WHAT ACCIDENT ANALYSIS TELLS ABOUT SAFETY EVALUATIONS OF PASSENGER VEHICLES

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CONTRIBUTIONS BY PRIMARY AND SECONDARY SAFETY TO OVERALL SAFETY AND CONSEQUENCES FOR SAFETY RATINGS

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ABSTRACT:

In the past, the overall safety of passenger vehicles was dominated by secondary safety features, the ability of vehicles to reduce the consequences of accidents by mitigating injuries. In the last ten years, crash avoidance devices which can reduce the likelihood of accidents were introduced into cars. These devices support the braking of drivers, such as brake assists, or they reduce the likelihood of skidding, such as ESC, others will follow. Accident research clearly and increasingly shows the effectiveness of such devices under European road conditions. Although road conditions in the U.S. are different, there are positive indications as well.

In Europe, for belted occupants, ESC-effectiveness is estimated to be higher than airbag effectiveness. The accident data, indicating this, has been consistent for a couple of years. This paper provides accident data predicting the amount of safety benefit to be attributed to the different safety features in terms of risk reduction. This might help to overcome the problem that current 4 and 5 star cars are said to be in fact better than cars with fewer stars, while there is no significant difference between 4 and 5 star cars in real world accidents. It is the goal of the paper to quantify the degree of the total safety, reflected by a crash test based rating, like the current rating in Europe.

INTRODUCTION

Most of the European EU-member states see a long and steady decrease of fatalities. Volkswagen accident research has to increase its area of investigation, because in the area, where in the past a lot of severe accidents happened, the number of severe accidents dropped significantly. This is very positive news. When positive things happen, everybody is willing to take credit. The highway engineers, the colleagues, introducing more or less feasible and beneficial regulation on cars, the police, managing the traffic etc. This paper will deal with the effect of a car design tool, which is very likely to become the number three with regard to life saving potential: ESC. In the list of life saving features which was: Belt, structure, and airbag, we have now a very effective newcomer. The list now is: Belt, structure, ESC, and airbag as the number 4. The data presented here will underline these findings from the past year. They will show important implications for future accident research and for car rating attempts, because ESC not only reduces the number of fatalities, which is easily detected by accident researchers. It clearly shows its potential of crash avoidance. And accidents that do not happen are very difficult to detect in accident data bases.

GIDAS ACCIDENT DATA

The analyses in this paper are based on data supplied by GIDAS (German In Depth Accident Study). The advantages of this database are two-fold: (1) the number of cases is high enough to provide statistically significant results, and (2) each case is documented in great detail, permitting in-depth-analyses where required.

GIDAS is a unique project involving the German government and the motor vehicle industry. The cornerstone of the GIDAS-project was laid in 1973 and based on the recognition that official statistics were not sufficient to answer important questions that arise during accident research. For this reason, the German Federal Highway Research Institute ("Bundesanstalt für Straßenwesen", BASt) initiated a project, in which interdisciplinary teams analysed highway accidents from a scientific perspective – independent of the objectives and needs of law enforcement. The project underwent an important change in 1985, when the choice of the accidents for detailed analysis began to follow a random sampling plan.

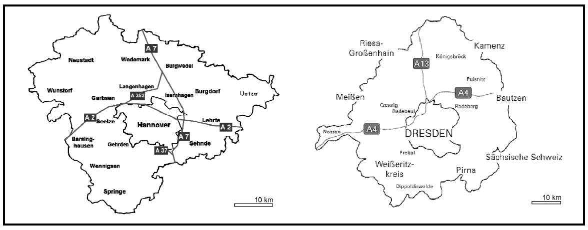

Figure 1. GIDAS Research Areas in Dresden and Hannover.

A second major improvement took place in 1999 when GIDAS was expanded to include cooperation with BASt and the German Association for Automotive Technology Research ("Forschungs-vereinigung Automobiltechnik e.V.", FAT). For this purpose, a second team was established at the Technical University of Dresden. Currently, the sampling criteria are as follows:

- road accident
- accident site in Hanover City and County or Dresden City and County
- accident occurs when a team is on duty
- at least one person in accident injured, regardless of severity

The data collected is entered in a hierarchical database. Depending on the type of accident, each case is described by a total of 500 to 3,000 variables, e. g accident type and environmental conditions (record Umwelt), vehicle-type, mass, drive train and the type of road it was on (record Fzg), the age, size, hours on the road and injury data for all persons involved (record Persdat and Verlueb). Each accident is reconstructed in detail including the pre-collision-phase. Available information includes initial vehicle and impact speed, deceleration as well as the collision sequence.

This database is representative of German national accident statistics, whereby severe cases are slightly over-represented.

SINGLE CASE ANALYSIS AT VW-GROUP-ACCIDENT-RESEARCH

With upcoming primary safety systems, VW implemented three brand research teams. The group accident research is located at Wolfsburg and performs on-scene accident research in an appr. 100 km radius of Wolfsburg. In addition to this at AUDI in Ingolstadt and at SVW in Shanghai, China, there exist local teams, providing on-scene accident investigation. The task for these teams is to increase the safety standard of all VW-Group products through detailed accident analysis of accidents with recent models of group-cars involved.

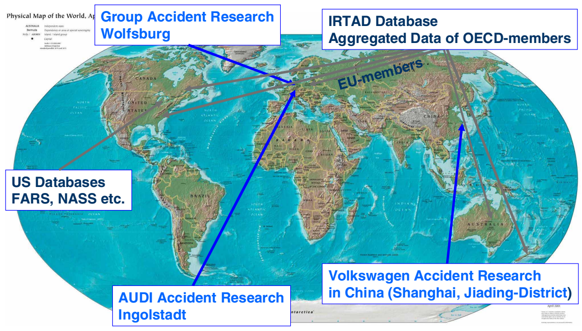

Figure 2. Main data sources of Volkswagen accident research

These teams consist of engineers, physicians and psychologists to gain a comprehensive understanding of the accident. These accident investigations include also technical analysis of the vehicle structure and suspension but also a complete reconstruction of the course of events of an accident, the medical analysis of injuries and the injury causing factors and last but not least a detailed view on accident causation by psychological analysis of the accident scene and interviews with the involved persons. The depth of the accident analysis depends on the willingness of the involved persons to co-operate. About 50% of the involved persons are willing to support us, even by answering the questions of our psychologists.

PROGRESS OF SECONDARY OR PASSIVE SAFETY

Significant progress was achieved by secondary or passive safety measures. The above mentioned GIDAS-database provides sufficient data, to investigate and quantify the progress.

