1. BACKGROUND

The aim of this study is to investigate the effects of Electronic Stability Control (ESC) on the frequency and severity of accidents. ESC is an active safety device for motor vehicles which enhances controllability by preventing skidding in cases of oversteering or understeering. Skidding occurs when speed, steering input, possibly also braking, are in excess of what is possible under the current friction conditions. It may be caused by too high speed in curves, collision avoidance manoeuvres, or icy roads. Skidding can result in road departure and collisions with objects or other vehicles. These collisions are relatively likely to be side collisions, because skidding involves rotation. Side collisions usually have quite severe consequences because vehicles provide less protection than in front collisions. The avoidance of skidding may not always avoid collisions, but if a side collision is replaced by a head-on collision, the severity of the consequences may be reduced. According to Zobel et al. (2000), the probability of at least one very severely injured (MAIS 5+) in accidents which (without ESC) would be side collisions, would be reduced by 50%. Front collisions can also have severe consequences, especially when occurring at high speeds. Under extreme dynamic conditions, skidding can result in roll-over. Accidents which involve skidding can be prevented by ESC, or the severity of such accidents may be reduced due to reduced probability of side collisions and roll-overs, increased probability for successful evasive manoeuvres, and reduced speed in collisions. Collisions in junctions and overtaking accidents are less likely to be prevented by ESC. Accidents which involve skidding, but in which the driver was driving extremely fast, very sleepy, or driving under the influence of alcohol or drugs, also are less likely to be affected by ESC.

ESC is already standard equipment in many cars of middle and upper price classes, but not in many smaller cars and SUV. There exists a large variety of ESC systems. The systems have in common that they increase the controllability of vehicles by regulating dynamic parameters (yaw characteristics, and sideslip). When the vehicle is beginning to slide or to spin, ESC counteracts by braking individual wheels, and reducing engine power. But ESC cannot overrun physics, and may not always prevent the vehicle from sliding.
The positive safety effects can be neutralized if drivers have too much trust in the system and drive faster (risk compensation). On the other hand, ESC can be informative, warning drivers about slippery driving conditions. How driver behavior is affected depends on whether the driver knows that the vehicle is equipped with ESC and how ESC works (many do not know this), whether the driver notices when ESC is getting active, and how the activity of ESC is perceived (e.g., as “danger” vs. “fun”). This is likely to be different for different drivers. It is also likely to be affected by properties of ESC like for example how strongly it affects driving dynamics and how much of its activity is perceived by the driver.

In this study, the proportion of accidents that may be affected by ESC, based on its influence on driving dynamics, is estimated by conducting an analysis of literature and accident statistics. Then, a review of empirical studies is conducted to estimate how many accidents actually are avoided in vehicles which are equipped with ESC. It is expected that accident involvement differs between cars with and without ESC, and that the difference varies between different types of accidents. Because of the potential of ESC to reduce accident severity, stronger effects are expected for more severe accidents. Changes in driver behavior may also affect the effectiveness of ESC.

2. AVOIDABLE ACCIDENTS

In order to estimate the proportion of accidents that may be avoided or affected by ESC, studies have been reviewed that have estimated the proportion of accidents that involve skidding or loss of control. Most studies have focused on specific types of accidents. In accident statistics, accidents are usually not classified according to whether or not skidding or loss of control has been a contributing factor. But several studies have estimated to what extent skidding is involved in types of injury accidents, which are represented in most accident statistics.

Campbell et al. (2003) have analyzed contributing factors for different accident types, based on US databases (Crashworthiness Data System, CDS, including ca. 18.000 accidents over 4 years, and General Estimates System, GES, including ca. 55.000 accidents over one year; both data bases include property damage, injury and fatal accidents). Skidding was a major contributing factor in 50% of all single vehicle off-road accidents, in 1% of all rear-end collisions, and in 8% of all lane-change accidents. In about half of the single vehicle off-road accidents, speeding (driving above the speed limit) was an additional contributing factor. Collisions between vehicles in crossing directions have not been included in the analysis.

According to the Insurance Institute for Highway Safety (IIHS, 2005) ESC could reduce the risk of fatal accidents by 56% for single vehicle accidents, by 17% for multi-vehicle accidents, and by 34% for all accidents. About 25% of all fatal single vehicle accidents are estimated to be caused by transient oversteering.
Langwieder et al. (2003) have analyzed reports of personal injury accidents in Germany. Skidding was a contributing factor in 39% of all single vehicle accidents (in total, 524 accidents), and in 12% of all collisions (in total, 1,111 accidents) involving more than one motor vehicle.

