# D8 - Harmonised analytic methods to predict casualty reductions of both accident and injury reduction measures – Part 1

**Contract No:** **GMA2-2001-52066 S07.17215**
**Acronym:** **PENDANT**
**Title:** **Pan-European Co-ordinated Accident and Injury Databases**


**Project Co-ordinator:**
Professor Pete Thomas
Vehicle Safety Research Centre
Ergonomics and Safety Research Institute
Loughborough University
Holywell Building
Holywell Way
Loughborough
LE11 3UZ


**Organisation name of lead contractor for this deliverable:**
Graz University of Technology

**Due Date of Deliverable: 30/06/2006**

**Submission Date: 15/06/2006**


**Author (s): Ernst Tomasch, Michael Stanzel, Lucy Rackliff, and Marianne Page**


**Project Start Date: 1st January 2003** **Duration: 3,5 years**


**Project funded by the European Community under the 'Competitive and Sustainable Growth' Programme (1998-2002)**

# Table of Contents



## Figures

## Tables

# 1 Executive Summary

In recent years the boundaries between active and passive safety blurred more and more. Passive Safety in the traditional term includes all safety aspects to prevent occupants from injuries or at least injury severity should be reduced respectively. Passive Safety starts with the collision (first vehicle contact) and ends with rescue (open vehicle doors). Within this phase the occupant has to be protected by the passenger compartment whereby no intrusion should occur. Active Safety instead was developed to interact prior to the collision whereby the goal is to prevent accidents. The extensive interaction between Active and Passive Safety led to the terminologies “primary” and “secondary” safety whereas the expression Integrated Safety Concept [32] was generated.
Even though the PENDANT database was focused primarily at passive safety issues an attempt was made to evaluate the effectiveness of active safety system, namely Electronic Stability Control Systems.

Many different active safety systems are already implemented in cars. Emergency Braking assistant (BAS) or Electronic Brakeforce Distribution (EBD) intervene according to the speed of operation of the brake pedal, to increase brake load. This leads to full deceleration in a short time in which a driver couldn’t produce it. To reach full deceleration some milliseconds earlier could stop the vehicle some meters sooner. If the accident won’t be avoided collision velocity would be reduced. In addition Antilock Braking System (ABS) prevents the wheels to lock and it is still possible to steer the vehicle. Another active safety system is Traction Control System (TCS) or the origin German terminus Acceleration Slip Regulation (ASR) which prevents the wheels from spinning. This system avoids losing friction during acceleration and ensures maximum contact between tyres and road surface even if there are not ideal conditions e.g. icy surface. Now Electronic Stability Program (ESP) comes into account. For consistency, all Electronic Stability Control Systems will be named “ESP” in this document, even though the respective manufacturer may have chosen a different name such as, e.g., DSC, ESC, VSC, PSM or other.
In combination of these active safety systems BOSCH interpretation of ESP is squaring ABS and TCS so that ESP becomes $(ABS + TCS)^2$. ESP should prevent skidding in dangerous situations e.g. too high velocity in a road bend. Sooner or later every driver is confronted with dangerous not identifiable situations. What does ESP do to support driver? ESP detect oversteer or understeer by monitoring vehicle’s response to the driver. Sensors detect if skidding conditions are developing and ESP takes over control. Depending on surface of road ESP brakes front or rear wheels or reduce excess power as needed so the vehicle keep the direction the driver is steering. Of course ESP cannot override the physically given limits. If a driver overstrains of the possibilities of chassis and ESP, then also ESP can not prevent an accident. [1], [2], [3].

The best protection against accidents is to prevent them in advance (www.bosch-esperience.de) or if this couldn’t be managed active safety should lead to another impact configuration (front instead of side impact) whereby passive safety features will protect the occupants and reduce injury severity respectively.

Within this task at the beginning a literature review done by VSRC will answer some basic questions like:

- What is Electronic Stability Program (ESP)
- How did ESP develop
- How does it work
- How widespread is implementation
- How might future systems evolve

Whilst reviewed studies acknowledge some limitations in the methodology, all reach the conclusion that ESP should be a significant development in reducing accidents and casualties.

According to the PENDANT work plan it was Volkswagen's assignment to analyze the data with respect to any possible ESP influence. This analysis was done in multiple stages.

At first the relevant information was extracted from the global PENDANT database, creating a subset of data on the accident and the vehicle level for passenger cars only. It must be stated that the whole collection procedure wasn't finished and therefore some data are missing. Most injury and all of the deformation information were not required for this analysis and therefore omitted.

The next step consisted of a plausibility (or, reliability) check on the database in order to detect and possibly fix miscoded values. For lack of exposure data (e.g., kilometres driven by cars with and without ESP by road condition, etc.) an ESP equipment rate was estimated based on a selection of accidents assumed to be insensitive to ESP. Then the ratio of ESP-equipped vs. non-ESP cars was determined and broken down by CARE accident type. As no information on skidding was found in the database this information was manually added by analyzing the accident narratives. The proportion of skidding related accidents vs. total number of accidents by ESP equipment was established for different road conditions.

Finally, the distribution of maximum injury severity by ESP equipment was analyzed.

Graz University of Technology investigated the pre-collision phase in single vehicle accidents. PENDANT database was analyzed to identify possible cases which could be used for ESP analysis. In case that PENDANT was more or less a passive safety project it was difficult to get access to cases were on-scene data was present. Only a few of the partners were investigating on-scene and so appropriate accidents were reduced to a small number out of PENDANT sample. Anyway these cases were studied and it should be found out if ESP could prevent accidents or at least lead to a different accident scenario. Additional to PENDANT database the database of TU Graz – ZEDATU (Zentrale Datenbank tödlicher Unfälle) were analysed to increase the number of single vehicle accidents. Finally 26 cases were found in PENDANT and ZEDATU at all.

It was found out that these analysed single vehicle accidents could be categorized at first into bends or straight roads. Furthermore the driver intervened to get back to the road when he left to either side to the verge or avoided a collision with an obstacle on the road. The third level was the steering behaviour of the driver afterwards. Depending on the road surface skidding occurred immediately after he pulled the steering wheel too much and the yaw angle exceeded physical threshold where counter steering became useless. The second possibility at this level was to counter steer certain times. In fact of the fast change between steering and counter steering the yaw angular velocity and the yaw angle are increasing. If the limit is reached the vehicle becomes unstable and starts to slide without any possibility to avoid a collision.

PENDANT cases were primary gathered from Germany. Some single vehicle accidents were identified from Netherlands, Austria and Sweden. Additional a second database (ZEDATU) were examined to increase the number of cases. Within this task it was figured out that approximately 30% of single vehicle accidents will be prevented by ESP. As it was seen, ESP could lead to a different impact configuration too. Frontal impacts could develop in side impacts and side impacts were led to frontal impacts. Mostly change of velocity was reduced but in some cases Delta-V increased. In cases when the wheels got stuck at the soil rollover occurred. Difficulties were noticed in the road side design. Poles/Posts and trees were mainly impacted. More than 22% of all single vehicle accidents present in PENDANT database resulted in rollovers. This might come from different relations to police of the partners and therefore different collection behaviour.

# 2 Introduction

Task 1.3 of PENDANT Work Package 1 has numerous objectives. In a first step statistical analysis has to be performed to compare the casualty of single vehicle accidents of cars with and without Electronic Stability Programme (ESP), (or other safety feature, as agreed with the EC depending on data availability). In a WP 1 meeting it was decided to use ESP for this purpose. Most of the cars are already equipped with ABS and another investigation to this active safety feature didn't sound reasonable.

In a second step the most well documented 30 (if available) single car accidents with cars not equipped with ESP should be identified. Those accidents were additionally investigated and reconstructed. In comparison each case should be simulated with the assumption that the cars are equipped with ESP. The differences regarding accident avoidance or severity as well as reduction of injury risk will be investigated and the effectiveness will be documented. An additional part for this analysis was the possibility that ESP could prevent accidents. Of course not every situation can be handled. In the end 26 cases were available for analysis.

Another important issue is the influence of engineering countermeasures. Therefore a general simplified multi-body car model for the collision phase will be used to predict acceleration, deformation and intrusion behaviour of the cars during a real world accident. The possibility of adapting this multi-body model to specific car makes and models will be explored. The validation of these models will be based on the crash test database developed in task 1. The simulation results of this new tool can than be used as input for occupant simulation to predict injuries or the effect of engineering countermeasures on the injury risk of the occupants.

Partners of this task were VSRC, VW, TNO and TUG and within those four parties the work were spread.

# 3 Literature review

## 3.1 What is ESP

ESP (as described by Bosch, 2000) is a closed loop control system, which prevents lateral instability of the vehicle. It integrates the antilock brake system (ABS), which prevents wheel lock-up, and the traction control system (TCS) which prevents the spin of the driven wheels, to prevent the wheels from *pushing out* of the turn when the vehicle is steered.

ESP improves active vehicle safety by

- Supporting the driver in laterally critical dynamic situations.
- Enhancing stability and tracking performance in all modes (full braking, partial braking, and acceleration)
- Enhancing directional stability, even during extreme steering manoeuvres (panic reactions), leading to a drastic reduction in the danger of skidding.
- Improving handling in limit situations.
- Depending on the situation, improving traction and stopping distances, steerability and stability.

It ensures that the vehicle remains on a track which corresponds as far as possible to the course of the steering angle

## 3.2 How did ESP develop

In the 1970s, the change to front wheel drive cars instigated the use of diagonal brake circuit splits. Following this development, Anti-Lock Braking (ABS) was introduced into mainstream vehicles in the 1980s. ABS uses digitally controlled electrics, wheel sensors and hydraulic control valves to control brake pressure to prevent wheels locking during braking, enabling the driver to steer and manoeuvre. This led to the development of Traction Control (TCS), an extension of ABS, which applies the brakes at driven wheels and reduces engine torque in order to decrease wheel spin during acceleration. ABS has been further enhanced by the introduction of Electronic Brakeforce Distribution (EBD) and Emergency Brake Assist which intervene according to the speed of operation of the brake pedal, to increase brake load in accordance with the maximum set by the ABS system.