Scenario	*Belted Occu-pant*	*Vehicle manu-factured 1995 or later*	*Airbag avail-able*	*Number of cases in GIDAS*
1	No	No	No	Ca.1 000
2	Yes	No	No	Ca.13 500
3	Yes	Yes	No	Ca. 630
4	Yes	Yes	Yes	Ca. 1 800

Figure 3. Scenarios and available data, describing the injury risk of passenger car occupants in accidents.

Figure 3 provides the scenarios which enable detection of the differences between driver populations. Comparing scenario 1 and 2, the difference should describe the benefit of using the belt. Scenario 2 and 3 describe the benefit of structural enhancements, achieved by implementing ECE R94 in Europe as a mandatory test for all passenger cars. And scenario 3 and 4 describe the additional benefit, achieved by front airbags. Looking into the data, regarding age and gender of the involved people, regarding collision mode and impact velocity, there is not much difference between the samples, so that the comparison is possible.

Belt	**No**	**Yes**	**Yes**	**Yes**
Manufactured	**..1994**	**..1994**	**1995..**	**1995..**
Airbag	**No**	**No**	**No**	**Yes**
Risk of				
MAIS 0..6	100%	100%	100%	100%
MAIS 1..6	78%	44%	38%	36%
MAIS 2..6	36%	12%	8,1%	7,0%
MAIS 3..6	16%	4,1%	2,1%	1,6%
MAIS 4..6	8,9%	1,8%	0,8%	0,5%
MAIS 5..6	6,5%	1,1%	0,6%	0,3%

Figure 4. Risk of MAIS-categories within the scenarios.

The conclusion of Figure 4 is that measures of passive safety were very beneficial in the past. This does not only hold for restraint systems, but also for the vehicle structure. The risk of high deformations and intrusions into the compartment decreased significantly. This topic was discussed in depth in former presentations.

THE DECREASE OF FATALITIES IN EUROPE

The effect of the findings of Figure 4 can be seen by the global data of most of the European member states. There is a positive trend in nearly all member states. Europe will reach a significant decrease of fatalities in the time period 2000..2010 of appr. 25%.

To make data from different countries comparable, in Figure 5 the year 1980 was chosen as 100% for all countries. Greece has its own development. There is also an unexplained increase in Spain between 1985 and 1990. With the exception of the period of reunification, Germany showed the highest decrease in the observed time period. This can also easily be seen, when the estimated progress for the time period 2000 and 2010 is estimated. This progress is relevant, because EU declared the goal of reducing fatalities in this period by 50%. This goal will be achieved only by Germany, if the current trend follows. On average, EU will achieve 25%. This is already a great success for European road safety.

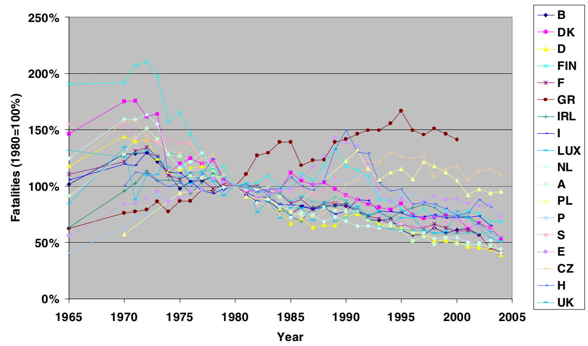

Figure 5. The positive trend of fatalities in Europe.

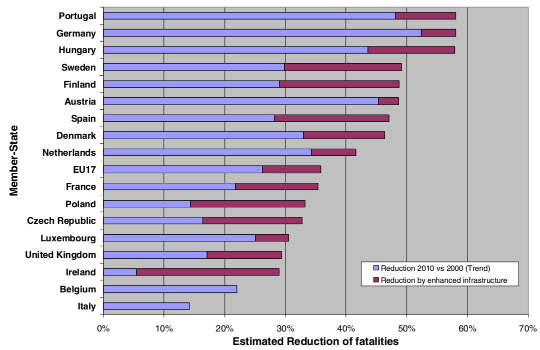

Figure 6. The expected decrease of fatalities in Europe in the time frame 2000..2010 and the additional progress that could be achieved, if infrastructure was enhanced so that 50% of rural traffic were on autobahns.

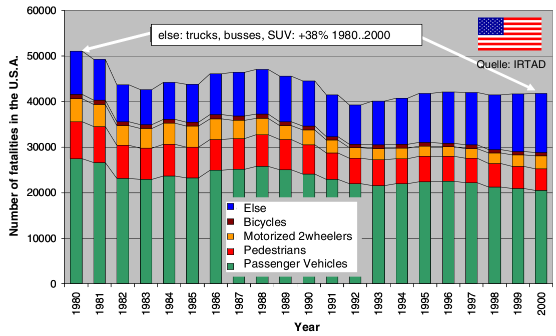

Figure 7. Number of fatalities in the U.S.A.

The main purpose of showing Figure 6 was to underline that European car fleet increased safety significantly in the past. This is not a trivial world wide effect, as the figures of U.S.A. (Figure 7) show. In the U.S., the absolute number of fatalities is not significantly changing. So the safety concepts in Europe are successful, including European car design.

It is difficult and probably not possible, to identify the reasons of these different developments. Europe has a very high belt usage rate, the U.S. has a high portion of SUVs, the increasing number is reflected by the blue bar of Figure 7. Europe is still dominated by European built cars. There is ECE R94 applied in Europe, FMVSS 208 in the U.S. etc.

THE MARKET PENETRATION OF ESC

In the past, Volkswagen and AUDI published a couple of papers, regarding ESC-effectiveness (Figure 8). The high effectiveness of ESC now has world-wide acceptance. Today we can add additional figures that show that ESC has potential to reduce property-damage accidents as well. A study, conducted by Volkswagen, together with the Volkswagen insurance (Volkswagen Financial Services), clearly showed a reduction of property damage volume by 9%.

	Effectiveness VW and AUDI ESP	Germany 2002		
		2002 Involved	Reduction by ESP	2002 Sum with VW and AUDI ESP
Minor injuries	16,5%	247.618	40.932	206.686
Hospitalization	24,9%	44.176	11.001	33.175
Fatalities	35,2%	4.004	1.411	2.593

Figure 8. Estimated reductions of fatalities and injuries, if current findings for Volkswagen and AUDI ESC would hold for the complete German fleet.

