic Control (VDC), Vehicle Stability Control (VSC) or Electronic Stability Control (ESC) are used, we will stay with the abbreviation ESP within this text. The intention of the presented study is to quantify the effect of ESP as an electronic system and the focus is not on possible differences according to make and model.

Of course, ESP is only one of the electronic primary safety functions newly registered cars are going to be equipped with. The Brake Assist (BAS) or the Emergency Brake, Adaptive Cruise Control (ACC), a Lane Keeping Assistant and a Lane Departure Warning System or an Obstacle & Collision Warning System or a Driver Condition Monitoring System are more examples among others.

We do not intend to give a detailed and complete technical description of these electronic safety systems and their working configurations. The main focus we are interested in is the effect of a primary safety function of vehicles on real world accidents. Since skidding accidents are usually rather dangerous for the driver and the other occupants of a car, the potential for an electronic system which is able to avoid to substantial ratios these types of accidents is of major interest. That is the reason why we mainly focus on the quantification of the effect of ESP. In Germany for example about more then 60 % of the recently registered vehicles already have an Electronic Stabilization Program on board. Since especially the rather severe injuries and fatalities occur in so-called loss-of-control accidents, it could be expected that the avoidance of a reasonable percentage of loss-of-control accidents by ESP is going to result in a substantial reduction of severe and fatal accidents.

Several papers considered the effect of ESP on accidents from different points of view. Aga and Okada (2003) considered the effectiveness of ESP in Japan, while Tingvall et al. (2003) investigated this question on the basis of accident data from Sweden. Recently Page and Cuny (2004) presented a study on the effectiveness of ESP on French roads. Concerning Germany, where nowadays more than 60 % of the newly registered vehicles are equipped with ESP, Zobel (2000), Langwieder et al. (2003) and (2004), Unselt et al. (2004) and Becker (2004) presented rather promising results based on German accident data from different sources. Based on European accident material (EACS data) Sferco et al. (2001) discussed the potential benefits of ESP. Concerning the effectiveness of ESP for single car crashes in the U.S. see Dang (2004). Recently an international comparison of ESP related results has been published by Langwieder (2005).

An overview of primary safety functions and first steps towards an evaluation of such systems can be found in the recent final report of the SEiSS-project of the European Commission.

Some relevant methodological considerations concerning the investigation of the possible effects of primary safety functions can be found in Becker et al. (2004), Busch (2005), Hautzinger (2003), Martin (2003), Otto (2004), Page and Cuny (2004) and Stanzel (2002) among others.

In this paper we intend to present a methodology which could be applied to the investigation of the possible effectiveness of a general primary safety function. Based on a large sample of German accident data for passenger cars for the years 1998-2002 from the German Federal Statistical Office (Deutsches Statistisches Bundesamt) we are going to apply the methodology especially to ESP. The obtained results of the study presented in this paper will underpin the substantial effectiveness of an Electronic Stabilization Program.
After having presented the used methodology from a quite general point of view (which easily allows for transferring the methodology to other primary safety functions) we are going to consider the effectiveness of ESP in detail. We not only consider accidents but we also have investigated the effectiveness of ESP according to the year of first registration, the age of the vehicle, vehicle size, different road conditions and locations of accidents (e.g. urban and rural) and age or gender of the driver. Another focus is on the most severe risks (i.e. the accidents with fatalities) in order to see the potential benefits from ESP here. It will be seen that the effect of ESP on accidents with fatalities fortunately is rather high. It is worth mentioning that we consider ESP within the presented study as an electronic system and that the results of this paper do not allow any conclusion concerning the effectiveness of ESP for specific makes and models.
In a further section we deal with the problem of misclassification of vehicles and accidents. A misclassification of vehicles occurs when the equipment with the primary safety function is not detected or when a vehicle incorrectly is assigned to be equipped with the safety function. Especially on the basis of mass accident data material it seems unavoidable that these misclassifications of vehicles occur and the effect on the outcomes of an investigation should be considered. The other way round it may also happen that for example an accident is erroneously assigned to be a skidding-accident and therefore one would assume that ESP has some effect on this specific accident which in fact was not possible. We will see in the section on correction of misclassification errors that misclassification of vehicles and misclassification of accidents always lead to an underestimation of the effectiveness of the primary safety function as long as there is in fact a positive effect of the electronic system of interest. This means that the real effectiveness of the primary safety function is always higher than computed from real world accident material, which always contains to a certain percentage errors. In other words this means that one should try to specify the equipment of vehicles and the accident type as proper as possible in order to measure the actual effectiveness of this primary safety function. Moreover we suggest a method which allows for an a posteriori correction of accident data concerning existing misclassifications. The presented methodology is finally applied to the above mentioned accident database and ESP as a primary safety function.

A section on the effectiveness of other primary safety functions as ESP and some conclusions will complete the paper.

STATISTICAL METHODOLOGY

In this section we summarize a reasonable way how to investigate the possible effectiveness of specific primary safety equipment in passenger cars on the basis of accident databases.