## 3.3 How does ESP work

A number of signals define the driver's input. These are:

- Steering wheel sensors
- Brake-pressure sensor
- Engine management

Feedback from the following sensors is used to calculate coefficients of friction between the tyres and the road:

- The lateral-acceleration sensor
- The yaw-rate sensor
- The brake-pressure sensor

ESP influences the vehicle's three degrees of freedom in the plane of the road (lateral and longitudinal velocities, and yaw moment about the vertical axis). The system compares how the vehicle should behave according to the drivers input (nominal behaviour), with its actual movement, and then acts to minimise the difference between the two, through control of tyre forces. So, in the case of under-steer, which is caused by the front wheels losing traction, stability control brakes one of the front wheels to cause rotation in the opposite direction to the one in which the vehicle is sliding, thus bringing the car back into line (left hand side of figure 1, below).  In the case of over-steer; the system would apply one of the rear brakes (depending on whether the vehicle was being steered to left or right) to cause rotation in the vehicle and help the front tyres gain grip (as shown by the right hand side of Fig. 1)

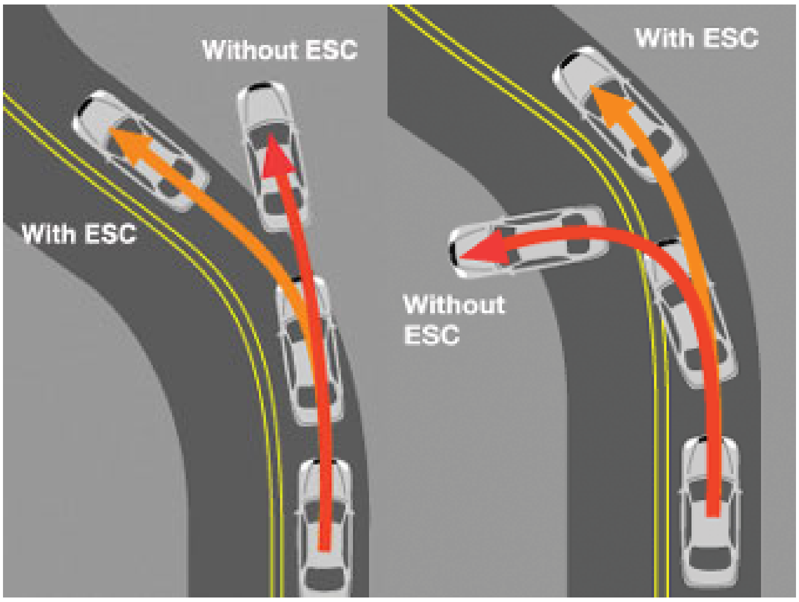



Fig. 1: How ESP helps to maintain vehicle control;

*Source: www.esceducation.org*

Various versions of the system exist, marketed under different names. These include Dynamic Stability Control and Cornering Stability Control (these are

both Bosch systems, but they differ slightly in the programming from ESP). General Motors has a system called “Active Handling Chassis Control System”, but this is designed primarily with sports cars in mind, and so has less emphasis on intervention. Other systems include Toyota (Vehicle Stability Control), BMW (Dynamic Stability Control) Ford, (AdvanceTrac), and Honda, Mitsubishi and Volvo also have their own systems. The way these systems are programmed to respond to the information from the sensors varies, in both how soon the system intervenes, and in how much control of speed is taken from the driver. For ease of understanding, the term electronic stability program (ESP) is used here throughout, regardless of the specific vehicle or system being referred to.
Fig. 1 shows how the various elements of the ESP system are coordinated.

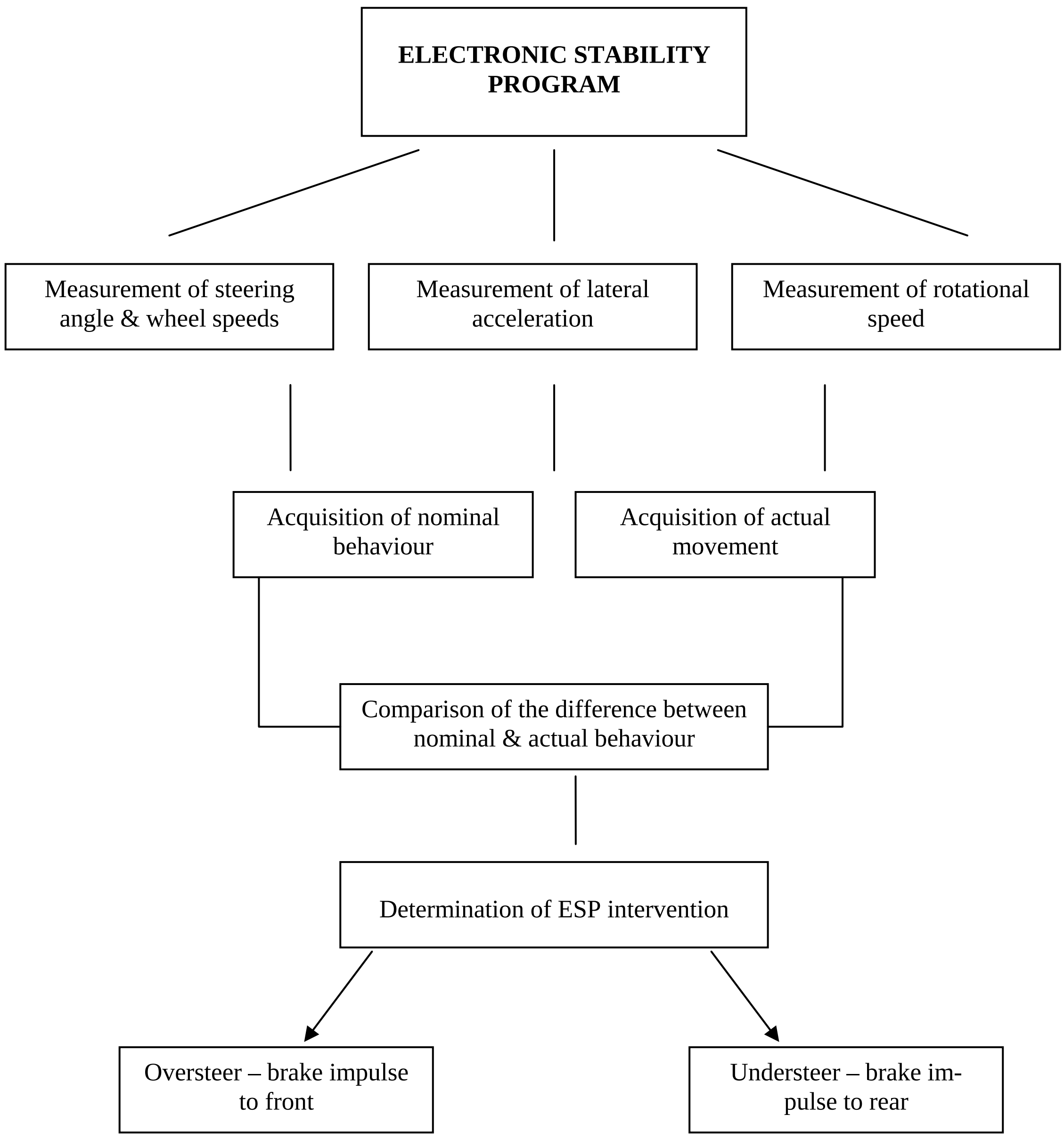



Fig. 2: Coordination of the ESP system

*Source; adapted from Giessen (2002)*

## 3.4 How widespread is implementation

ESP was initially fitted as an option on luxury vehicles in the mid 1990s, and was fitted as standard to all Mercedes-Benz passenger car models from mid 1999 onwards.

Tab. 1, below, describes the availability of some form of ESP on various car makes and models.

Europe.

| **Manufacturer** | **Availability of ESP** |
|---|---|
| Peugeot | Optional charged extra on lower specification models of 206, 407, 607. Standard on higher specification. |
| Vauxhall | Optional charged extra on lower specification models of Zafira, Astra and Vectra. Not available on 1.6L models. |
| Ford | Standard on Mondeo |
| VW | Available on all models, standard on Golf, Jetta, Touran, Beetle, Eos, Passat, Sharan, Phaeton, Touareg (specs for Germany) |
| BMW | Standard across range. |
| Nissan | Available on 350Z |
| Fiat | Available as an option even on smaller models such as Punto. |

US

| **Manufacturer** | **Availability of ESP** |
|---|---|
| BMW | Standard across range. |
| GMC | Optional on Yukon, standard on Savana. |
| Cadillac | Optional on CTS and DeVille, standard on ESV, STS, SRX, XLR |
| VW | Standard on Golf, Jetta, Beetle. Passat, Phaeton and Touareg. |
| Ford | Optional on Expedition and Freestar, standard on Explorer. |
| Chrysler | Optional on 300, standard on Crossfire. |

Tab. 1: Availability of stability protection on selected car make and models

Source, www.safercar.gov/pages/ESC-equippedvehicles-2005.htm, and car-manufacturers own websites.

Tab. 2 gives estimates for the proportion of new car registrations in various countries which are equipped with a stability protection system. This table shows that the highest proportion of registered new cars with ESP is found in Germany. This may be because ESP is more commonly offered as standard here, or it may be because German consumers value such additional safety technology. Together, the five countries shown in this table are responsible for 80% of new car registrations across the EU.