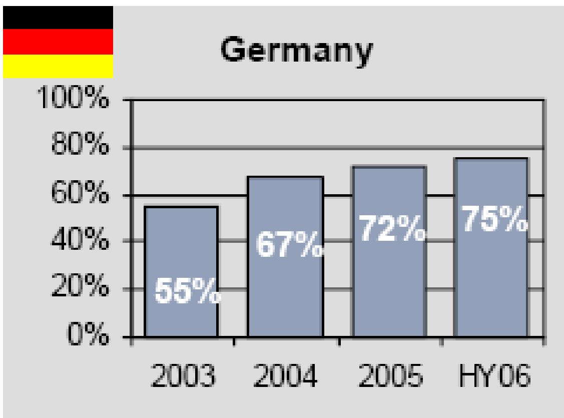

Figure 9. ESC-share in new car registrations. (Data kindly provided by Robert-Bosch-AG)

Another approach, which shows the crash avoidance potential of ESC, can be derived from GIDAS data. The share of ESC-equipped vehicles is published by Robert-Bosch-AG as shown in Figure 9. Together with the vehicle age distribution of Figure 10, we can compute the number of ESC-vehicles in German car fleet. We can compare this to the share of ESC-vehicles in GIDAS. This provides the chance to identify “lost accidents.” These are accidents that did not happen, because ESC prevented them from happening.

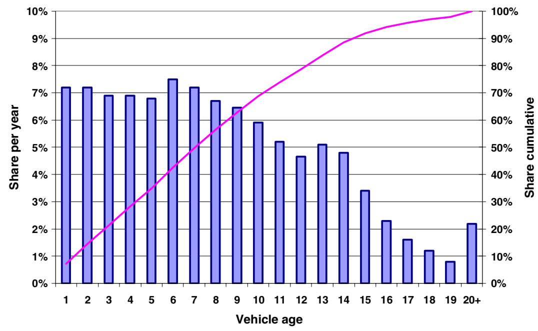

Figure 10. Vehicle age distribution in Germany. (Data kindly provided by Dr.Schepers, BASt)

To do so, we use the following formula:

A_Y Number of vehicles with system (Exposure)

A_N Number of vehicles without system (Exposure)

$A = A_N + A_Y$ Total number of vehicles (Exposure)

R_Y Accident risk with system

R_N Accident risk without system

P_E Observed frequency of system in exposure data

$$P_E = \frac{A_Y}{A}$$

P_A Observed frequency of system in accident data

$$Eff = \frac{R_N - R_Y}{R_N} \quad \text{Effectiveness of system}$$

From

$$P_A = \frac{A_Y * R_Y}{A_N * R_N + A_Y * R_Y}$$

and using the substitutions

$$R_Y = R_N * (1 - Eff) \quad \text{and} \quad A_Y = P_E * A$$

one can derive

$$P_A = \frac{P_E * (1 - Eff)}{1 - P_E * Eff}$$

or

$$Eff = 1 - \frac{P_A * (1 - P_E)}{P_E * (1 - P_A)}$$

This formula permits estimates of the effectiveness of a system to be calculated, when an observed frequency in exposure data and in accident data is available. As GIDAS reflects all accidents with injuries, this estimation explains, how many accidents with injuries are no longer accidents with injuries and thus disappear from GIDAS due to the effectiveness of ESC. So this research goes beyond the knowledge, derived from the observation that 80% of the skidding accidents will no longer occur. This proves the capability of ESC to avoid injury accidents.

Figure 11 provides for the years 2000 to 2004 the observed frequency of ESC-cars in GIDAS data base. The comparison to fleet data together with the formula, derived above, shows an effectiveness of ESC to avoid accidents of about 40%. This value is rather stable.

Taking into account that every year, the share of ESC-cars increases by 5 to 8%, we can expect that the positive trend in Germany will continue for a couple of years. And there are additional measures under development that will make this trend continue, when ESC has reached its 100% in the market.

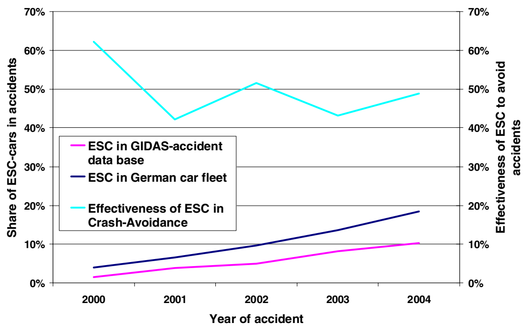

Figure 11. Effectiveness of ESC in avoiding accidents with injuries, derived from GIDAS data base and German fleet data.

These findings include a warning for all accident researchers, when studying their results. Due to lack of data, normally a risk is described as the ratio between the number of persons injured at a certain severity level, divided by the number of persons in the data base. This is frequently done, e.g. to compare the risk of young drivers and the risk of elderly drivers, or male vs. female drivers etc. When we know that injury accidents disappear from our data base, this means that in such computations, both, numerator and denominator are changed. The result is unpredictable. So after the introduction of ESC, there is even more careful data analysis necessary, before we can come to conclusions. When preparing this paper, the authors lost a lot of time, due to this effect in GIDAS data base. The effect has to be studied more in depth. Methodology has to be provided to analyze data, taking into account these effects of "disappearing accidents." It is not only ESC responsible for this effect, it is also the airbag. The likelihood that an accident is completely without injured persons, increased significantly due to the on-going enhancement of the restraint systems. This is a very positive effect, but for the accident researcher, things became more complicated: With current knowledge, we would not rely on a comparison on the basis of accident data before 2000 compared to data of accidents after 2000.

Accident Avoidance Capability of ESC for Different Degrees of Severity

The results of the preceding chapter can be applied to the different MAIS-classes to compute the injury mitigation capability of ESC. This was done by the same calculation. Instead of all involved persons, we look for persons with an injury of MAIS X+. Relevant for all these results is Figure 10. The results depend on these estimations. The higher the market share of ESC in the GIDAS area, the higher the effectiveness of ESC and vice versa. According to the increased market share of Volkswagen and AUDI cars in the Hannover area, we would expect an ESC above average in this area. In the Dresden area, there might be less so that for GIDAS, the combination of both areas, the German average might be a good estimation.