In a first step it is necessary to carefully collect accident situations in which the specific primary safety feature of interest is likely to have some effect on the accident outcome (primary safety feature sensitive accident) or has definitely no effect (primary safety feature non-sensitive accident). All other accidents, e.g. accidents for which it is not clear whether an effect for at least one accident–involved party can be expected or not, should be excluded from the further investigation. Together with the selection of accidents we additionally have to assign for each accident (if more than one vehicle is involved in the accident) a car which we will focus on. For the assigned cars we have to be able to decide whether or not these cars are equipped with the primary safety function of interest.

From this selection we end up with a number of cars involved in accidents (for the sake of simplicity also called accidents in the following) for which an effect of the primary safety feature is expected or can definitely be excluded.

The main idea will be to compare the behaviour of the vehicles equipped with a specific primary safety feature and the non-equipped vehicles according to both groups of sensitive and non-sensitive accidents.

This first step already is not very easy to realize on mass accident databases. In such databases typically only a rough classification of accident situations is available. Therefore a clear-cut decision, whether the accident outcome for a vehicle involved in an accident is sensitive or non-sensitive to a specific primary safety feature is impossible. Thus one has to face the problem that the group of sensitive accidents contains cases which in fact have not been affected by the primary safety feature of interest and vice versa. We will see in the case that there indeed is a positive effect of the primary safety function that this dilemma will lead in any case to an underestimation of the effect of the primary safety function. We will come back to this point later on.

The selection of safety function sensitive accidents and accidents which are not affected by the safety function (safety non-sensitive accident for short) also includes the selection of one accident involved vehicle for which the safety function has an expected effect on the accident outcome. This is not a problem as far as single car accidents are considered, but for most primary safety functions it is advisable to take into account car-to-car crashes as well, since in most types of accidents a collision with another vehicle cannot be excluded.

Having selected sensitive and non-sensitive accidents and corresponding accident involved vehicles moreover one has to decide in a further step, whether or not these cars have been equipped with the safety function. Since mass accident databases usually do not contain this information explicitly, one has to derive it from available car characteristics. In many cases it is possible to obtain the likely equipment from the make and model, the date of the first registration and additional input from the manufacturers. Unfortunately again a clear-cut decision of the question whether a specific car is equipped or not with the safety function is limited. Usually there is the possibility to separate the following three groups

- Cars most likely equipped with the safety function
- Cars most likely not equipped with the safety function
- Cars for which the equipment is not known

One has to exclude the accident cases in which no almost sure information about the equipment can be obtained from the further investigation and one again has to face the problem that for the remaining cases there is a certain rate of misclassification. As before, existing misclassification leads to a further underestimation of the effect of the safety function. We will argue below that up to a certain extent a correction for this underestimation as well as for the underestimation which is due to the misclassification of sensitive and non-sensitive accidents is possible.

Now we have selected accidents which can be split into primary safety function sensitive and non-sensitive accidents and for each accident involved vehicle we know with at least high probability whether the car is equipped or not with the safety function of interest. In order to be able to guarantee a serious investigation on the effect of the primary safety function of interest we have to reduce the number of accident cases once more. The reason is that we are mainly interested in recently introduced primary safety functions. This implies that it typically will be the case that the vehicles contained in the accident database which are equipped with the safety function are only a few years old (e.g. up to 5 years). In contrast the non-equipped cars of course will be to a considerable percentage much older. In order to receive a meaningful comparison one should take into account vehicles with first year of registration belonging to the same time window. E.g. if we are interested in a primary safety function introduced to the market about 1998/1999 then one should only include accidents from 1999 until today and involved vehicles with year of first registration not earlier then 1999.

Of course there are many other factors which may influence the accident outcome of a crash (e.g. the driver age and gender, the road conditions, the location of the accident, the size of the vehicle and so on). If the accident-involved vehicles equipped or not with the safety function of interest differ substantially in one or more of these factors, then it would become rather difficult to decide whether a possible effect on the accident outcome is caused by the primary safety function or by a confounding factor in which the two groups of equipped and non-equipped vehicles substantially differ. The most ideal situation, i.e. a situation in which we can base the investigation on a huge number of very similar vehicles, driven by similar people in similar locations, which only differ in the equipment with a specific primary safety function, is completely unrealistic. So we have to live with a certain amount of differences in the population of the underlying vehicles. Nevertheless one has to do the best in order to be sure to exclude that a pretended effect of the primary safety function indeed is due to a completely different causation. Therefore in some cases it is advisable to separate the results according to different years of first registration, or to different gender of the driver, or the location of the accident, or the road conditions and so on in order to be able to detect whether there are differences in accident outcome due to one or another factor.

Table 1.
Underlying accident data for an investigation of the effectiveness of a primary safety function

		Primary safety function-sensitive accident		Total
		No	Yes	
Vehicle equipped with primary safety function	No	N_{00}	N_{01}	N_{00} + N_{01}
	Yes	N_{10}	N_{11}	N_{10} + N_{11}
Total		$N_{00}+N_{10}$	$N_{01}+N_{11}$	N

Furthermore it may be advisable to separately consider light or no injury accidents and severe or fatal accidents.

Finally we end up with accident data which can be represented as is stated in Table 1. On this representation we will base our statistical investigation.