It is estimated that ESP is now fitted on around one in three new car registrations in Europe, but only 6% in the US (www.ergoboy.com/news/europe_electronic_stability_control.php). It is possible that variations in the availability of ESP on different makes and models in different countries may be driven by the different requirements of consumers in those countries. Stability control is standard on three-door Ford Focus sold in Germany. On the same vehicle for sale in the UK, it is a charged option, but in the US it is a more expensive option ($1220 and $1625 respectively). It may be therefore, that manufacturers believe German consumers value additional safety features highly, but fewer UK and US consumers do. There are other potential explanations for these differences, such as variations in price-elasticity across different countries, but drawing conclusions about the role of these in influencing implementation and take-up rates is beyond the scope of this study.

| Country | Percentage |
|---|---|
| France | 35 |
| Germany | 55 |
| Italy | 14 |
| Spain | 25 |
| UK | 20 |
| Average | 29 |

Tab. 2: Percentage of new car registrations equipped with stability protection

Source: Bosch[2]

## 3.5 Likely effectiveness in reducing accidents

a) Issues to be considered

- Assessment on a test track or in a simulator may not provide results that are directly transferable to real life. Many of the estimates for the effect of other safety developments (for example, ABS), turned out to be over-optimistic. This may be because in real-life situations, the presence of technology such as ABS causes the driver to behave differently from how he/she would when facing the same situation in a non-equipped car. (Farmer, 2001)

- Assuming that a real-life study is required, choosing and identifying suitable vehicles then becomes a critical part of the study. The introduction of such technology occurs in a way that makes *scientific* study of its effects difficult. For example, it may be introduced initially as an optional extra, as ESP has been on many car makes and models. In this case, the drivers who chose to pay for the extra safety feature may have a different personality-type from those who don't, which may affect their likely accident-involvement. ESP may be linked to other design elements (such as high performance) which will have their own effect on accident involvement and outcome. Even once technology becomes "main stream" it may be on none of a company's vehicles prior to a particular model year, and then be on all of them. In this case, non-equipped cars will all be older than the equipped cars, which will affect their level of exposure and thus possibly accident involvement.

- Whilst the number of ESP-equipped cars is increasing all the time, it is still a small enough proportion of the total-vehicle-fleet to make it difficult to produce statistically robust analysis.

b) Results

A number of studies have been done which aim to assess the effectiveness of ESP in different countries. Tab. 3, below summarises the results of these studies, which are set out in detail onwards.

| Author (s) | Year | Study Area | Accident type | Estimated reduction |
|---|---|---|---|---|
| Tingvall et al | 2004 | Sweden | Fatal LOC<br>Injury-only LOC | 67%<br>42% |
| Farmer | 2004 | United States | Single-vehicle fatal<br>All fatal | 56%<br>34% |
| Dang | 2004 | United States | SUV single vehicle fatal<br>Single vehicle fatal | 67%<br>30% |
| Aga & Okakada | 2003 | Japan | All single vehicle<br>Head-on collisions | 35%<br>35% |

Tab. 3: Summary of main findings of ESP studies

### Tingvall et al (2004)

The methodology for this study involved using a measure of induced exposure to estimate the exposure to accidents of equipped and non-equipped cars. The method is based on the identification of at least one type of event which is assumed not to be affected by the presence in the vehicle of ESP. ESP-sensitive and ESP-insensitive accidents and road conditions were matched in relation to ESP-equipped and non-equipped cars. Similar (or where possible, identical) car makes and models were used, in order to isolate the effects of ESP. All of the accidents included in the study occurred in Sweden between 2000 and 2002. The main findings of the study were as follows;

- On all road-surfaces and in all accidents except rear-end impacts, the effectiveness is 22.1%. The effectiveness estimate ranges from 1.1 to 43.1%.
- On wet roads the effect is at least 7.8%, with 95% confidence limits. These accidents account for 30% of the accident population.
- On roads covered with ice & snow the effectiveness is higher – at least 12.1% (lower bound of the 95% confidence limit). These accidents account for 10% of the accidents in the study.

It is stressed that the results should not necessarily be generalised beyond Sweden, due to

- The limited number of accidents included in the analysis.
- The fact that Sweden is a very small country.
- The inclement weather in Sweden for part of the year. The effect of the weather is particularly important, given that ESP is predicted to be more effective in wet or icy conditions. In areas where icy roads are very rare, the effectiveness of ESP may be appreciably lower.

### Farmer (2004)

For this study, the models eligible were those for which ESP was standard equipment in 2000 or 2001 model year. In addition, there must have been an earlier model year for which the design was identical, save for the availability of ESP (I.e. it was previously unavailable, or was an option only). The primary study group was vehicles which changed from no ESP to standard ESP in consecutive years. Information relating to the collision-involvement of those vehicles was extracted from the State Data System for the states of Florida, Illinois, Kansas, Maryland, Missouri, New Mexico and Utah. Vehicle make and model year was identified from the data system by decoding vehicle identification number (VIN), with the states selected for study being those for which data for 2001 and 2002 containing VINs was available. If ESP has no effect on accident involvement, then crash rates per registration should be the same for the equipped and the non-equipped models. An "expected crash rate" can thus be calculated, which is the product of the crash-rate for the non-ESP version of the car, and the registration count of the ESP version. In this study, a risk ratio was then calculated, being the sum of the observed crash counts for equipped vehicles, divided by the sum of the expected crash counts. Risk ratios were computed for various levels of crash severity, and different crash types (multiple-vehicle, single-vehicle).

The main findings were –

- ESP-equipped vehicles had a single-vehicle crash risk approximately 41% lower than non-equipped vehicles.
- ESP reduced fatal single-vehicle accident risk by approximately 56%
- There is little (if any) effect on multiple-vehicle crashes, specifically head-on crashes and those on wet roads.
- ESP reduces overall fatal crash risk by an estimated 34%

The main issues to consider with this study are;

- The estimate for reduction of single-vehicle fatal accidents is derived from very little data.
- The equipped vehicles were 1-3 years newer than the non-equipped vehicles. Some researchers have identified a link between vehicle age and crash risk (Blows et al, 2003, for example). Should this be the case, the estimates here would over-state the effectiveness of ESP. However, Farmer does point out that some research suggests that the increase in crash-risk occurs only in vehicles over four years old. Should this be the case, the estimates for ESP effectiveness would not be affected.

**Dang (2004)**

This study analysed information from the state databases used by Farmer (above), and also information contained within the Fatal Accident Reporting System (FARS). State data from 1997 to 2002 for Florida, Illinois, Maryland, Missouri and Utah was used. Again, these states were chosen for the availability of VIN information in the data files. The effectiveness of ESP in fatal accidents was assessed using FARS data from 1997 to 2003. The analysis compares specific make and model of car and SUV equipped with ESP with earlier, non-equipped models. Vehicles with ESP as an option were excluded from the analysis because of the difficulty of establishing which vehicles are actually equipped and which are not. A preliminary analysis used multi-vehicle crash involvement as a control group, essentially assuming that ESP has no effect on crash involvement.

The main findings were;

- Single vehicle crashes reduced by 35% in passenger cars and 67% in SUVs.
- Fatal single vehicle crashes are reduced by 30% in cars and 63% in SUVs

The points for consideration are

- The estimates are based primarily on accidents involving BMW and Mercedes cars. Vehicles from these manufacturers constituted 61% of the cars in the sample. Effectiveness could vary between different manufacturers because of differences in the equipment itself, but also because of differences in the type of driver (age, gender), or differences in where the vehicles are used (urban, rural).
- Toyota and Lexus constituted 78% of the SUVs in the sample.

**Aga and Okada (2003)**

The methodology for this study involved the selection of three popular Toyota cars in which ESP had been installed between model changes. The investigation period was limited to the first five years of the vehicle's life, in order to cancel out as far as possible the effect of vehicle age on accident-involvement. The data used came from the Institute for Traffic Accident Research and Data Analysis (ITARDA) in Japan. In total, the cases yielded approximately 980,000 vehicle-years without ESP, and 390,000 vehicle-years with ESP. Accident and casualty rates were calculated from this.

The main findings were;

- 35% reduction in single-car accidents.
- 30% reduction for head-on collisions with other vehicles.
- 50% and 40% reductions for single and head-on collisions respectively where severe or moderate damage occurred. In other words, the more severe the crash, the more effective ESP is.
- Reduction in the casualty rate of approximately 35% in both single accident and head-on collisions.
- ESP may be more effective in higher speed accidents.

There were too few fatal and serious injuries in the sample for reduction-ratios for these accidents to be estimated.

**Sferco et al (2001)**

The focus of this study differs slightly from those outlined above (hence its exclusion from table 3.). Because of the difficulties which have already been outlined in comparing accident rates between an equipped and a non-equipped fleet, this study looked at accident records, and relied on expert opinion to determine whether or not ESP would have been likely to have influenced the outcome of each accident. The database from which accidents were selected was the European Accident Causation Survey (EACS), which at the time the ESP study was carried out contained details of about 1674 accidents in 5 European countries. Experts were asked to use their knowledge experience and expertise to judge how the outcome of the accident would have changed if ESP had been available.

The experts were asked to record their judgement as follows;

- ESP would have definitely not influenced the accident.
- ESP would have maybe influenced the accident.
- ESP would probably have influenced the outcome.
- ESP would have definitely influenced the accident
- ESP would have definitely avoided the accident

The main findings were;

- ESP could have a probable or definite influence in about 34% of fatal accidents and 18% of injury accidents.
- Looking only at loss of control accidents, (approximately 40% of cases), ESP could have a definite or probable effect in about 67% of fatal and 42% of injury accidents.
- ESP is most likely to be effective in accidents occurring on roads with one lane in each direction, in the rain, and at high speed.
- It appears that ESP would be more effective in fatal accidents.

The main limitations of this study are;

- There is clearly some degree of subjectivity in assessing the potential impact of ESP on accident outcome. Also, it may be less likely that those assessing the accidents would feel able to commit to the category "ESP would have definitely avoided the accident". They may feel more able to say that ESP would have *influenced* the accident. In this case, the estimates may be an under-statement of the likely impact of ESP.
- The accidents contained within the EACS are not representative of the accidents occurring in Europe. Only 6 countries participate, and for those countries, the sampling area is not representative of the country as a whole. For example, whereas 70% of EACS accidents occur outside urban areas, for Europe as a whole, the percentage of accidents occurring outside urban areas is nearer 30%. All of these studies suggest that ESP is likely to be more effective outside urban areas, where drivers are more likely to lose control because of higher speeds and winding roads. This suggests that these estimates would be unrealistically high if generalised to all accidents.

**Langwieder et al (2003)**

For car accidents Langwieder et al. used insurance files on 1100 car-to-car and 524 single vehicle accidents resulting in MAIS3+ casualties plus a second set of data obtained from a local police station focusing on accidents with young drivers. Depending on the source, the authors found that around 27% of all and up to 60% of the single vehicle accidents involved skidding. 30 to 40% of the skidding related accidents occurred on straight road sections and some 40 to 50% of skidding in curves occurred below the critical speed for the given trajectory. All in all, this study expects ESP to be beneficial in at least 60% of the skidding related car accidents.