Sferco et al. (2001) have analyzed 2,674 accidents in the European Accident Causation Survey (EACS, based on data from 5 European countries). They estimated the proportion of accidents which might have been avoided or affected by ESC with various degrees of probability. 2% of all injury accidents would “definitively” have been avoided, 9% would definitively have been avoided or affected, and 18% would “probably” have been avoided or affected with ESC. The figures for fatal accidents are nearly twice as high as for all injury accidents. At a maximum, 31% of all injury accidents, and 48% of all fatal accidents might be affected by ESC. The proportion of accidents involving loss of control which might be affected by ESC is estimated to be 42% for all injury accidents, and 67% of all fatal accidents.

Unselt et al. (2004) have analyzed data from a representative sample of over 2 million accidents in Germany in 2002. They have estimated, that loss of control was involved in 21% of all injury accidents, and in 43% of all fatal accidents in Germany. About 50% of all cars were equipped with ESC in 2002 in Germany.

Zobel et al. (2004) have analyzed 10,000 accidents in the data base of the Medizinische Hochschule Hannover. They have estimated that 44% of all accidents with at least one very severely injured (MAIS 5+) involved skidding. The proportion of accidents involving skidding is higher in curves (53%) that on straight sections (40%). On wet roads, the proportion is larger than on dry roads on straight sections, but lower than on dry roads in curves.

According to vehicle manufacturers, the potential of ESC to avoid accidents is somewhat larger. According to Volkswagen, 80% of all accidents involving skidding and 20% of all road fatalities could be avoided if all vehicles were equipped with ESC. According to DaimlerChrysler, the probability to be involved in an accident is 6% lower for vehicles that are equipped with ESC than for vehicles without ESC.

According to accident statistics from different EU countries, Norway and USA, about 30% of all injury accidents are single vehicle accidents, and about 10% of all injury accidents are collisions between vehicles in oncoming directions. These figures are very similar in different countries. Among fatal accidents, the proportion of single accidents is larger, but varies considerably between countries.

Based on these results, the proportion of injury accidents that may be affected by ESC is between 40% and 50% of single vehicle accidents and around 10% of multi-part accidents. Ca. 20% of all accidents may be affected by ESC. Affected means that consequences may be less severe, or that accidents can be altogether avoided.
These estimates are associated with a large amount of uncertainty. The studies are conducted in different countries in which infrastructure, speed limits, driving habits and other factors vary considerably. In most studies it is unknown which proportion of vehicles involved in the analyzed accidents are equipped with ESC. All studies have arrived at the estimates by very different methods. Taking into account all these differences between the studies, the results are differing to a quite low degree.

3. AVOIDED ACCIDENTS

How many accidents are avoided by ESC is examined in a meta-analysis which includes studies that have investigated numbers and types of accidents of cars with and without ESC. The following studies are included in the analysis:

- Aga & Okada, 2003 (Japan)
- Dang, 2004 (USA)
- Farmer, 2004 (USA)
- Lie, Tingvall, Krafft & Kullgren, 2004 (Sweden)
- Bahouth, 2005 (USA)
- Page & Cuny, 2006 (France)

The results of these studies were combined by means of the log-odds method of meta-analysis (Cristensen, 2003; Elvik, 2005; Fleiss, 1981). Estimates of effect were computed as rate ratios, based on the numbers of accidents reported in the studies:

\[
\text{Estimate of effect} = \frac{\frac{\text{Study acc. with ESC}}{\text{Study acc. without ESC}}}{\frac{\text{Control acc. with ESC}}{\text{Control acc. without ESC}}}
\]

Study accidents refers to the type of accidents, for which the effect of ESC is estimated, e.g. single vehicle accidents. In most studies, types of accidents that are not assumed to be affected by ESC were used as control.

For combining estimates of effects from different studies, each estimate is assigned a statistical weight, and the weighted mean of the estimates is computed.

The statistical weights assigned to the effects are inversely proportional to its variance. The variance of the logarithm of the odds ratios is:

\[
\text{Variance} = \sum \frac{1}{\text{Number of accidents}}
\]

The weighted mean of estimates of effect is computed by summing up all products of the logarithms of the estimates of effects and the corresponding
weights, and dividing the sum by the sum of all weights. The result is then rescaled from the logarithmic scale in order to obtain the combined estimate of effect in terms of odds ratios. This estimate indicates the proportion of accidents, that is not avoided by ESC. If the estimate is for example 0.89, the reduction in the number of accidents in vehicles with ESC is 11% ([1-0.89] * 100% = 11%).