One statistically consolidated method is to base the investigation on the so-called odds-ratio OR, i.e. on

$$OR = \frac{N_{11} / N_{10}}{N_{01} / N_{00}} = \frac{N_{11} \cdot N_{00}}{N_{01} \cdot N_{10}} \qquad (1).$$

In the context of the evaluation of the effectiveness of an Electronic Stabilization Program (ESP) the odds-ratio has been successfully been used by Stanzel (2002), Martin (2003), Tingvall et al. (2003), Otto (2004) and Page (2004), see also Hautzinger (2003). An odd in our context is the ratio of the probability of suffering a primary safety function sensitive accident and the probability of suffering a primary safety non-sensitive accident. Since we only take accidents of this two types into account both probabilities add up to 1. The odd is computed for the group of equipped and non-equipped vehicles separately and the ratio of the two odds is the odds-ratio OR.

If one interchanges the role of the variables vehicle equipment and accident sensitivity one could also define an odds-ratio in comparing the odds of the probability that a car with the primary safety function on board is involved in the accident for both groups of primary safety function sensitive and non-sensitive accidents, i.e.

$$OR = \frac{N_{11} / N_{01}}{N_{10} / N_{00}} \qquad (2).$$

But this odds-ratio exactly coincides with the odds-ratio from above. Thus is does not matter in which sequence the two variables are considered. Even if one considers the ratio of the odds based on conditional probabilities

$$\mathrm{P}\left(\{\text{Sensitive Accident}\}\middle|\{\text{Equipped Car}\}\right)$$

and

$$\mathrm{P}\left(\{\text{Non-sensitive Accident}\}\middle|\{\text{Non-equipped Car}\}\right)$$

one ends up with exactly the same odds-ratio OR as above.

In case that the primary safety function has some positive effect (note that this effect can only occur in the group of the primary safety function sensitive accidents) the odds-ratio OR is less than one and vice versa (the assertion $OR \geq 0$ holds always true). Since the odds are monotonic function of the corresponding probabilities we have that the smaller the odds-ratio is the more effective is the primary safety function. That is why the quantity

$$E = 1 - OR \qquad (3)$$

is used as a measure of effectiveness of a primary safety function in the literature.

In real data situations (especially when the underlying sample size (i.e. the underlying number of accidents) is low or moderate, one has to avoid that the reason for obtaining an odds-ratio OR which is less than one is only due to statistical fluctuation. This means that we need confidence limits for the odds-ratio OR. Such a confidence interval with a coverage probability of 95% is given for example through the following formula (cf. Agresti (1996), page 24)

$$OR \cdot \exp\left(\pm 1.96 \cdot \sqrt{\frac{1}{N_{00}} + \frac{1}{N_{10}} + \frac{1}{N_{01}} + \frac{1}{N_{11}}} \right) \qquad (4).$$

This confidence interval easily carries over to a confidence interval with coverage probability of 95% for the effectiveness E.

The meaning of such a confidence interval is, that we expect with a probability of 95% that the underlying theoretical odds-ratio of probabilities in this interval. Thus, if the upper confidence limit is less than one this would be a statistically significant indication that there indeed is a positive effect of the primary safety function to be investigated. Unfortunately we usually need an at least moderate sample size of accidents in order to obtain statistically significant results.

The effectiveness E can in fact be interpreted in the way that an effectiveness of E means that E·100% primary safety function sensitive accidents could be avoided if all vehicles on the market are equipped with the specific primary safety function. It is a matter of fact, that the Odds-ratio is indeed an approximation of the usual ratio of the following two conditional probabilities

$$\mathrm{P}\left(\{\text{Sensitive Accident}\} \middle| \{\text{Equipped Car}\}\right)$$

and

$$\mathrm{P}\left(\{\text{Sensitive Accident}\} \middle| \{\text{Non-equipped Car}\}\right).$$

The reason for this matter of fact is that the ratio of the primary safety function equipped and the non-equipped vehicles within the group of accidents non-sensitive to the primary safety function can be viewed as a reasonable approximation to the ratio of both numbers of vehicles on the market.

Of course one could also compute the market share of vehicles equipped and non-equipped with the primary safety function on the basis of *all accidents* in the underlying database. In case that the primary safety function indeed has a positive effect on some accidents this computation will underestimates the share of primary safety function equipped vehicles and therefore will automatically lead to an overestimation of

$$\mathrm{P}\left(\{\text{Sensitive Accident}\} \middle| \{\text{Equipped Car}\}\right).$$

Finally this in turn implies that a possible effect of the primary safety function of interest is always underestimated.

A comparison on the basis of these two conditional probabilities concerning the effectiveness of a Electronic Stabilization Program (ESP) has been carried through by Unselt et al. (2004).

One might be tempted to think that the above two conditional probabilities coincide with the following ratio, which could easily be obtained from Table 1:

$$\frac{N_{11}}{N_{10} + N_{11}}$$

and

$$\frac{N_{01}}{N_{00} + N_{01}},$$

but this is not the case since Table 1 only contains a selected number of accidents and not *all accidents*, as is really necessary.

If one additionally takes into account the percentage of the primary safety sensitive accidents among all possible accidents then one may compute the reduction among all accidents that are possible if the primary safety functions would have been a standard equipment of all vehicles in a country.