For trucks, Langwieder et al. examined 850 accidents involving 917 trucks (GVW 3.5 tons and above) using police reports, tachograph diagrams, photography and reconstruction data where available. GDV experts rated 8.6% of the total cases as "ESP relevant", i.e. an ESP would have avoided or at least mitigated the accident. A breakdown by vehicle category shows that 9.6% of tractor/semi-trailers, 8% of truck/trailers and 7.2% of the solo trucks would have benefited from an ESP. These findings were then projected to German national statistics resulting in an annual number of about 430 severe truck accidents with about 90 fatalities that could be positively influenced by the presence of ESP.

### Becker et al (2003)

In 2003 Becker et al. used data from the German In-Depth Accident Study (GIDAS). They identified 2339 cars (96 of which had ESP) who caused an accident. In 15% of the non-ESP vehicles and 8.3% of the ESP vehicles the accidents were described as skidding-related, lea-ding to an ESP effectiveness of about 45%. This number must be interpreted with caution since it is based on a relatively low number of ESP vehicles in GIDAS (which in turn is due to the random sampling plan making GIDAS representative of the overall fleet).

As Volkswagen's and Audi's own on-the-scene studies were never intended to be representative of the fleet, they have a significantly higher rate of ESP-equipped vehicles. In these data sets the ESP efficiency also turns out to be significantly higher. Projected to German national statistics an overall reduction of fatalities by at least 500 could be expected, assuming 100% of ESP-equipped vehicles on the road.

### Daimler-Chrysler

DaimlerChrysler launched a press release in November 2002 that was subsequently picked up by a number of newspapers and magazines. They used data from the German Federal Statistics Authority that had been merged with motor vehicle registration data to allow identification of DaimlerChrysler cars by model and year of first use. The sample contained about 1.5 million accidents. DC found an 11% reduction of the overall accident rate of cars first registered in 2000/2001 compared to the previous model year whereas the reduction for Mercedes passenger cars was found to be 15% for the same time period. Since ESP was introduced as a standard equipment for the 2000 model year this difference in accident rate was attributed mainly to ESP.

Another analysis based on the same set of data shows that the share of loss-of-control accidents within all accidents1 dropped from 15% (for Mercedes cars first licensed in 1999) to 10.6% (first licensed in 2000), whereas for the average of all other brands the rate remained at a constant 14.5%. Since this reduction occurred between the 1999 and 2000 model years it was also attributed mainly to ESP.

### Conclusions of literature review

Whilst all of these studies acknowledge some limitations in the methodology, all reach the conclusion that ESP should be a significant development in reducing accidents and casualties. Tingvall et al suggest that, *"In a general sense the equipment should eliminate loss of control".* Farmer believes that "*ESC should be a significant benefit to highway safety*", and the Insurance Institute for Highway Safety concludes that, "*Widespread application of ESC in the vehicle fleet can be expected to afford a significant safety benefit*"

As vehicles equipped with ESP begin to form a larger proportion of the fleet, it will be possible to assess more accurately the impact ESP will actually have on real-world accidents. Key issues which have not been addresses by these studies include;

- Will drivers begin to adjust their driving style to the presence on vehicles of ESP, by, for example cornering more quickly? This effect is known as "risk compensation", and it has been identified by some as the reason why predicted benefits of ABS have not materialised.

- In what other unexpected ways might drivers respond to widespread availability of ESP? In an estimated 50% of accidents the driver fails to recognise the hazard prior to an accident. Different stability control systems differ in how much control they take from the driver, and at what point they intervene. How does this interaction between driver and system affect outcome?
- Might ESP have an effect on the severity of outcome, as well as the rate of accident involvement? For example, is it possible that in single-vehicle loss of control accidents, where the accident cannot be prevented, it can be turned from a side-impact, to a potentially less damaging frontal impact?
- As cars carry more technology, are there hazards arising out of the interaction of increasing numbers of active safety systems?

As Jaguar helpfully point out, ESP cannot overcome the laws of physics (www.jaguar.com). However, as it becomes a more common-place piece of equipment, it will be possible to draw firmer conclusions about precisely what it is capable of in terms of accident and casualty reduction.

## 3.6 How might future systems evolve

According to Mercedes (Giessen, 2002), the focus of the latest developments in safety technology is on how to bridge the gap between active and passive vehicle safety. The future of systems such as ESP, is certainly in the area of pre-crash sensing, SMART safety systems and a more holistic approach to safety, combining active and passive systems. Pre-crash technologies such as ESP and adaptive cruise control (ACC) would be integral in the ‘assistance phase’ and the ‘collision avoidable state’ of integrated safety concepts. The sensors which make ESP possible can be used in a seven-phase integrated approach, outlined below.

1. **Warning phase**

Sensors monitor driving behaviour. When driving dynamics limits are reached, a warning is activated in the vehicle.

2. **Assistance phase**

ABS or ESP intervenes in a supportive manner to make critical situations more controllable for the driver.

3. **PRE-SAFE Phase**

Sensors detect an increased likelihood of an accident. In preparation, seatbelts are tightened, rear seats are put in their optimal positions and the sunroof is closed.

4. **Very light accident**

Up to 15km/h bumpers and front crash boxes absorb the impact, automatic seatbelt mechanism is blocked, sensors monitor the severity and trigger the airbags if necessary.

5. **Light accident**

Body structure supports absorb the energy and distribute forces across the vehicle. Seat-belt tensioners are activated and the driver airbag is deployed. Depending on the severity of the impact, the passenger airbag is deployed at first stage. In side impact, side and window airbags deploy. The fuel supply to the engine is blocked.

6. **Severe accident**

Passenger's airbag is deployed at second stage. Seat-belt force limiters are activated.

7. **Rescue phase**

After the accident, doors are automatically unlocked, emergency call system (TELEAID) alerts rescue services. The hazard lights are turned on.

Adaptive Cruise Control (ACC) is a further driver aid now offered on a number of vehicles. ACC recognises preceding vehicles, using a radar sensor, calculates their speed and keeps a required distance by acting on the brake and engine. The Electro-hydraulic Brake (EHB), also in production, is the first fully electronically controlled brake-by-wire system for vehicles.

The principles behind ESP have provided the technical conditions for other advances in car safety, such as active curve lights, where the headlights follow the steering movement of the driver around a corner and move quickly to the side when a curve is targeted, improving the illumination of the road by up to 90%. The information required for this technology is all sent by the steering wheel and speed sensors of the ESP.

Further extensions of ESP systems include using the technology not only as a driver aid and to intervene when a collision is avoidable, but also to activate features when an accident is inevitable, such as triggering the raising of a rollover bar or pedestrian protection features and also positioning seats and seatbelts to their optimum settings for crash protection.

# 4 Analysis with respect to ESP

## 4.1 Data preparation

All analyses in this study are based on the MS Access version of the database. It needs to be pointed out that the investigation started during the data collection period and not all data fields might be filled in. For a better overview, an extract of the ESP-relevant variables was created. The variables were exported from table 100 (accident), 101 (CARE), and 200 (vehicle), respectively.

Given the low fleet penetration or even availability of ESP for commercial vehicles the analysis was restricted to passenger cars (in the strict sense of the word, i.e. leaving out SUVs, MPVs, Minibuses etc.).

## 4.2 Detecting the presence or absence of ESP

The variable “ESP” was readily coded in the database, valid values were:

(0) – not applicable
(1) – ESP present
(2) – no ESP present
(9) – presence of ESP unknown

To get an idea of the reliability of the data, the coded ESP presence was checked against the manufacturer’s production records, based on the vehicle identification number (VIN). For obvious reasons this was only possible on Volkswagen vehicles. Including all observed spellings of this brand name 180 such vehicles were found in the database (table 200 only, i.e. regardless of the relationship structure described above).
For 38 of the 180 vehicles checked no VIN was given, in 56 cases the given VIN was not found in the production records. For the 86 found VINs a match between the PENDANT and the production database was observed 74 times, a mismatch was observed 11 times (the one remaining vehicle was coded as unknown).

| | | ESP from VIN (Volkswagen cars only) | | | |
|---|---|---|---|---|---|
| | | **VIN invalid / unknown** | **no** | **yes** | **total** |
| **ESP coded in database** | **no** | 70 | 59 | 4 | 133 |
| | **unknown** | 1 | 1 | 0 | 2 |
| | **yes** | 23 | 7 | 15 | 45 |
| | **total** | 94 | 67 | 19 | 180 |

Given that more than one third of the coded VINs were not found in the production records (and even the ones found are valid VINs, but might well be from a different vehicle) no attempt of recoding the data was made, i.e. the codings from the PENDANT database were taken at face value1.

Another plausibility check was performed on the coding of antilock brake and traction control systems. Since ESP technically depends on the presence of ABS any vehicle coded as ESP equipped should also have ABS coded. With only few exceptions this relation as also found in the database. Although not strictly a technical requirement, traction control can also be expected to be found wherever ESP is. According to the database however only 193 of the 245 cars coded as ESP-equipped are also coded as having traction control. Please note that the two following tables refer to all cars, regardless of manufacturer:

| | **Antilock Brakes** | | | | |
|---|---|---|---|---|---|
| **ESP** | **n/a** | **yes** | **no** | **unknown** | **total** |
| **n/a** | 272 | 262 | 11 | 3 | 548 |
| **yes** | 1 | 243 | 1 | | 245 |
| **no** | | 525 | 213 | 12 | 750 |
| **unknown** | | 26 | | 10 | 36 |
| **total** | 273 | 1056 | 225 | 25 | 1579 |

| | **Traction control** | | | | |
|---|---|---|---|---|---|
| **ESP** | **n/a** | **yes** | **no** | **unknown** | **total** |
| **n/a** | 520 | 28 | | | 548 |
| **yes** | 32 | 193 | 15 | 5 | 245 |
| **no** | 1 | 65 | 683 | 1 | 750 |
| **unknown** | 1 | 1 | 7 | 27 | 36 |
| **total** | 554 | 287 | 705 | 33 | 1579 |

## 4.3 Estimation of exposure

In the past, accidentology has mainly dealt with questions of passive (sometimes also called secondary) safety. For most questions of risk assessment it was sufficient to deal with accident data and define risk as, e.g. the probability of sustaining a certain injury in a given accident situation. Usually it is assumed that only the outcome, but not the occurrence of an accident will depend on the system under discussion.