Cases without ESC from GIDAS								Share of
Year	MAIS 0+	MAIS 1+	MAIS 2+	MAIS 3+	MAIS 4+	MAIS 5+	MAIS 6	Non-ESC
2000	3489	1501	351	118	59	46	44	96,1%
2001	3185	1355	276	97	59	51	46	93,5%
2002	2553	1055	262	100	64	46	41	90,3%
2003	2725	1130	246	87	56	41	36	86,4%
2004	2799	1107	229	71	48	29	25	81,6%
Cases with ESC from GIDAS								Share of
Year	MAIS 0+	MAIS 1+	MAIS 2+	MAIS 3+	MAIS 4+	MAIS 5+	MAIS 6	ESC
2000	47	19	2	0	0	0	0	3,9%
2001	125	48	9	1	0	0	0	6,5%
2002	125	47	7	2	1	1	0	9,7%
2003	213	77	9	5	2	1	1	13,6%
2004	266	96	16	4	3	2	2	18,4%
Expected cases with ESC, due to its market share, if there were no ESC-effectiveness								
Year	MAIS 0+	MAIS 1+	MAIS 2+	MAIS 3+	MAIS 4+	MAIS 5+	MAIS 6	
2000	143	61	14	5	2	2	2	
2001	222	94	19	7	4	4	3	
2002	275	114	28	11	7	5	4	
2003	430	178	39	14	9	6	6	
2004	630	249	52	16	11	7	6	
Resulting effectiveness of ESC								
Year	MAIS 0+	MAIS 1+	MAIS 2+	MAIS 3+	MAIS 4+	MAIS 5+	MAIS 6	
2000	67,1%	69,1%	86,1%	100,0%	100,0%	100,0%	100,0%	
2001	43,7%	49,2%	53,2%	85,2%	100,0%	100,0%	100,0%	
2002	54,6%	58,6%	75,2%	81,4%	85,5%	79,8%	100,0%	
2003	50,4%	56,8%	76,8%	63,6%	77,4%	84,5%	82,4%	
2004	57,8%	61,5%	69,0%	75,0%	72,2%	69,4%	64,5%	
Wheighted effectiveness of ESC. Every year wheighted with ist ESC-share.								
	MAIS 0+	MAIS 1+	MAIS 2+	MAIS 3+	MAIS 4+	MAIS 5+	MAIS 6	
	53,5%	58,2%	69,1%	72,2%	76,2%	75,8%	70,4%	

Figure 12. Computation of ESC effectiveness for every injury severity class.

Figure 12 is computed from GIDAS data together with the ESC-share in German car fleet. So accident data and fleet data are combined. Possible different mileages between ESC and non-ESC-cars are neglected. But it is assumed that the mileage exposure of ESC-cars, which tend to be the larger cars, is higher than the mileage exposure of non-ESC-cars. The expected cases with ESC, due to its market share, if there were no effectiveness of

ESC, are computed by the following formula, which also allows to derive the effectiveness of ESC. You get the identical result, when you use the formula, mentioned in chapter "The market penetration of ESC."

The overall effectiveness was computed as a weighted average of the yearly effectivenesses. The alternative was to make one large class, adding the respective data of 2000..2004 and computing an effectiveness from this data. This provides an even higher effectiveness, so that we think, this approach is more conservative and as an average of four estimations statistically more reliable.

N_{ESC} GIDAS - cases with ESC

N_{noESC} GIDAS - cases without ESC

$N_{\exp ESC}$ Expected GIDAS - cases with ESC

p fleet share of ESC

eff effectiveness of ESC

$$N_{\exp ESC} = \frac{N_{noESC}}{1-p} * p$$

$$eff = 1 - \frac{N_{ESC}}{N_{\exp ESC}}$$

From Figure 12 it can clearly be seen, what was estimated from former effectiveness estimations based of the observed ESC-effectiveness of Volkswagen and AUDI ESP. Volkswagen and AUDI accident research found in their field studies an 80% reduction of skidding accidents by ESC. From this research, we predicted a fatality reduction as provided in Figure 8. This research was often blamed to over-estimate the benefit of ESC. We heard these arguments with a certain degree of satisfaction, because it is not our problem, when the observed Volkswagen and AUDI ESP effectiveness is higher than the overall effectiveness of ESC in general. But the figures provided show that there is a significant benefit of ESC which has to be taken into account in future analysis.

	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	MAIS 6
2000	57,0%	33,0%	6,7%	1,7%	0,4%	0,1%	1,3%
2001	57,5%	33,9%	5,6%	1,2%	0,3%	0,2%	1,4%
2002	58,7%	31,1%	6,3%	1,4%	0,7%	0,2%	1,6%
2003	58,5%	32,4%	5,8%	1,1%	0,6%	0,2%	1,3%
2004	60,5%	31,4%	5,6%	0,8%	0,7%	0,1%	0,9%

Figure 13. Distribution of the AIS-Classes for different accident years and belted non-ESC passenger car occupants.

Figure 13 provides for the years from 2000 to 2004 the MAIS-distributions for belted occupants in non-ESC cars. This shows that there are also increases in passive safety in this time-frame. This distribution can be used to compute the ESC-effectiveness for the police-recorded data.

	uninjured	injured no hospital	injured hospital	injured fatally	Share of no-ESC-pc	Reduction by ESC
MAIS 0	99,7%	0,0%	0,2%	0,0%	60,5%	50,5%
MAIS 1	0,0%	82,3%	17,3%	0,3%	31,4%	55,4%
MAIS 2	0,0%	39,4%	60,0%	0,6%	5,6%	67,8%
MAIS 3	0,0%	29,1%	68,2%	2,8%	0,8%	63,8%
MAIS 4	0,0%	27,0%	55,1%	17,9%	0,7%	76,7%
MAIS 5	0,0%	11,5%	23,0%	65,5%	0,1%	100,0%
MAIS 6	0,0%	0,0%	0,0%	100,0%	0,9%	70,4%
Distribution Without ESC	60,3%	28,5%	9,9%	1,3%		Sum 100,0%
With ESC	29,8%	12,4%	3,9%	0,4%		46,5%
Reduction	50,5%	56,6%	61,0%	71,9%		Average 53,5%

Figure 14. Computation of ESC-effectiveness (i.e. risk reduction) for injury categories of police data.

Figure 14 provides the relative probabilities describing the relationship between MAIS and police-recorded severity classes. Note that the reduction by ESC is not directly taken from Figure 12, because Figure 12 describes the effectiveness for MAIS 3+ and not MAIS 3. But the effectiveness used in Figure 14 can easily be derived from that provided in Figure 12.