EFFECTIVENESS OF AN ELECTRONIC STABILIZATION PROGRAM

In this section we apply the methodology of the preceding section to a special primary safety function, namely to the Electronic Stabilization Program (ESP). As accident database we use the accident statistics from the German Federal Statistical Office (Statistisches Bundesamt) for the years 1998-2002. This database contains quite a lot of accident data all over Germany. In total for the five years period we have about 690’000 police recorded passenger car accidents available. Not only accidents with at least one injured person are contained in the database but also material damage only accidents have been recorded in quite a large portion. The recorded passenger car accidents consist of single-car and car-to-car crashes.

The specification of types of accident is rather rough in the database, as is usual for mass accident databases. The German Federal Statistical Office uses seven types of accidents in order to describe the conflict situation which leads to the accident. We decided to use the accidents classified to the type of accident "Driving Accident" as accidents which are most likely to be influenced by ESP (*ESP sensitive accidents*). In the terminology of the Federal Statistical Office a "Driving Accident" is defined as *caused by the driver's losing control of his vehicle (due to not adapted speed or misjudgement of the course or the condition of the road, etc."*. In order to be able to compare the accident behaviour of ESP-equipped and ESP non-equipped vehicles we need a control group of accidents which contains only accidents which most likely are definitely not affected by an Electronic Stabilization Program. Here we selected the types of accident "Accident caused by turning off the road", "Accident caused by turning into a road or by crossing it" as well as so-called "Accident caused by crossing the road (by a pedestrian)" and "Accident involving stationary vehicles". All the accidents belonging to one of the above mentioned types are assigned to be ESP-non-sensitive accidents. All accidents belonging to the types of accidents "Accident between vehicles moving along in carriageway" and "Other accident" are regarded as accidents which may or may not be influenced by ESP. Since for these accidents a clear-cut decision seems to be not possible we excluded them from the further investigation.

Concerning the names of the types of accidents we stay here with the official English terms published by the German Federal Statistical Office.

Now we come to the accident involved vehicles. Here we choose for all accidents the vehicle of the so-called "guilty driver". This is the driver of the car which is mainly responsible for the accident.

With the help of several car manufacturers from Europe as well as from Japan we have been able to detect – up to a reasonable degree of reliability – the vehicles which have ESP as standard equipment or not. Makes and models which are equipped to more than 80% with ESP are regarded ESP-equipped vehicles. All vehicles which do not have an Electronic Stabilization Program as standard equipment are stated to be non-ESP-equipped vehicles. In cases in which we are unsure about possible equipment with ESP we excluded the whole accident from the investigation.

In order to include only comparable vehicles in the study we further excluded all accidents in which the vehicle of the guilty driver has been registered for the first time before 1998.

Doing so, we end up in total with a little more than 40'000 German accidents of passenger which we have taken into account for our investigation. This accident data will serve as the basis for the investigation of the effectiveness of ESP. Note that ESP is taken as a system that operates similarly in all cars. Possible differences between makes and models are not considered. The results should rather be considered as average results. The data can be condensed to a 2x2 table (cf. Table 2).

Table 2.
Underlying accident data for an investigation of the effectiveness of an Electronic Stabilization Program (ESP)
All accidents from the years 1998-2002 of passenger cars firstly registered in 1998 or later and only accidents which have been assigned to be sensitive or definitely non-sensitive to ESP and vehicles most likely equipped or not-equipped with ESP
Data Source: German Federal Statistical Office

		ESP-sensitive accident		Total
		No	Yes	
Vehicle equipped with ESP	No	18035	10387	28422
	Yes	9075	3535	12610
Total		27110	13922	41032

From Table 2 we easily obtain an odds-ratio of OR=0.676, which leads to an effectiveness E of 32.4% for the Electronic Stabilization Program ESP, which means that at least one third of the ESP-sensitive accidents could be avoided by ESP.

In order to get a deeper insight in the effectiveness of ESP we present in Figure 1 a plot of the effectiveness of ESP for different years of first registration separately. I.e. we created 4 separate tables like Table 2, in which we only included accidents of vehicles registered for the first time in a specific year. Since in 1998 only a rather few number of vehicles equipped with ESP have been registered for the first time we don't take this year of first registration into account.

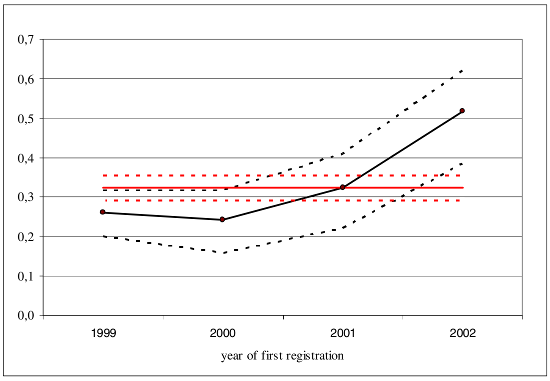

Figure 1. Effectiveness of ESP for different years of first registration (1999-2002) (black) with 95% confidence limits (dotted) and overall effectiveness including 95% confidence limits (red)