Active (or, primary) safety systems like ESP however aim mainly at accident avoidance. In this context, risk is usually understood as the number of accidents, casualties or injuries divided by some measure of exposure. Good measures of exposure are vehicle kilometres driven or time in traffic, but normally these are not available with the required level of detail (like a breakdown by time of day, type of road, type of vehicle or, in this case, ESP fleet penetration).

It is therefore a common practice to estimate exposure based on the accident data. The method is called “induced exposure”. It relies mainly on the assump-

[1] This is also true for some vehicles coded as ESP-equipped although the respective type and/or model year were never made with ESP

tion that the driver who causes an accident does not deliberately select his opponent, i.e. the opponents are “sampled” at random. If this is true the distribution of, e.g. ESP in the sample is representative of the distribution in the overall population.

Unfortunately, the PENDANT database does not state the role of the vehicles (at fault or random opponent), so this approach had to be discarded. Instead, the fleet penetration of ESP had to be estimated based on accidents assumed to be insensitive to this system, an idea similar to the one used by Tingvall et al. in their study [36].

Within the selection of possible accident types, all of the following ones were assumed insensitive to ESP:

| Accident Type | Description |
|---|---|
| **B2L** | Accidents with parked vehicles - opening doors |
| **B2R** | Accidents with parked vehicles - opening doors |
| **D12L** | At least two vehicles - same direction - rear end collisions |
| **D12R** | At least two vehicles - same direction - rear end collisions |
| **E11L** | At least two vehicles - turning or crossing - same road - same direction - rear end collision |
| **E11R** | At least two vehicles - turning or crossing - same road - same direction - rear end collision |

For the remaining accidents, the narratives were checked for evidence of an ESP insensitive scenario such as, e.g. a rear end collision. This way a total of 188 vehicles involved in any of the ESP insensitive accidents were found. 28 of them (15%) had ESP, 155 (82%) had no ESP and for 5 vehicles it was unknown whether or not they had this system on board. This distribution was then taken as the baseline for comparison of cars involved in other, potentially ESP-sensitive, accident scenarios.

## 4.4 Analysis of effectiveness

To evaluate the ESP effectiveness it was first examined which accident types show a significant over- or under-representation of ESP-equipped vehicles. The analysis consisted of a breakdown of accidents by the first character of the type code (for a comprehensive list of CARE Plus accident type codes see Annex). These groups of accident types were cross-tabulated against ESP. It was than calculated whether ESP-equipped vehicles were over- or underrepresented in the respective accident types.

As was mentioned before PENDANT does not state the role of the vehicles with respect to accident causation. The following tables do therefore list all vehicles involved in the respective accidents, not only the ones at fault. This is contrary to common practice for analysis of active safety systems and blurs the results (except in case of single vehicle accidents). Given the limitations of the PENDANT database however the standard approach was not feasible.

The following table shows the absolute number of vehicles involved:

| | # vehicles with ESP on board | | | |
|---|---|---|---|---|
| **1st char. of CARE accident type** | **no** | **yes** | **unknown** | **total** |
| **Pedestrian accidents (type Axxx)** | 63 | 2 | 1 | 66 |
| **Acc. with parked vehicles (type Bxxx)** | 9 | 4 | | 13 |
| **Single vehicle accidents (type Cxxx)** | 274 | 41 | 1 | 316 |
| **>1 vehicle, same or opposite direction (type Dxxx)** | 541 | 105 | 23 | 669 |
| **>1 vehicle, crossing direction (type Exxx)** | 400 | 87 | 10 | 497 |
| **total** | 1287 | 239 | 35 | 1561 |

In the next step, the distribution of ESP was calculated and compared to the baseline distribution as described in the section on exposure. Please note that some accident types were rarely observed which severely limits the significance of the respective line. This is especially true for type Bxxx, i.e. accidents with parked vehicles.

| **1st char. of acc. Type (known and valid values only)** | **# of cars by ESP presence** | | | | **% of cars by ESP presence** | | | |
|---|---|---|---|---|---|---|---|---|
| | **no** | **yes** | **unkn.** | **total** | **no** | **yes** | **unkn.** | **total** |
| **Pedestrian accidents (type Axxx)** | 63 | 2 | 1 | 66 | 95% | 3% | 2% | 100% |
| **Acc. with parked vehicles (type Bxxx)** | *9* | *4* | | *13* | *69%* | *31%* | *0%* | *100%* |
| **Single vehicle accidents (type Cxxx)** | 274 | 41 | 1 | 316 | 87% | 13% | 0% | 100% |
| **>1 vehicle, same or opposite direction (type Dxxx)** | 541 | 105 | 23 | 669 | 81% | 16% | 3% | 100% |
| **>1 vehicle, crossing direction (type Exxx)** | 400 | 87 | 10 | 497 | 80% | 18% | 2% | 100% |
| **total** | 1287 | 239 | 35 | 1561 | 82% | 15% | 2% | 100% |

| **1st char. of acc. Type (known and valid values only)** | **# of cars by ESP presence** | | | | **% of cars by ESP presence** | | | |
|---|---|---|---|---|---|---|---|---|
| | **no** | **yes** | | **no** | **yes** | | **no** | **yes** |
| **Pedestrian accidents (type Axxx)** | 5% | 1% | 3% | | | | | |
| **Acc. with parked vehicles (type Bxxx)** | *1%* | *2%* | *0%* | | | | | |
| **Single vehicle accidents (type Cxxx)** | 21% | 17% | 3% | | | | | |
| **>1 vehicle, same or opposite direction (type Dxxx)** | 42% | 44% | 66% | | | | | |
| **>1 vehicle, crossing direction (type Exxx)** | 31% | 36% | 29% | | | | | |
| **total** | 100% | 100% | 100% | | | | | |

For better overview, both the percentages in upper right and the lower left sub-tables have been visualized. The following graph compares the proportion of ESP-equipped vehicles in the CARE accident type groups Axxx through Exxx with the baseline estimate of ESP equipment rate as described above. In group Axxx, ESP equipped vehicles were underrepresented, Bxxx is insignificant due to low number of observations. In groups Cxxx through Exxx the rate of ESP vehicles was very close to that of the baseline estimate.

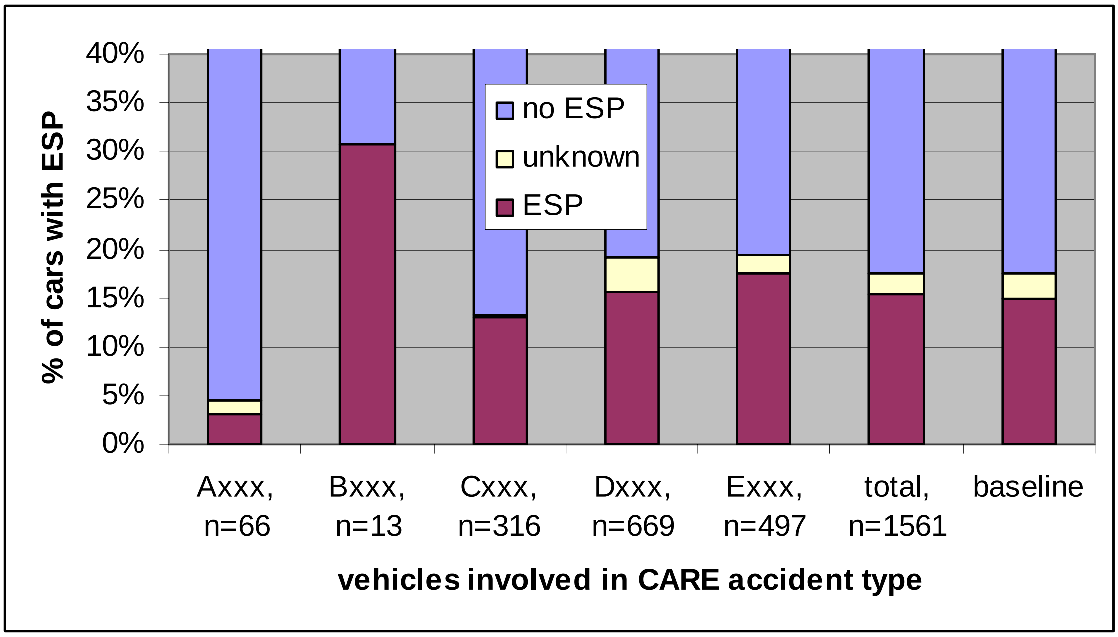



Fig. 3: Vehicles involved in CARE accident types

A complementary graph can be created for the distribution of accident types by ESP equipment. Again, types Axxx and Bxxx have a low share of the overall numbers; the remaining types are similarly distributed for vehicles with and without ESP.

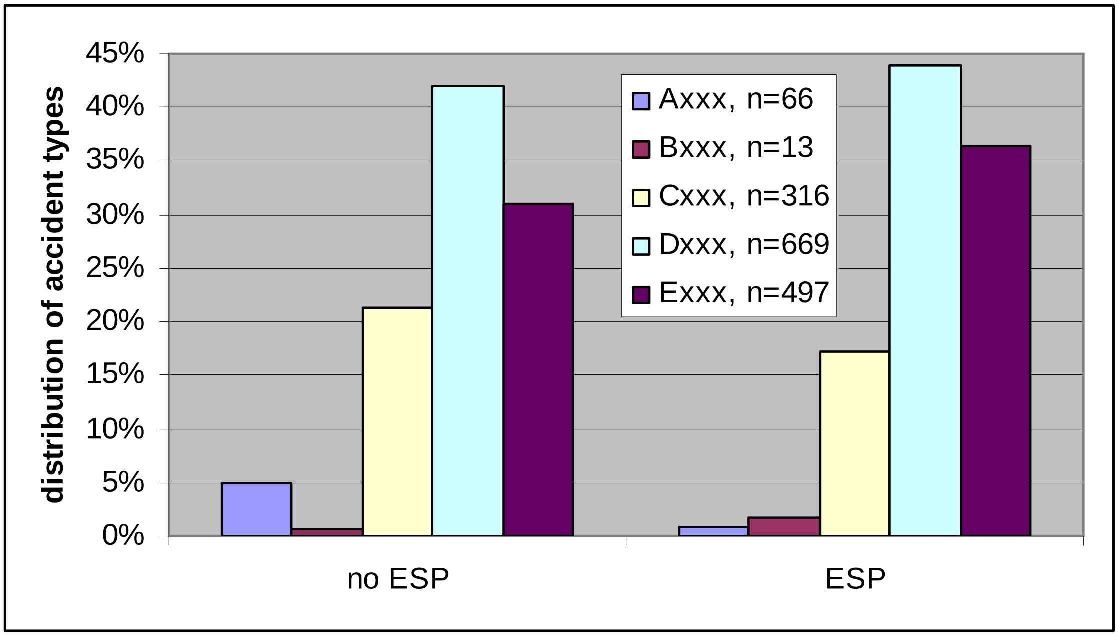



Fig. 4: Distribution of accident type

This observation is surprising and by no means in line with the established effectiveness studies of ESP as listed in the references section. Since the accident type groups do neither indicate the causes of the accidents nor the vehicle that caused them (and many of the more detailed type groups are sparsely populated anyway) no further analysis of accident types was done.