THE PREDICTED AND OBSERVED DEVELOPMENT OF FATALITIES INFLUENCED BY ESC

The calculations of the preceding chapter can be used to predict the number of fatalities for Germany, if market penetration of ESC continues in a foreseeable manner. By starting this calculation with 1997, it can also be studied how far ESC explains the progress, already seen in the past.

Figure 15 computes in the column "Progress expected by ESC" the progress to be expected, when the fatalities of the preceding year are used to predict a new fatality number from the increasing share of ESC-vehicles and the assumed effectiveness of 71,9%. For all years besides 2002, this computation underestimates the decrease of fatalities. 541% means that the expected decrease (4023-3926) is 541% of the actual decrease of (4023-4005).

This underestimation of the decrease of fatalities means that additional effects influenced the positive trend in Germany. It is the authors' opinion that these are mainly the better compartments of current vehicles and the airbags. [11]. Beginning with 2006, the 100% of the progress is explained by ESC, because no other predictions were included.

For the near future, there are at least two factors to be considered as well, the ongoing change of vehicle fleet towards more stable compartments etc. But on the other hand the economic growth has also to be considered, because we know that under better economic conditions, people are more willing to drive.

Scenario 1 Things go on like today: 75% of the new cars are equipped with ESC 71,9% Fatality reduction by ESC Beginning with 2006, data a predicted according to scenario					
		Passenger Cars			
Year	Share of ESC-cars	Passenger car fatalities expected due to higher share of ESC	Actual number of passenger car fatalities	Progress explained by ESC	Progress compared to 2000
1997	0,00%	5622	5249	0,0%	119,4%
1998	0,66%	5224	4741	4,9%	107,8%
1999	1,98%	4696	4640	44,8%	105,6%
2000	3,93%	4574	4396	27,1%	100,0%
2001	6,52%	4312	4023	22,5%	91,5%
2002	9,73%	3926	4005	541,0%	91,1%
2003	13,62%	3884	3774	52,2%	85,9%
2004	18,38%	3631	3238	26,7%	73,7%
2005	23,46%	3102	2833	33,6%	64,4%
2006	28,67%	2705	2705	100,0%	61,5%
2007	34,07%	2573	2573	100,0%	58,5%
2008	39,47%	2441	2441	100,0%	55,5%
2009	44,87%	2308	2308	100,0%	52,5%
2010	50,27%	2176	2176	100,0%	49,5%
2011	55,67%	2044	2044	100,0%	46,5%
2012	61,07%	1911	1911	100,0%	43,5%
2013	66,47%	1779	1779	100,0%	40,5%
2014	71,87%	1647	1647	100,0%	37,5%
2015	75,00%	1570	1570	100,0%	35,7%
2016	75,00%	1570	1570	-	35,7%
2017	75,00%	1570	1570	-	35,7%
2018	75,00%	1570	1570	-	35,7%
2019	75,00%	1570	1570	-	35,7%
2020	75,00%	1570	1570	-	35,7%

Figure 15. Estimated progress by ESC for passenger car occupants, if 75% of new car registrations are ESC-equipped cars.

Figure 16 adds the data of the other traffic participants, so that the influence of this progress on all traffic fatalities in Germany is shown. Every other effect is neglected in the data. The 505% of 1999 mean that the progress achieved by decrease of passenger car fatalities (4741-4640) is 505% of the progress achieve, when all road traffic fatalities are taken into account (7792-7772).

The message of Figure 16 is that in 2010 Germany will achieve a drop of fatalities compared to 2000 to 62,7%. So ESC alone is nearly able to reach the goal of EU-commission, to achieve a 50% fatality reduction. So when the commission realizes today that it will not achieve its goal, (compare the predictions of the authors in [11]), the message is clear: Make ESC available EU-wide by convincing the customers, providing incentives, doing what you can to promote ESC.

If in 2007 Germany would have started to sell ESC in 100% of all cars (Figure 17), the car occupant fatalities would go down to 46,5% in 2010 (53,5% less than 2000) or in absolute numbers to 2044. In this case, when 100% ESC in the fleet (not only registrations) is reached, Germany's car occupant fatalities would go down to 957, to 21,8% of the 2000-level, which was also a low level, because in the nineties, after an increase in the period of reunification, there was a steady decrease as well.

	Total number of road traffic fatalities	Progress explained by passenger cars	Progress compared to 2000
1997	8549	-	113,9%
1998	7792	67,1%	103,9%
1999	7772	505,0%	103,6%
2000	7503	90,7%	100,0%
2001	6977	70,9%	93,0%
2002	6842	13,3%	91,2%
2003	6613	100,9%	88,1%
2004	5842	69,5%	77,9%
2005	5361	84,2%	71,5%
2006	5233	100,0%	69,7%
2007	5101	100,0%	68,0%
2008	4969	100,0%	66,2%
2009	4836	100,0%	64,5%
2010	4704	100,0%	62,7%
2011	4572	100,0%	60,9%
2012	4439	100,0%	59,2%
2013	4307	100,0%	57,4%
2014	4175	100,0%	55,6%
2015	4098	100,0%	54,6%
2016	4098	-	54,6%
2017	4098	-	54,6%
2018	4098	-	54,6%
2019	4098	-	54,6%
2020	4098	-	54,6%

Figure 16. Scenario 1 of Figure 15, but progress computed for all road traffic fatalities, to show the effect of ESC for road traffic in general.

Scenario 2 Actions to increase share of ESC-equipped cars Beginning with 2008, all new cars are equipped with ESC 71,9% Fatality reduction by ESC Beginning with 2006, data a predicted according to scenario					
		Passenger Cars			
Year	Share of ESC-cars	Passenger car fatalities expected due to higher share of ESC	Actual number of passenger car fatalities	Progress explained by ESC	Progress compared to 2000
1997	0,00%	5622	5249	0,0%	119,4%
1998	0,66%	5224	4741	4,9%	107,8%
1999	1,98%	4696	4640	44,8%	105,6%
2000	3,93%	4574	4396	27,1%	100,0%
2001	6,52%	4312	4023	22,5%	91,5%
2002	9,73%	3926	4005	541,0%	91,1%
2003	13,62%	3884	3774	52,2%	85,9%
2004	18,38%	3631	3238	26,7%	73,7%
2005	23,46%	3102	2833	33,6%	64,4%
2006	28,67%	2705	2705	100,0%	61,5%
2007	34,07%	2573	2573	100,0%	58,5%
2008	41,27%	2397	2397	100,0%	54,5%
2009	48,47%	2220	2220	100,0%	50,5%
2010	55,67%	2044	2044	100,0%	46,5%
2011	62,87%	1867	1867	100,0%	42,5%
2012	70,07%	1691	1691	100,0%	38,5%
2013	77,27%	1514	1514	100,0%	34,4%
2014	84,47%	1338	1338	100,0%	30,4%
2015	91,67%	1162	1162	100,0%	26,4%
2016	100,00%	957	957	100,0%	21,8%
2017	100,00%	957	957	-	21,8%
2018	100,00%	957	957	-	21,8%
2019	100,00%	957	957	-	21,8%
2020	100,00%	957	957	-	21,8%

Figure 17. Scenario of ESC-promotion by additional incentives, so that beginning with 2008 all new cars are equipped by ESC.