In a first step, a sensitivity analysis is conducted to test if there is publication bias. Publication bias exists when studies which do not find significant effects in the expected direction are not published. When there is publication bias, the largest effects are found in small studies, because effects have to be larger in smaller studies in order to become significant. When there is no publication bias, also studies which do not yield significant results in the expected direction are published, and the effects will be uncorrelated to the study size. Only more extreme values will be more frequent in smaller studies. A simple method to test for publication bias is to investigate the relationship between the effect sizes and the weights of the corresponding studies in funnel plots (Christensen, 2003). A funnel plot is a scatter diagram with the logarithm of the effect sizes (Ln(effect) on the x-axis, and the statistical weights on the y-axis. Logarithms of effect sizes are used instead of effect sizes because the weights refer to the logarithm of the effects. A “funnel” is drawn around the average Ln(effect). Without publication bias, the Ln(effects) are expected to be assembled symmetrically in the shape of a funnel around the average, where the larger studies are grouped around the average effect. For single vehicle and multi part accidents, the effects of ESC are expected to be different. Funnel plots are shown in figure 1 for single vehicle accidents and in figure 2 for head-on collisions. Fatal accidents are shown as circles. The summary estimates for all injury / unspecified accidents are shown as vertical lines.
As seen in figure 1 and 2, there is large variety in the estimates, especially in the effects on single vehicle accidents. The distribution of the single vehicle accidents is somewhat asymmetrical. Large negative effect sizes (large accident reductions) have been found in smaller studies. This is to be expected when there is publication bias. A possible alternative explanation is that studies in which the accident severity is unspecified include material...
damage accidents. For material damage accidents, no large effects are expected, and they are more frequent (have larger statistical weights) than injury accidents or fatal accidents. The effects on head on collisions are quite symmetrically distributed around the summary estimate. These effects are probably not affected by publication bias.

For fatal single accidents there are only four effect sizes, all of which are quite far away from the summary estimate (which is about the same as for injury / unspecified accidents). For fatal head-on collisions there is only one effect size.

The estimates of effect for different types of accidents and different degrees of accident severity are shown in table 1. Additionally, 95% confidence intervals are shown.

Table 1: Estimated reductions of accidents for vehicles equipped with ESC

<table>
<thead>
<tr>
<th>Accident severity</th>
<th>Type of accidents</th>
<th>Best estimate</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>All / unspecified</td>
<td>Single vehicle</td>
<td>-46</td>
<td>(-49; -43)</td>
</tr>
<tr>
<td>All / unspecified</td>
<td>Loss of Control</td>
<td>-44</td>
<td>(-67; -7)</td>
</tr>
<tr>
<td>All / unspecified</td>
<td>Head on</td>
<td>-13</td>
<td>(-18; -9)</td>
</tr>
<tr>
<td>Unspecified</td>
<td>Multi vehicle</td>
<td>+3</td>
<td>(-2; +9)</td>
</tr>
<tr>
<td>All injury accidents</td>
<td>Single vehicle</td>
<td>-38</td>
<td>(-49; -25)</td>
</tr>
<tr>
<td>Fatal accidents</td>
<td>Single vehicle</td>
<td>-45</td>
<td>(-56; -32)</td>
</tr>
<tr>
<td>All injury accidents</td>
<td>Head on</td>
<td>no data available</td>
<td></td>
</tr>
<tr>
<td>Fatal accidents</td>
<td>Head on</td>
<td>-79</td>
<td>(-97; +61)</td>
</tr>
<tr>
<td>All injury accidents</td>
<td>Multi vehicle</td>
<td>-1</td>
<td>(-11; +9)</td>
</tr>
<tr>
<td>Fatal accidents</td>
<td>Multi vehicle</td>
<td>-37</td>
<td>(-56; -10)</td>
</tr>
</tbody>
</table>

For single vehicle and loss of control accidents quite large reductions were found, also the number of head-on collisions was reduced significantly. For all types of accidents, the effects on fatal accidents are larger than the effects on other accidents. The difference is largest for multipart accidents, where a significant effect only was found on fatal accidents, but not on other accidents.