Instead, the accident narratives were manually checked for any indication of skidding or swerving as having lead to the accident. A new variable "(evidence of) skidding" was created, see the following table. In some cases, the vehicles in the narrative could not be clearly linked to the vehicle data tables, so the new variable had to be established on a per-accident basis. Again, this causes a certain blur but was the only feasible way, given the information available.

In the first step no further differentiation by road condition was done. In the group of non-ESP cars 24% of them were involved in accidents related to skidding whereas among the ESP cars this rate was only 17%:

| **all roads** | **ESP coded** | | | |
|---|---|---|---|---|
| **skidding** | **no** | **yes** | **unknown** | **total** |
| **n** | 991 | 203 | 32 | 1226 |
| **y** | 307 | 42 | 4 | 353 |
| **total** | 1298 | 245 | 36 | 1579 |
| **n** | 76% | 83% | 89% | 78% |
| **y** | 24% | 17% | 11% | 22% |
| **total** | 100% | 100% | 100% | 100% |

Subsequently a breakdown of the above table by road condition was made. As expected, on dry roads the rate of vehicles involved skidding related accidents is lowest, namely 15% for non-ESP and 11% for ESP equipped vehicles:

| dry roads | ESP coded | | | |
|---|---|---|---|---|
| skidding | no | yes | unknown | total |
| n | 705 | 149 | 20 | 874 |
| y | 128 | 18 | 3 | 149 |
| total | 833 | 167 | 23 | 1023 |
| n | 85% | 89% | 87% | 85% |
| y | 15% | 11% | 13% | 15% |
| total | 100% | 100% | 100% | 100% |

Again not surprisingly, on wet roads this rate is substantially higher, namely 36% for non-ESP and 29% for ESP equipped cars:

| wet roads | ESP coded | | | |
|---|---|---|---|---|
| skidding | no | yes | unknown | total |
| n | 218 | 50 | 9 | 277 |
| y | 121 | 20 | 1 | 142 |
| total | 339 | 70 | 10 | 419 |
| n | 64% | 71% | | 66% |
| y | 36% | 29% | | 34% |
| total | 100% | 100% | | 100% |

Finally, the same kind of table was established for icy roads. In this case however the overall number of vehicles was low at only 51, and only one of these vehicles was ESP equipped. Therefore, no percentages were specified in the table:

| icy roads | # of vehicles with ESP coded as | | | |
|---|---|---|---|---|
| skidding | no | yes | unknown | total |
| n | 22 | | 1 | 23 |
| y | 27 | 1 | | 28 |
| total | 49 | 1 | 1 | 51 |
| n | 45% | | | 45% |
| y | 55% | | | 55% |
| total | 100% | | | 100% |

Another way of looking at the effectiveness of ESP is the outcome of the accidents in terms of injury severity. At first sight, this approach may seem inappropriate for an active safety system, which is supposed to avoid accidents in the first place.

However, even if the system is not able to avoid a given accident completely it may still be beneficial by reducing sideslip angle and hence transforming a lateral collision into an oblique or frontal one, resulting in a lower injury risk to the occupants.

To verify this hypothesis injury severity was cross-tabulated against ESP equipment. Please note that injury severity in this context was understood as the highest MAIS in the crash, not the individual vehicle:

| | # of vehicles with ESP coded as | | | |
|---|---|---|---|---|
| **MAIS in crash** | **no** | **yes** | **unknown** | **total** |
| **1 – minor** | 635 | 144 | 15 | 794 |
| **2 – moderate** | 221 | 36 | 3 | 260 |
| **3 – serious** | 110 | 17 | 3 | 130 |
| **4 – severe** | 52 | 7 | 3 | 62 |
| **5 – critical** | 56 | 6 | 2 | 64 |
| **6 – unsurviv-able** | 38 | 7 | 1 | 46 |
| **unknown** | 41 | 8 | 1 | 50 |
| **missing** | 145 | 20 | 8 | 173 |
| **total** | 1298 | 245 | 36 | 1579 |

Due to the low number of high MAIS values especially in the ESP-cars all known and valid values were combined to form only two groups, namely MAIS1-2 and MAIS3+. 23% of the non-ESP cars were involved in severe crashes with a maximum AIS of 3 or above whereas in the group of ESP cars this rate was only 17%:

| | # of vehicles with ESP coded as | | |
|---|---|---|---|
| **MAIS in Crash** | no | yes | unknown |
| **MAIS1-2** | 856 | 180 | 18 |
| **MAIS3+** | 256 | 37 | 9 |
| | | | |
| **MAIS1-2** | 77% | 83% | 67% |
| **MAIS3+** | 23% | 17% | 33% |

## 4.5 Confounding factors

The effectiveness figures reported above are, inter alia, based on the assumption that the presence or absence of ESP in a given vehicle is (at least with a good degree of approximation) independent of other factors. This assumption however is not necessarily true, e.g. with respect to vehicle age, see the graphs below. The effectiveness figures established in the previous sections must therefore be taken with care.

With respect to vehicle year of manufacture, the following diagram has been established. Two observations catch the eye, namely

- The vehicles in the PENDANT sample are typically of a later year than in the (German) average fleet. This can be directly attributed to the sampling scheme, which calls for a maximum age of seven years for the case car and therefore results in a severe bias towards newer vehicles.

- The median (50th percentile) year of manufacture is different by about three years for ESP- and non-ESP vehicles. Given an average product life cycle of six years for a passenger car this represents half a vehicle generation.

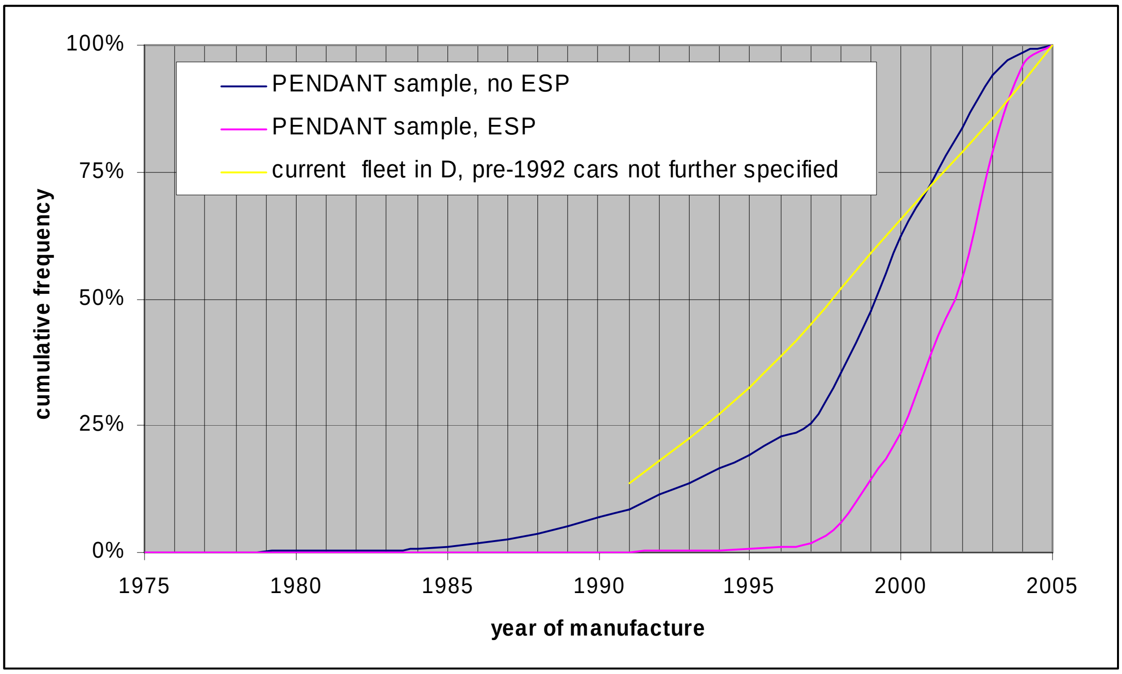



Fig. 5: Year of manufacture and cumulative frequency of ESP cars

Another possible confounding factor to vehicle stability is the drive train layout – front, rear or four-wheel drive. The vehicle table in PENDANT has this variable, but for 203 out of 1579 cars (13%) it is coded as "not applicable", see the following table. Given that the driven axles are easily determined by visual inspection of the vehicle this rate is surprisingly high and hence, the reliability of this information doubtful.

| | # of vehicles with ESP coded as | | | |
|---|---|---|---|---|
| **drivetrain layout** | **no** | **yes** | **unknown** | **total** |
| **front** | 947 | 163 | 23 | 1133 |
| **n/a** | 224 | 40 | 9 | 273 |
| **rear** | 84 | 33 | 3 | 120 |
| **4x4** | 42 | 9 | 1 | 52 |
| **unknown** | 1 | | | 1 |
| **total** | 1298 | 245 | 36 | 1579 |

# 5 Single vehicle accident analysis

Accident reconstruction is a field of practice that requires specialized study, training and experience. For the reconstruction of vehicle accidents the steering, braking or acceleration behaviour of the vehicle driver can usually only be estimated. Other important aspects are human factors and outside influences. Those aspects lead to fast or slow reaction time and are essential for accident avoidance. For complex and complicated traffic situations the reaction time is long. Is it clear and simple and an obstacle can be detected soon the reaction time will be short. There are differences in driver's age and attention.