Figure 18 shows, what this means in terms of all traffic fatalities. The column “Additional benefit cumulative” shows, how many lives could be saved, if we would run into a 100% ESC-fleet instead of a 75% ESC fleet like in scenario 1 of Figure 16. By 2010 this would mean cumulative 265 fatalities less.

	Total number of road traffic fatalities	Progress explained by passenger cars	Progress compared to 2000	Additional benefit compared to Scenario 1	Additional benefit cumulative
1997	8549	-	113,9%	0	0
1998	7792	67,1%	103,9%	0	0
1999	7772	505,0%	103,6%	0	0
2000	7503	90,7%	100,0%	0	0
2001	6977	70,9%	93,0%	0	0
2002	6842	13,3%	91,2%	0	0
2003	6613	100,9%	88,1%	0	0
2004	5842	69,5%	77,9%	0	0
2005	5361	84,2%	71,5%	0	0
2006	5233	100,0%	69,7%	0	0
2007	5101	100,0%	68,0%	0	0
2008	4925	100,0%	65,6%	44	44
2009	4748	100,0%	63,3%	88	132
2010	4572	100,0%	60,9%	132	265
2011	4395	100,0%	58,6%	176	441
2012	4219	100,0%	56,2%	221	662
2013	4042	100,0%	53,9%	265	926
2014	3866	100,0%	51,5%	309	1235
2015	3690	100,0%	49,2%	408	1643
2016	3485	-	46,5%	613	2256
2017	3485	-	46,5%	613	2869
2018	3485	-	46,5%	613	3481
2019	3485	-	46,5%	613	4094
2020	3485	-	46,5%	613	4706

Figure 18. Scenario 2 of Figure 17, but progress computed for all road traffic fatalities. The last two columns show the additional benefit per year and cumulative that can be achieved, when scenario 2 occurs instead of scenario 1.

Scenario 3
Scenario 2 and actions to increase the change to new cars in the fleet
Increase of new car registrations by 1% of fleet (14% of new car registrations)
71,9% Fatality reduction by ESC
Beginning with 2006, data a predicted according to scenario

		Passenger Cars			
Year	Share of ESC-cars	Passenger car fatalities expected due to higher share of ESC	Actual number of passenger car fatalities	Progress explained by ESC	Progress compared to 2000
1997	0,00%	5622	5249	0,0%	119,4%
1998	0,66%	5224	4741	4,9%	107,8%
1999	1,98%	4696	4640	44,8%	105,6%
2000	3,93%	4574	4396	27,1%	100,0%
2001	6,52%	4312	4023	22,5%	91,5%
2002	9,73%	3926	4005	541,0%	91,1%
2003	13,62%	3884	3774	52,2%	85,9%
2004	18,38%	3631	3238	26,7%	73,7%
2005	23,46%	3102	2833	33,6%	64,4%
2006	28,67%	2705	2705	100,0%	61,5%
2007	34,07%	2573	2573	100,0%	58,5%
2008	42,27%	2372	2372	100,0%	54,0%
2009	50,47%	2171	2171	100,0%	49,4%
2010	58,67%	1970	1970	100,0%	44,8%
2011	66,87%	1769	1769	100,0%	40,2%
2012	75,07%	1568	1568	100,0%	35,7%
2013	83,27%	1367	1367	100,0%	31,1%
2014	91,47%	1166	1166	100,0%	26,5%
2015	100,00%	957	957	100,0%	21,8%
2016	100,00%	957	957	-	21,8%
2017	100,00%	957	957	-	21,8%
2018	100,00%	957	957	-	21,8%
2019	100,00%	957	957	-	21,8%
2020	100,00%	957	957	-	21,8%

Figure 19. Scenario of a two incentives promoting ESC. Firstly, beginning with 2008, all new cars are equipped with ESC. Secondly, new car registrations are increased by 14%, so that additional 1% of fleet are changed into new cars. Only the ESC-effect is reflected, other effects like better restraint systems, better compartments are only reflected up to 2005.

Scenario 3 now deals with the velocity of the change of fleet. It was assumed that 1% more than the current 7,2% (i.e.8,2%) are exchanged per year. This would mean, that we reach the 100% ESC fleet already in 2015 one year earlier. Additional 846 fatalities would not take place.

Figure 21 combines all these scenarios and clearly shows that for the next 10 years we can expect a very steady decrease of fatalities in all countries that implement ESC in a significant amount into the car fleet.

ESC is only the beginning of this process. LaneDepartureAlert, Drowsiness monitoring, Side assist and other tools will support the driver, so that accidents become more and more unlikely to happen. Car-to-car-communication will provide a situation that cars organize their use of junctions e.g. by themselves and co-operate in organizing a as far as possible error-free traffic flow.

	Total number of road traffic fatalities	Progress explained by passenger cars	Progress compared to 2000	Additional benefit compared to Scenario 2	Additional benefit cumulative
1997	8549	-	113,9%	0	0
1998	7792	67,1%	103,9%	0	0
1999	7772	505,0%	103,6%	0	0
2000	7503	90,7%	100,0%	0	0
2001	6977	70,9%	93,0%	0	0
2002	6842	13,3%	91,2%	0	0
2003	6613	100,9%	88,1%	0	0
2004	5842	69,5%	77,9%	0	0
2005	5361	84,2%	71,5%	0	0
2006	5233	100,0%	69,7%	0	0
2007	5101	100,0%	68,0%	0	0
2008	4900	100,0%	65,3%	25	25
2009	4699	100,0%	62,6%	49	74
2010	4498	100,0%	60,0%	74	147
2011	4297	100,0%	57,3%	98	245
2012	4096	100,0%	54,6%	123	368
2013	3895	100,0%	51,9%	147	515
2014	3694	100,0%	49,2%	172	686
2015	3485	100,0%	46,5%	204	890
2016	3485	-	46,5%	0	890
2017	3485	-	46,5%	0	890
2018	3485	-	46,5%	0	890
2019	3485	-	46,5%	0	890
2020	3485	-	46,5%	0	890

Figure 20. Scenario 3 of Figure 19, but progress computed for all road traffic fatalities. The last two columns show the additional benefit per year and cumulative that can be achieved, when scenario 3 occurs instead of scenario 2.