It can easily be seen from Figure 1 that the effectiveness of ESP increased with the year of first registration. One might be tempted to conclude from this that the Electronic Stabilization Program has improved over the years. Since we have accident material only for years 1998-2002 at hand we have to be careful. Since we can observe for the most recent vehicles registered for the first time in 2002 only possible accidents during the year 2002, i.e. accidents with a rather new vehicle, in contrast to vehicles registered for the first time in 1998 for which we are able to see potential accidents over a five year period, it might be the case

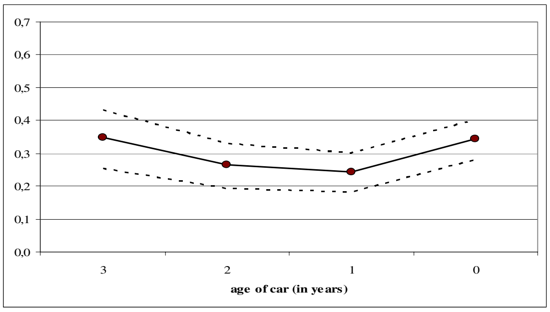

Figure 2. Effectiveness of ESP for different ages of vehicles at time of accident (accidents from the years 1998-2002) including 95% confidence limits

that the effect of increasing effectiveness can be completely explained by a different handling of brand-new and older vehicles. In order to see whether this is the case, we will have a look onto the effectiveness of ESP depending on the age of the vehicle at time point of the accident (cf. Figure 2).

It can be seen that there really is a moderate (but not significant) difference in the effectiveness of ESP according to the age of the vehicle. But it is easily seen that these differences are not able to explain the increase in Figure 1, which underpins, that in fact there is an increase in effectiveness of ESP for more recent vehicles which can't be explained by the age of the vehicle at time of accident. This justifies the assertion that there probably is a technical progress in implementing Electronic Stabilization Programs in vehicles.

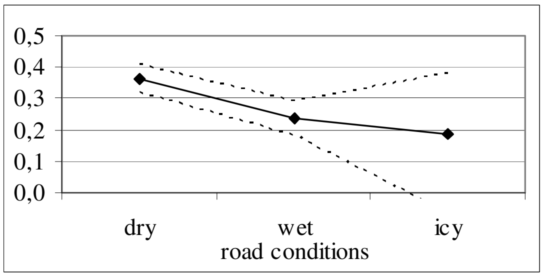

Figure 3. Effectiveness of ESP for different road conditions (accidents from the years 1998-2002) including 95% confidence limits

We further investigated whether there are factors or situations in which ESP-equipped and non-ESP-equipped vehicles differently behave.

Concerning the different daylight conditions (daylight, twilight, darkness) we don't detect any differences in the behaviour of cars equipped or not with ESP, which is accordance with the technical functioning of ESP.

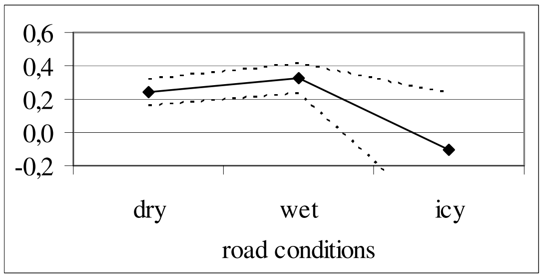

Figure 4. Effectiveness of ESP within built-in areas for different road conditions including 95% confidence limits

In contrast to this we detect some differences depending on the road conditions (cf. Figure 3).
Especially it can be seen that the effectiveness of ESP on a dry road is higher than on wet (and icy) roads. Indeed the difference is statistically significant. Let us have a closer look on the effectiveness

of ESP in dependence on the road conditions. We split the accidents according to their location within or outside built-in areas and computed the effectiveness separately (cf. Figures 4 and 5).

The slightly negative odds-ratio in Figure 4 on icy roads within built-in areas is by far not significant. It may be interpreted only in the way that no effect of ESP on the basis of all accidents can be detected for such situations. For special interest in the effectiveness of ESP in such rather rare situations a more specified investigation is necessary.

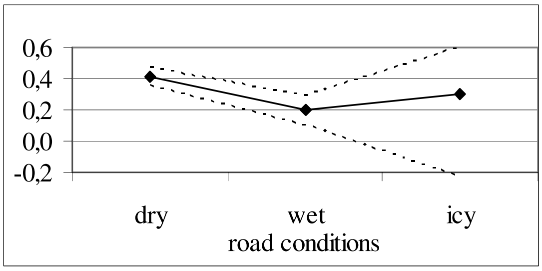

Figure 5. Effectiveness of ESP outside built-in areas for different road conditions including 95% confidence limits

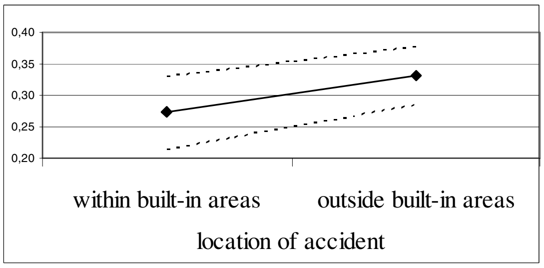

Figure 6. Effectiveness of ESP according to location of the accident including 95% confidence limits

We see from Figures 4 and 5, that the effectiveness of ESP on dry roads is significantly better outside built-in areas where it could be expected that the driving speed is higher than in urban areas and one could on wet roads more easily come into situations, where the physical limits are reached or even exceeded. In contrast, in urban areas one drives usually at lower speed and the risk to skid is higher on wet roads. Because of the lower driving speed one can substantially benefit from a present Electronic Stabilization Program. If one compares the behaviour of ESP for different accident locations (within or outside built-in areas), a substantially, but not significantly, better performance of ESP outside built-in areas can be observed (cf. Figure 6).