It was not possible to compute a combined effect for all types of accidents, because most studies have focused on specific types of accidents. Weighing the results for single accidents and head-on collisions with the proportions of these accidents, results in a reduction of 15% of all accidents (all severities).
A further analysis is conducted in order to test if the effects are dependent on the type of study. There were two types of studies. Before-and-after studies have investigated accident involvement of one or more types of cars before and after ESC became standard equipment in these cars. In these studies, the types of cars with and without ESC are identical, but ESC is not the only change that was made to the vehicles as ESC became standard equipment. Case-control studies compare accident involvement between different types of vehicles with and without ESC. In these studies there are different types of cars with and without ESC. But the vehicles have been matched with respect to properties that are relevant for active and passive safety, which are not controlled for in before-and-after studies. Effects of time trends can be assumed to be present in before-and-after studies, but not in case control studies. Vehicle age is controlled in most studies.

For single vehicle accidents, estimates of effects on accidents (all severities or unspecified severity) is compared between the two types of studies. The estimate of effect in case-control studies is a reduction by 38%. In before-and-after studies the estimate of effect is a reduction by 51%. The difference is statistically significant. For multi part accidents this comparison is not possible because none of the case control studies has investigated effects on multi part accidents.

In summary, cars equipped with ESC seem to be involved in fewer accidents, especially in fewer single vehicle accidents, in fewer head-on collisions, and in fewer fatal accidents. There are large differences between the results of different studies. These differences do not seem to be caused by publication bias, but at least partly by methodological weaknesses. The number of studies and effect sizes does not allow further analyses of factors that might be responsible for the larger variance in the effect sizes.

4. SUMMARY AND CONCLUSIONS

Accident analyses and accident statistics show a considerable potential of ESC to reduce the number of accidents, and to reduce accident severity, especially for single vehicle accidents (ca. 40-50% reduction), and for head-on collisions (ca. 10% reduction). The effects are expected to be larger for more severe accidents.

A review of studies that have investigated accident involvement of cars with and without ESC has found reductions of the number of accidents of nearly the same magnitude. The reduction of the number of single vehicle accidents is 46%. The reduction of the number of head-on collisions is 13%. All multi-vehicle accidents do not seem to be affected by ESC, but the number of fatal multi vehicle accidents is reduced by 37%.

Since not all accidents that might be affected or avoided can be expected to actually be avoided, the results of the empirical studies seem to be even a bit
too much in accordance with the theoretical potential of ESC to affect accidents. There are several possible explanations for this finding.

Firstly, the accordance may not be as large as it seems. There is large uncertainty associated with the estimated theoretical potential, and large variance in the empirical results on the numbers of accidents. Not surprisingly, more conservative estimates, and better controlled studies yield lower effects. Effects may become even smaller in studies that would more actively control for confounding factors, e.g. by applying multivariate models.

Secondly, most studies which have been used for estimating the theoretical potential of ESC to avoid accidents have not taken into account that many of the vehicles in the studies already are equipped with ESC. Taking this into account, the estimated potential would probably become even larger, and the accordance with the empirical results on accidents less surprisingly large.

Thirdly, other factors than the ability of ESC to increase controllability may have contributed to the results. If ESC were functioning as a warning device which leads to more careful driving under slippery conditions, this would improve the effectiveness of ESC, and might at least partly explain the large empirical effects on accidents in the meta-analysis. It does not seem likely that ESC provokes more risky driving. In this case, the empirical studies on accidents would have shown smaller effects. However, given the uncertainty associated with the empirical results, and without studies on how ESC actually affects driver behaviour, this remains speculative.

Lastly, it is not known what other differences besides ESC there are between cars with and without ESC in the empirical studies. Before-and-after studies have not controlled for other improvements made to the cars besides ESC. Case-control studies have controlled for several other properties of the cars, but for example not for dynamic properties or for the types of tyres. Both are relevant for the performance of cars under slippery conditions, and for the performance of ESC. Side airbags are another example for a safety aspect that can be assumed to be associated with the effectiveness of ESC, and that is not included in the list of factors that have been controlled for in the empirical studies. Side airbags can not avoid accidents, but they can reduce the severity of side collisions (Zobel et al., 2004). Infrastructure improvements can also reduce the occurrence and severity of accidents. In case-control studies they are probably less relevant, but they may have contributed to the accident reductions in before-and-after studies. Examples are infrastructure measures that aim at reducing off-road and curve accidents are rumble strips, chevron markings or guardrails.

5. BIBLIOGRAPHY


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