We are not of the opinion that we will have a VISION-ZERO traffic without any accidents, any fatalities. Appr. 10% of our fatalities in car crashes are suicide. A system that prevents suicide from happening is not possible in a free society. But we will reduce the number of accidents not only by some percents, but by a significant factor in a foreseeable future of 20 years or so.

When studying these scenarios it becomes clear that all efforts, all resources are needed to reach this ambitious goal. With this background it is unbelievable, why most of the efforts of scientific institutes, involved in safety research, are still related to passive safety issues. Passive safety was very successful in the past, that is acknowledged without any reservations. But for the future, we have to emphasize on issues that provide similar progress of safety, as passive safety did in the past. All discussions on passive safety enhancements are dealing with very small portions of safety progress, in some cases, it is even unclear, whether there is progress or whether negative side effects dominate (compatibility discussion). So it is worth to study, how the world of ESC-cars will look like. This is done in the following chapter.

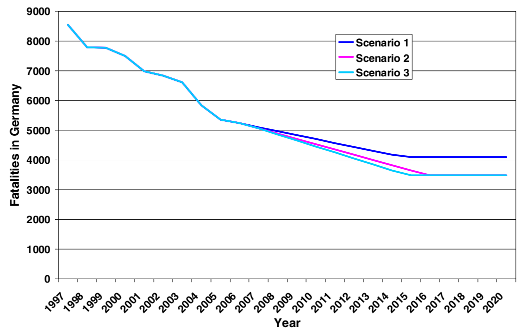

Figure 21. Decrease of total number of fatalities in Germany. For 2007 and the following only the effect of ESC and the different scenarios of introducing ESC into the fleet are reflected.

Influence of Fleet Change on Collision Modes

In the past, Volkswagen and AUDI published a couple of papers (see references), regarding ESC-effectiveness (Figure 8). Our first computations of the high effectiveness of ESC are now world-wide accepted and the data is rather clear. This does not mean that ESC is effective in every single case, but in general, there is a positive effect in the German accident data. It must be stated that American data was not available to the authors, to make similar analysis for the U.S.A. The different road situation in the U.S. with more straight roads, more cross-roads might lead to different results. The authors are not able to investigate the influence of these differences, because no comparable in-depth data like GIDAS was available to the authors.

Figure 22 is an example of an observation that ESC positively influenced GIDAS data. In the nineties, skidding accidents were at a level of 10 to 15%. A decrease started in 1998 with the fleet penetration of ESC. When we look deeper into the data, we see that the average age of the skidding drivers did not change. It is approximately 30 years, the non-skidding drivers are 10 years older (Figure 24). This means that ESC supports all drivers, not only drivers that have special skills. The normal driver will not realize ESC in his normal driving situations. It helps, when it is needed, the driver probably is not aware of the intervention of ESC. This is part of the success of ESC, only experts can willingly create a situation of ESC-intervention. Volkswagen and AUDI researchers did a lot to implement an ESC that does only intervene when necessary and as far as possible, prevents the driver from playing with ESC.

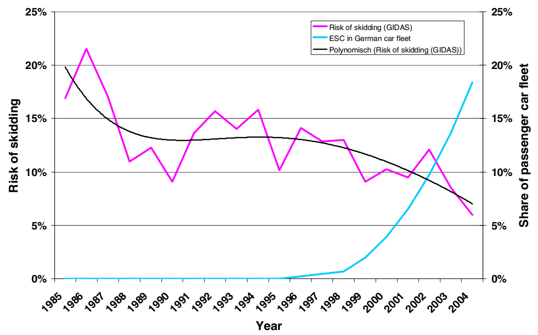

Figure 22. The risk of skidding and the market penetration by ESC.

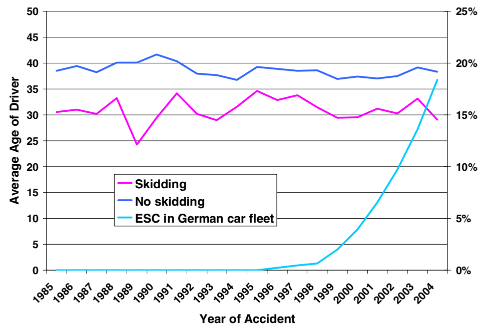

Figure 23. Skidding accidents and the average age of drivers. Drivers involved in skidding tend to be younger. The age mean value is not influenced by ESC.

The increase of the share of females in Figure 24 is in line with the general observation that females more often have a car of their own, are more often driving, so that this increase is more or less surprisingly low and not an indication of anything else.

The next figure (Figure 25) deals with the question, whether ESC influences collision modes positively. The effectiveness of ESC for different collision modes has to be examined. The idea of this computation is to take into account the crash-avoidance capability of ESC. The 100% accidents, as observed in the sample of cars without ESC, will be reduced to 46,5%, due to the 53,5% crash-avoidance capability of ESC. So the distribution of accident types of ESC-cars, as described in Figure 25, in fact is the distribution of the 46,5% accidents still occurring after implementing ESC. This distribution is given in column 3 of Figure 26.

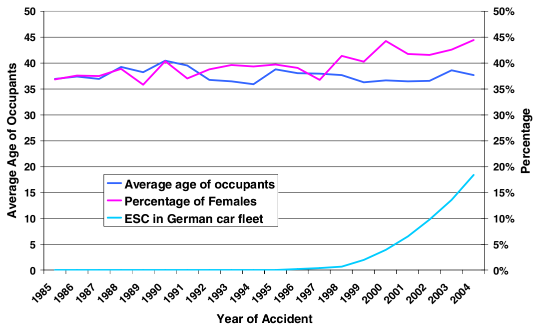

Figure 24. Average age of occupants, involved in accidents is constant versus time, share of female occupants increased.

Accident type		
	GIDAS: Passenger car	
	with ESC	without ESC
Driving accident	191	3673
Accident caused by turning off the road	329	3888
Accident caused by turning into a road or by crossing it	478	6916
Accident with pedestrian crossing the road	208	2421
Accident involving stationary vehicles	67	924
Accident between vehicles moving along in carriageway	540	6413
Other accident	108	1312
Unknown	25	66
Sum	1946	25613

Figure 25. Number of accidents for different types of accidents for passenger vehicles with and without ESC as found in GIDAS.