Concerning the age of the driver of the vehicle no different effect of ESP shows up, i.e. ESP works well for all age groups of drivers.

Of course it is of great interest to see, how an Electronic Stabilization Program performs for accidents with severe or even fatal injury outcome. The effectiveness of ESP for accidents with fatal injury outcome has proved to be even higher than the effectiveness of ESP regardless the injury outcome of the accident. From the German accident data it is obtained that the effectiveness of ESP for accidents with fatal injury outcome is 55.5% in contrast to an effectiveness of 32.4% over all accidents (including material damage only accidents). The 95% confidence interval for the effectiveness of ESP in fatal accidents reads (31.2 % , 71.2 %). Nevertheless the potential of an Electronic Stabilization Program to avoid especially extremely severe accidents is rather striking. More then every second fatal driving accident can be avoided by ESP.

Finally let us come back to the driver population and let us compare the effectiveness of ESP for different gender of the driver. Surprisingly it showed up that ESP-effectiveness in women-driven vehicles is significantly better than ESP-effectiveness in men-driven vehicles (cf. Figure 7). A more detailed analysis revealed that this effect is linked to car size, as we will see in the following.

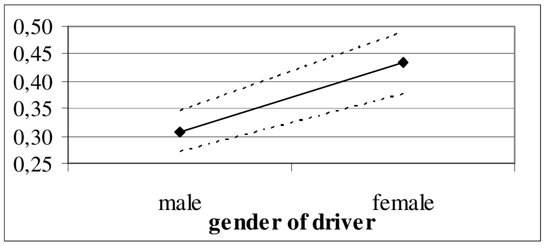

Figure 7. Effectiveness of ESP separately for gender of driver including 95% confidence limits

To this end we investigated within this study as a further factor the size of the vehicle and possible differences in the effectiveness of ESP. It is obtained that the effectiveness indeed differs with the curb-weight of a vehicle (cf. Figure 8). Moreover we see from Figure 8 that especially for smaller cars (curb-weight less than 1100 kg) ESP-effectiveness is rather high and decreases with increasing curb-weight.

In addition to the effectiveness of ESP for different curb-weights in Figure 8 we plotted there the percentage of female drivers within the respective mass categories. It is striking that both curves (effectiveness of ESP and percentage of female drivers) correspond rather well.

This result strongly suggests that the influence of the gender reported in Figure 7 in fact is an influence resulting from the size of the vehicle. Moreover gender of driver and size of vehicle are obviously (cf. Figure 8) strongly correlated variables and this strong correlation likely leads to the effects presented in Figure 7.

The reason for the high ESP-effectiveness especially for smaller vehicles could be that the incremental safety gain by an Electronic Stabilization Program for those cars is rather high.

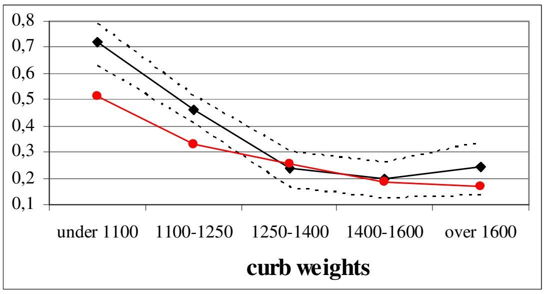

Figure 8. Effectiveness of ESP separately for different curb-weights (in kg) including 95% confidence limits (black solid and dashed lines) together with the percentage of female drivers in the respective curb-weight category (red line)

METHODOLOGY FOR CORRECTION OF ERRORS DUE TO MISCLASSIFICATION

As is already mentioned above we have to face the situation that we can't avoid some errors in classifying accidents into primary safety function sensitive accidents and definitely primary safety function non-sensitive accidents. Especially when an investigation is based on mass accident databases, only a few categories of types of accident exist (e.g. the German Federal Statistical Offices uses seven types of accidents) and the lines are blurred. Concerning the primary safety function ESP we assigned in order to obtain the results of the proceeding section all so-called Driving Accidents to be ESP-sensitive. Of course it is reasonable to assume that a large percentage of the driving accidents are indeed influenced by an Electronic Stabilization Program but it is unrealistic to assume that all driving accidents without any exception have been influenced by ESP. Vice versa it is possible that a small percentage of accidents assigned to be ESP-non-sensitive may have been influenced by the primary safety function. Thus we think that the assumption that a small percentage p_{acc} of accidents has been falsely assigned to be primary safety function sensible and the other way round is reasonable. We consider the values 0.05 and 0.10 for p_{acc}.

The same argumentation holds true for the determination whether or not a specific accident involved vehicle has been equipped with the primary safety function or not. Since we usually have to conclude the equipment of a vehicle from the year of registration errors concerning the vehicle equipment are even more likely then erroneously classifying accidents. We assume for the following that the probability that a vehicle of being falsely categorised to the group of vehicles having the primary safety function on board and vice versa is p_{car}. Here values of p_{car} = 0.10 or 0.15 seems reasonable.