For the reconstruction of an accident evidence taken from scene is very important. Usually police is present on scene and they take pictures, measure skid marks, highlight rest positions significant for reconstruction. If none (police, special accident investigation unit) is present on-scene no information will be available and reconstruction becomes impossible.

Find in the following diagram the accident distribution amongst all project partners. At this moment 958 accidents were present in PENDANT.

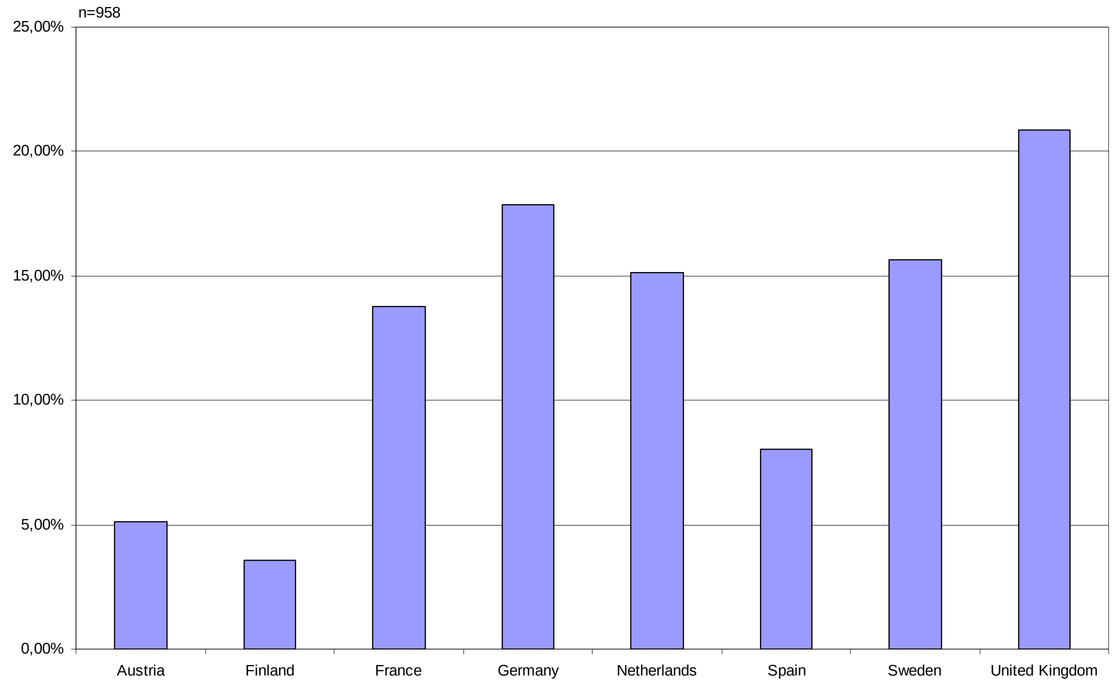



Fig. 6: Case distribution amongst partners

In the next figure (Fig. 7: Number of involved vehicles) the accident situation is shown regarding number of vehicles involved. Most of the accidents were with one or two cars which was the main criterion in PENDANT (car to car accidents whereby at least one of them must be manufactured post 1998 and at least in one vehicle an injury had to be occurred). During the collection period it was decided that pedestrian accidents should be investigated too.

Approximately 44% were single vehicle accidents and about 49% were accidents with two participating vehicles.

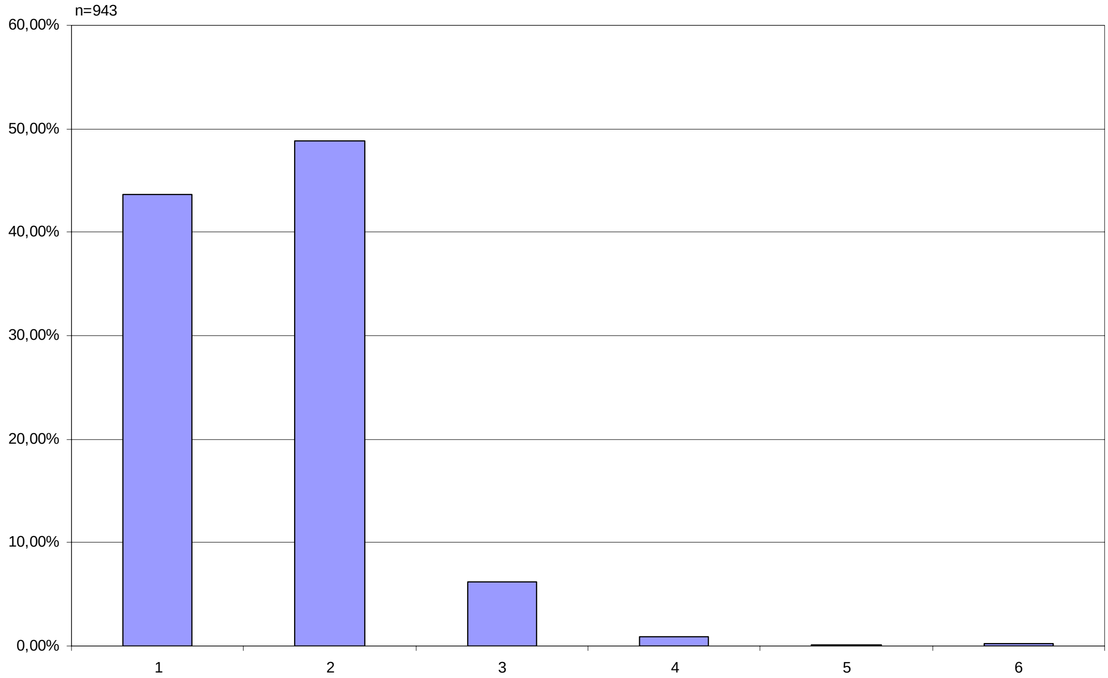



Fig. 7: Number of involved vehicles

A classification of accidents has been made with the coding system of CARE Plus. Subsequent list are the main groups of CARE Plus accident type configurations:

- Accident with pedestrians (group A)
- Accident with parked vehicles (group B)
- Single vehicle accidents (group C)
- Accidents with at least two vehicles and no turning (group D)
- Accidents with at least two vehicles and turning (group E)

Key object in this task were CARE Plus main group C – *Single vehicle accidents*. The whole CARE dataset situation in PENDANT is analysed in the next graph and the detailed table below.

As it was figured out UK had a disproportionate high share of single vehicle accidents whereby Germany, Austria or Netherlands were disproportionate low.

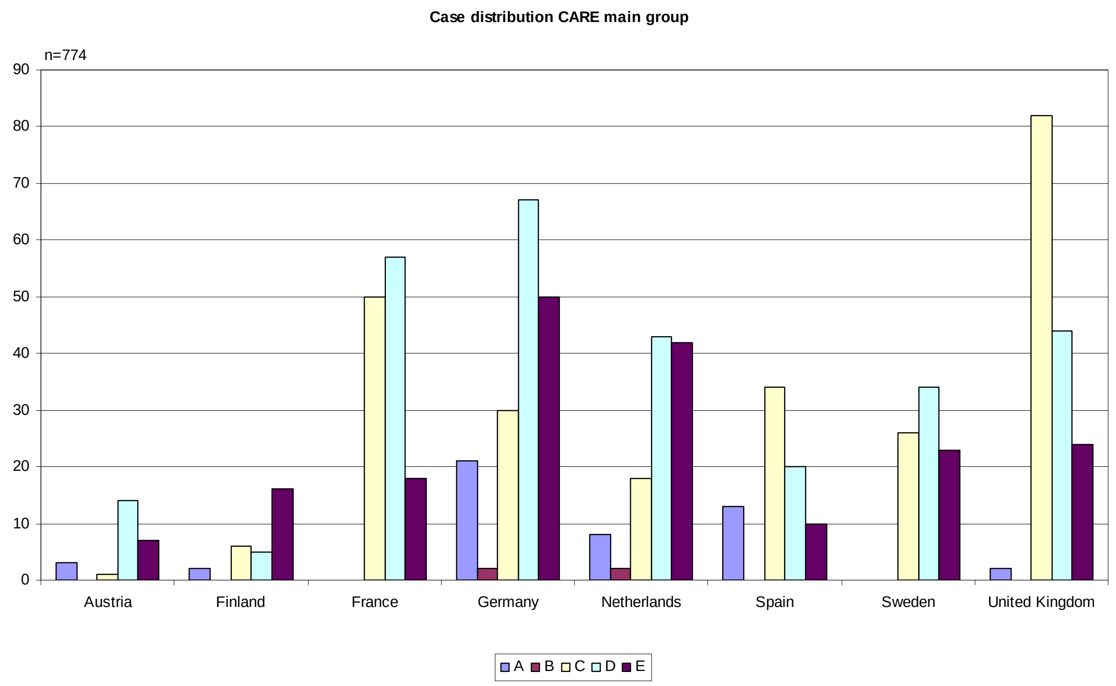



Fig. 8: Case distribution CARE main group

Find the values in next table:

| Country of Investigation | A | B | C | D | E | Result |
|---|---|---|---|---|---|---|
| Austria | 3 | | 1 | 14 | 7 | 25 |
| Finland | 2 | | 6 | 5 | 16 | 29 |
| France | | | 50 | 57 | 18 | 125 |
| Germany | 21 | 2 | 30 | 67 | 50 | 170 |
| Netherlands | 8 | 2 | 18 | 43 | 42 | 113 |
| Spain | 13 | | 34 | 20 | 10 | 77 |
| Sweden | | | 26 | 34 | 23 | 83 |
| United Kingdom | 2 | | 82 | 44 | 24 | 152 |
| Result | 49 | 4 | 247 | 284 | 190 | 774 |

Tab. 4: Case distribution CARE main group - values

To get now the accidents for Task 1.3 only CARE group C was taken (whole description with pictures in Appendix A).
Subgroup 1:

- C1L Single vehicle accidents without obstacles on the road - left
- C1R Single vehicle accidents without obstacles on the road - right
- C11 Single vehicle accident - leaving straight road - either side of the road
- C12 Single vehicle accidents on the road (often two-wheelers)
- C13 Single vehicle accidents in a bend - going either side of the road
- C14 Single vehicle accidents in junctions or entrances
- C19 Single vehicle accidents – others

Subgroup 2:

- C2L Single vehicle accidents with obstacles on the road - left
- C2R Single vehicle accidents with obstacles on the road - right
- C21 Single vehicle accidents with animals
- C22 Single vehicle accidents with obstacles on or above the road
- C23 Single vehicle accidents with roadwork materials
- C24 Accidents between train and vehicle
- C29 Single vehicles accidents with obstacles - others

In the next figure all accidents of group C are listed. Approximately 33% single vehicle accidents have been collected in UK: Close to 20% were collected in France and about 16% in Germany. Spain and Sweden have a portion of ~11% of PENDANT single vehicle accidents. Finland, Netherlands and Austria in sum collected about 11%.
At this point about 254 cases could be provided for ESP investigation. A discrepancy between figures Fig. 8: *Case distribution CARE main group* and Fig. 9: *Accident cases CARE group C - partners* can be found. In Fig. 9: *Accident cases CARE group C - partners* vehicle information regarding ESP and year of manufacture was taken into account too. After analysing these seven cases which were different it was found out that the CARE Form accident type code was wrong. Even if there were more vehicles involved main group C was used for the accident type.