Accident type	Distribution		53,5% crash-avoidance capability of ESC
	with ESC	without ESC	
Driving accident	9,8%	14,3%	4,6%
Accident caused by turning off the road	16,9%	15,2%	7,9%
Accident caused by turning into a road or by crossing it	24,6%	27,0%	11,4%
Accident with pedestrian crossing the road	10,7%	9,4%	5,0%
Accident involving stationary vehicles	3,4%	3,6%	1,6%
Accident between vehicles moving along in carriageway	27,7%	25,0%	12,9%
Other accident	5,5%	5,1%	2,6%
Unkown	1,3%	0,4%	0,6%
Other accident	100,0%	100,0%	46,5%

Figure 26. Distribution of accident types for passenger vehicles with and without ESC. For ESC-cars, the 53,5% crash-avoidance capability of ESC (compare Figure 14) is taken into account in a separate computation.

Figure 26 provides two columns to be compared to the original data, the distribution of vehicles without ESC. Figure 27 shows the result, when effectiveness computation is conducted for these two columns. It is mathematically clear that the comparison of two distributions (sum is 100% in both cases) provides positive and negative effectiveness. Taking into account the crash-avoidance potential, overcomes this problem. The result is seen in the second column of Figure 27.

Accident type	Comparison of distributions	ESC effectiveness
Driving accident	31,4%	63,3%
Accident caused by turning off the road	-11,5%	40,3%
Accident caused by turning into a road or by crossing it	8,9%	51,3%
Accident with pedestrian crossing the road	-13,3%	39,4%
Accident involving stationary vehicles	4,4%	48,9%
Accident between vehicles moving along in carriageway	-11,0%	40,6%
Other accident	-8,5%	41,9%

Figure 27. Effectiveness, derived from the distributions of Figure 26. Only when taking into account the crash-avoidance capability of ESC, meaningful results are achieved.

The column "Full ESC Effectiveness" of Figure 27 shows that the highest effectiveness of ESC is seen for driving accidents. A car is driving on difficult road conditions or changing road conditions, is e.g. skidding, and an accident occurs. This is a very typical ESC situation attributed to small and winding European roads. The lowest effectiveness ESC shows for pedestrians. It is surprising that ESC even shows effectiveness even in this case. These phenomena have to be studied more in depth to understand, whether and why this is possible. One possible explanation is the fact that ESC cars are more able to obey the steering input of the driver. It shall also be noted at this point that a group of accident researchers uses the double pair approach to estimate probabilities. These researchers would assume that pedestrian accidents do not change (the double pair in this case are the accidents of the pedestrians with the ESC-cars vs. the accidents with non-ESC-cars). They would find an effectiveness of ESC between the effectiveness of column "Full ESC Effectiveness" of Figure 27 and zero for pedestrians. Everything else is positive. But the authors are of the opinion that this is not an adequate analysis, because of the arguments given above.

Impact type	Comparison of distributions	ESC effectiveness
Front	7,5%	57,0%
Side	-5,1%	51,1%
Rear	-76,8%	17,8%

Figure 28. ESC-effectiveness for different impact types. All passenger vehicles. Same calculation as in Figure 25 to Figure 27.

Figure 28 provides the results of a similar calculation for front, side and rear impact. ESC is mainly beneficial for front- and side impact, less beneficial for rear impact, but it is beneficial for all collision modes. What does this mean for a car rating: Whatever the estimation of the benefit of the conducted test procedure is: More than 50% of the possible benefit is attributed to the fact whether the vehicle is equipped by ESC or not. For sure passive safety measures will not completely prevent injuries from happening, so the fact that a car is ESC-equipped describes probably 60 or 70% of the car's safety potential.

Single Vehicle Accident	62,50%
Skidding before accident	74,30%
Roll-over	79,40%
Roll-over with MAIS 1+	71,40%
Roll-over with MAIS 2+	51,60%
Roll-over with MAIS 3+	58,70%
Roll-over with MAIS 4+	41,50%
Roll-over with MAIS 5+	58,90%
Roll-over with MAIS 6	78,10%

Figure 29. ESC-effectiveness for different accident situations. Computation always takes into account the crash avoidance capability of ESC.

The situation is even more clear, when single-vehicle accidents or accidents with skidding or roll-over accidents are taken into account. The countermeasure is clearly ESC and nothing else. All other measure, imaginable, are far below the level, expressed by the effectiveness provided in Figure 29.

CONCLUSIONS

- There is a high benefit in ESC in crash avoidance and in injury mitigation.
- The crash avoidance capability of ESC can be derived from the share of ESC-cars in the fleet and in the accident data. ESC-equipped cars will have approximately 50% less accidents than other cars.
- The number of severe injuries will decrease by more than 60% for cars, equipped with ESC.
- The number of fatalities will decrease by more than 70% for cars, equipped with ESC.
- The positive trend in German fatalities will continue for the next decade, if 75% of newly registered cars are equipped with ESC.
- ESC alone will decrease the fatality figures of 2000 to a level of 55%, if 75% of newly registered cars are equipped with ESC.
- If 100% of the newly registered cars are equipped with ESC, ESC alone will decrease the fatality figures of 2000 to a level of 46%.
- The most valid measure of roll-over protection, of frontal impact protection, of side impact protection is ESC. ESC will reduce the risk in all of these accidents by more than 50%. This must be taken into account regarding future regulations and new car assessments.
- When rating a car, more than 50% of the safety rating figures or stars or whatever should be attributed to ESC. This means that a rating, which takes into account passive safety only, is incomplete and possibly misleading.
- Governments should change their safety politics to stop the further increase of weight and cost of the car by more and more inefficient passive safety requirement and should prioritize active safety measures.
- Tools like side assist, lane departure alert, and drowsiness monitoring should be studied instead, because they have similar potential to ESC.
- Accident research must take into account the crash avoidance potential of systems like ESC, because when they neglect it, they will achieve misleading results, because ESC not only changes the enumerator of benefit calculations by reducing severe injuries and fatalities, but it also changes the denominator of all accidents, because a lot of accidents disappear from the accident data file.
- Accident research, benefit studies, prioritizations should be made prospective. They should try to predict the future of the car fleet, because collision mode distribution will change significantly.

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