Table 3.
Accident cases corrected for misclassified vehicles (misclassification rate p_{car})

		Primary safety function-sensitive accident	
		No	Yes
Vehicle equipped with primary safety function	No	$\tilde{N}_{00}$	$\tilde{N}_{01}$
	Yes	$\tilde{N}_{10}$	$\tilde{N}_{11}$

where

$$\begin{aligned}\tilde{N}_{00} &= \frac{(1-p_{car})N_{00} - p_{car}N_{10}}{1-2p_{car}}\\ \tilde{N}_{01} &= \frac{(1-p_{car})N_{01} - p_{car}N_{11}}{1-2p_{car}}\\ \tilde{N}_{10} &= \frac{(1-p_{car})N_{10} - p_{car}N_{00}}{1-2p_{car}}\\ \tilde{N}_{11} &= \frac{(1-p_{car})N_{11} - p_{car}N_{01}}{1-2p_{car}}.\end{aligned} \qquad (5).$$

Since the errors in categorising accidents as well as vehicles do not depend on the accident outcome we are able to reconstruct from the observed data in Table 1, to data which do not contain the errors due to misclassification any more. In a first step we correct for vehicle misclassification and obtain (assuming a misclassification rate of p_{car}) Table 3.

In a second step we additionally correct for errors in classifying accidents incorrectly. Assuming a misclassification rate of p_{acc} we obtain the corrected Table 4, which now can be viewed as a table of accidents without miss-specified accidents and vehicles.

Table 4.
Accident cases corrected for misclassified vehicles and accidents (misclassification rates p_{car} and p_{acc})

		Primary safety function-sensitive accident	
		No	Yes
Vehicle equipped with primary safety function	No	n_{00}	n_{01}
	Yes	n_{10}	n_{11}

where

$$n_{00} = \frac{(1-p_{acc})\tilde{N}_{00} - p_{acc}\tilde{N}_{01}}{1-2p_{acc}}$$
$$n_{01} = \frac{(1-p_{acc})\tilde{N}_{01} - p_{acc}\tilde{N}_{00}}{1-2p_{acc}}$$
$$n_{10} = \frac{(1-p_{acc})\tilde{N}_{10} - p_{acc}\tilde{N}_{11}}{1-2p_{acc}} \qquad (6).$$
$$n_{11} = \frac{(1-p_{acc})N_{11} - p_{acc}N_{10}}{1-2p_{acc}}.$$

It can be shown that the Odds-ratio computed from Table 3 is always smaller than the odds-ratio computed from the not-corrected underlying Table 1 as long as there is a positive effect of the primary safety function, i.e. as long as the odds-ratio from Table 1 is less than one. Furthermore in this case the odds-ratio computed from the completely corrected Table 4 is again smaller than the odds-ratio computed from Table 3 and therefore also smaller then the odds-ratio computed from the completely uncorrected Table 1. In other words this means that in the case where we in fact have a primary safety function which leads to an improved behaviour in accidents which are sensitive to this specific primary safety function we obtain from the underlying Table 1 an upper bound for the true interesting odds-ratio, which is the odds-ratio from Table 4.

Turning to effectiveness this means that the effectiveness obtain from the uncorrected Table 1 underestimates the true effectiveness as long as there in fact is a positive effect of the primary safety function at all. The effectiveness computed from the completely corrected Table 4 may serve as a good approximation of the wanted effectiveness as long as we have specified the misclassification rates properly.

CORRECTION OF MISCLASSIFICATION ERRORS IN THE INVESTIGATION OF AN ELECTRONIC STABILIZATION PROGRAM

In this section we apply the methodology from the preceding section to the special case of ESP. Application of the two correction steps summarized in Tables 3 and 4 together with formulas (5) and (6) leads for the ESP-accident data presented in Table 2 the following corrected accident data (expected numbers with respect to the rates of misclassification)

Table 5.
Accident data for an investigation of ESP corrected for misclassified vehicles (misclassification rate 10%) and misclassified accidents (misclassification rate 10%)

		No	Yes	
Vehicle equipped with ESP	No	20144	10255	30399
	Yes	8614	2019	10633
Total		28758	12274	41032

It can easily be computed that the corrected Table 5 leads to an odds-ratio of OR=0.46 and an effectiveness of ESP of 54.0% (in contrast to the effectiveness of ESP of 32.4% obtained from Table 2 directly. It is worth mentioning again that the effectiveness of 32.4% obtained from Table 2 is in fact a lower bound for the effectiveness of ESP. If one agrees with the assumed misclassification rates of 10% for both vehicles and accidents then one should prefer the effectiveness of 54.0% obtained from the corrected Table 5. This effectiveness of 54% means that ESP is able to avoid even more then every second ESP-sensitive accident, which really is impressing. Assuming a misclassification rate of 5% for the accidents and of 10% for the vehicle equipment this leads along the same lines as above to a computed effectiveness of ESP of about 47.5%.

It should be mentioned that one obtains from In-depth accident data (e.g. from the GIDAS accident database) an effectiveness of ESP from about 48.6% (in contrast to an effectiveness of ESP of 32.4% obtained from the mass accident data material used in this study). An explanation could be that the accident classification and the knowledge about vehicle equipment in In-depth databases is much better and that one should compare the results obtained from In-depth data with the computed effectiveness from mass accident data corrected for errors of misclassification. In doing so the obtained effectiveness from corrected mass accident data and from In-depth accident data fit quite well.

Finally Figure 9 compares the effectiveness of ESP separately according to the year of first registration on the basis of uncorrected as well as for misclassification corrected accident data material.

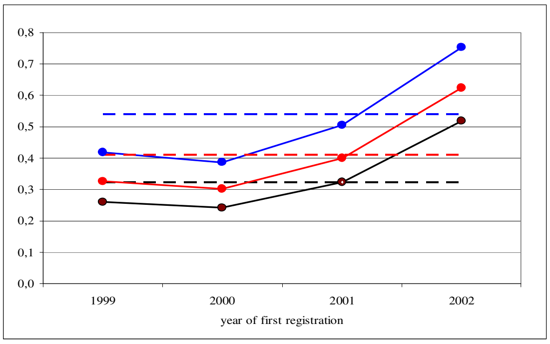

Figure 9. Effectiveness of ESP for different years of first registration (black solid line) and overall according to uncorrected data (black dashed line) and according to corrected data (misclassification rate 5% in red, misclassification rate 10% in blue)

As we have seen above, ESP especially works well for ESP-sensitive accidents with a fatal injury outcome. Above we obtained an effectiveness of ESP for this group of most severe ESP-sensitive accidents of 55.5%. If we correct these fatal accidents along the lines of Tables 3 and 4 together with formulas (5) and (6) from the preceding section for misclassified accidents and vehicles with the same misclassification rate of 10% as above, we obtain an effectiveness of ESP for fatal ESP-sensitive accidents of 77.9%.

If we only take a misclassification rate of 5% for both vehicles and accidents this leads to an effectiveness of ESP for fatal ESP-sensitive accidents of about 65.9%.

EFFECTIVENESS OF FURTHER PRIMARY SAFETY FUNCTIONS

Concerning the effectiveness of a primary safety function that assists the driver of a vehicle to brake as efficient as possible in emergency situations, it seems to be rather difficult to detect the potential effects on accident material from mass databases. Braking is a function which is more or less activated in every accident so we expect difficulties in separating between types of accidents which are sensitive and definitely not sensitive to braking.

Concerning the effectiveness for example of the Brake Assist (BAS) we most likely have to base the investigations on in-depth accident material. The BAS is constructed in order to reach in an emergency braking manoeuvre the optimum deceleration. It seems to be difficult for a not trained driver to achieve this without the help of an electronic assistant system. Optimum braking in critical situations will lead to the lowest possible speed at the time of the crash, which is of course advantageous for the injury outcome.

From the technical description of the Brake Assist it should be possible to quantify the amount of so-called delta-v reduction which could be reached by the system. Having this information at hand we then need information on injury outcome of accidents depending on delta-v. Such investigations exist and can for example be found in Busch (2005).

The quantification of the effectiveness of a system like the Brake Assist based on real world accident data is still under investigation and will be an ongoing research topic.

An overview of other systems like Adaptive Cruise Control (ACC) or Lane Departure Warning can be found in the SEiSS-report (2005).

CONCLUSIONS

In this paper we presented a statistical methodology which can be applied in investigations based on real world accident data in order to detect and to quantify a possible effectiveness of a primary safety function in vehicles. The methodology is based on a thorough selection and evaluation of accident data in a first step. The main statistical method is the method of so-called odds-ratios in categorical data. This methodology has already been used in other papers in the literature about effectiveness of primary safety functions. Given confidence intervals for odds-ratios allow for the decision whether from accident data observed facts are statistically significant or not.

The presented methodology is then applied to a large sample of German passenger car accidents for the years 1998-2002 recorded by the German Federal Statistical Office. The main focus is on the effectiveness of an Electronic Stabilization Program (ESP). The results demonstrate clearly and significantly that there in fact exists a substantial benefit of ESP. The effectiveness of ESP is quantified for different factors like different road conditions and different locations of the accidents as well as different age and gender of the driver and different sizes of the vehicles. Additionally the effectiveness is presented separately for accidents with fatal injury outcome. The amount of effectiveness of ESP varies over different factors but the main message is that ESP is a successful electronic primary safety function for vehicles.

Moreover the paper contains a proposal on how to correct for misclassification of accidents (primary safety function sensitive or definitely non-sensitive) and vehicles (equipped with the primary safety function or not). Again based on the German data it is demonstrated what the effects of such a correction are concerning ESP. The results show that all misclassifications lead in any way to an underestimation of the actual ESP-effectiveness.

In general it has been found that ESP-effectiveness in all ESP-sensitive crashes amounts at least to 32.4% and may increase to 54.0% by correcting misclassification. The ESP-benefit in fatal accidents is even higher and amounts to 55.5% (based on ESP-sensitive crashes) and may increase to about 77.9%, if for a certain percentage of misclassification is corrected. In summary ESP has again proven to be a most effective safety system and it should be integrated in all modern cars.

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