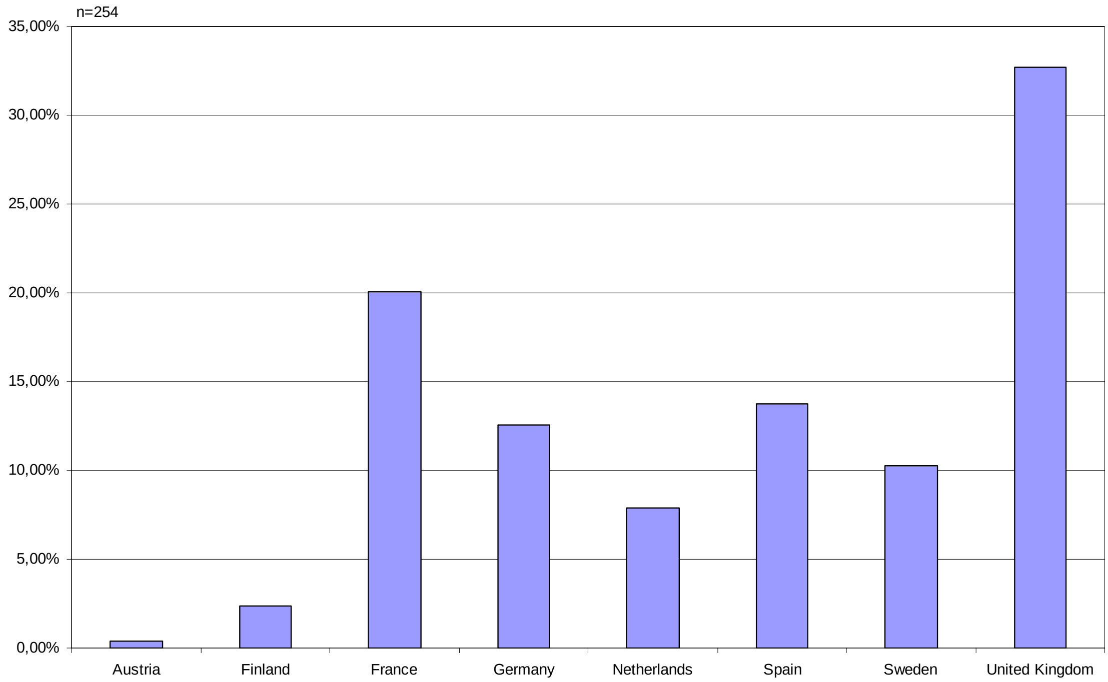



Fig. 9: Accident cases CARE group C - partners

Unfortunately not all partners are collecting on-scene accident material. Out of all partners only Hannover, TNO, TUG and Chalmers collected on-scene data and measurement. Chalmers provided a small number of cases which were from a national project as well as for PENDANT. There were more cases for interest but sadly no scene information available.

After deleting the other countries and CARE subgroup C2 the number of accidents had been reduced down to 69.

Within this sample about 32% were *“Single vehicle accidents without obstacles on the road – C1”* at Level 2. The vehicle left the road on either side. In CARE it is not possible to code the leaving direction. 30,43% of the single vehicle accidents of Level 3 – *C11 – Single vehicle accident – Leaving straight road – either side of the road*. About 35% are *“Single vehicle accidents in a bend - going either side of the road – C13”.* Additional two accidents happened at junctions.

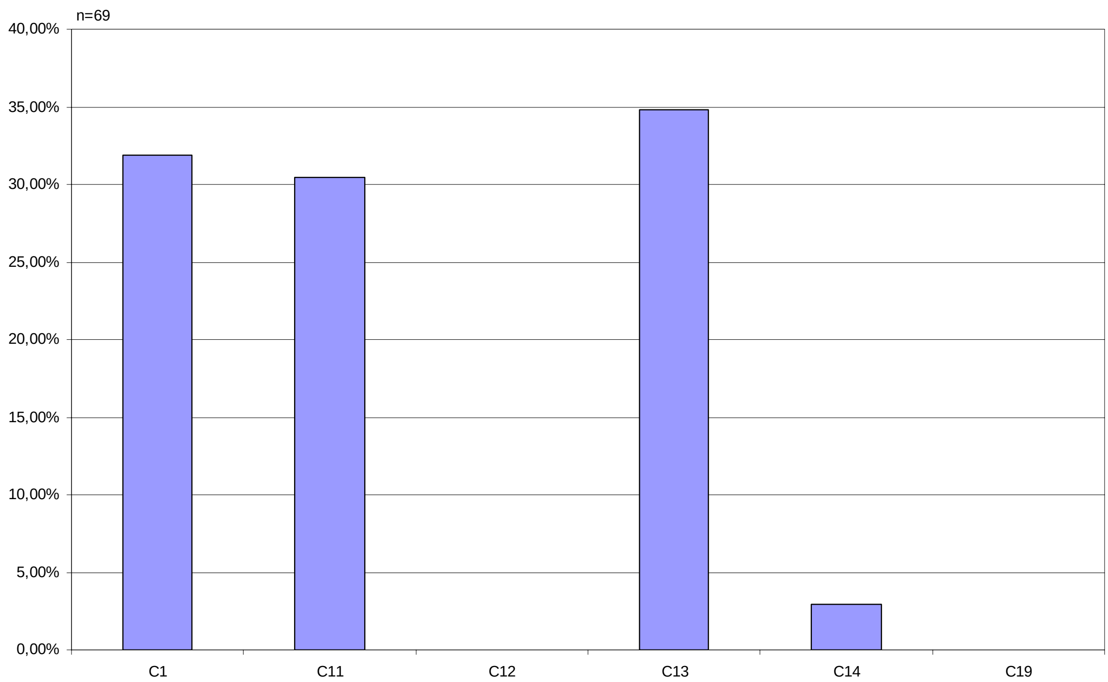



Fig. 10: Single vehicle accidents CARE group C

An investigation of accidents with vehicle which already had ESP on board is ridiculous and so the number of possible cases decreased again. Finally only 17 cases could be used for this purpose and enough on-scene material, measurement of skid marks and photos were available too. Imagine not every single vehicle accident results automatically in skidding.

To identify only cases with a MAIS 3+ seemed to be unreasonable as well and wasn't investigated due to the low portion of accidents.

Another interesting issue were the road conditions in CARE subgroup C1. Find in the following figures the appropriate values. In the left picture a general analysis has been performed. Approximately 45% happened on dry roads and close to 40% occurred on wet. Only a small portion ~4% of single vehicle accidents happened on icy surface. About 11% of the cases the road information was not known or not applicable respectively. In the right diagram the subgroup C1 was split to the certain levels and the values are present in the table below.

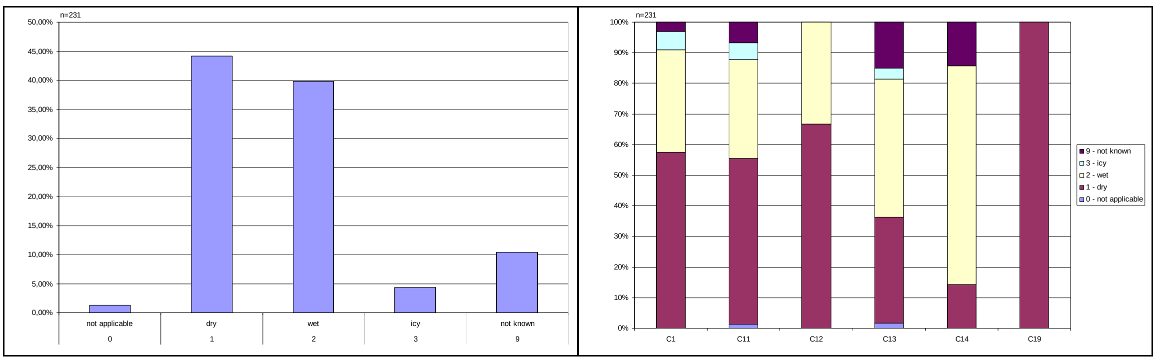



Fig. 11: Single vehicle accidents and road condition

| | not applicable | dry | wet | icy | not known | Result |
|---|---|---|---|---|---|---|
| **C11** | 1 | 40 | 24 | 4 | 5 | 74 |
| **C12** | | 2 | 1 | | | 3 |
| **C13** | 2 | 39 | 51 | 4 | 17 | 113 |
| **C14** | | 1 | 5 | | 1 | 7 |
| **C1** | | 19 | 11 | 2 | 1 | 33 |
| **C19** | | 1 | | | | 1 |
| **Result** | 3 | 102 | 92 | 10 | 24 | 231 |

Tab. 5: Single vehicle accidents and road condition

To increase the number of single vehicle accidents the database ZEDATU (Zentrale Datenbank tödlicher Unfälle) of TU Graz were studied. Within the current datasets only fatalities were collected.
Due to the accident coding system in Austria it is possible to find out accidents in which sliding occurred. For this purpose the data record from 2003 were analysed. This data were available for this task and consists of 847 cases in sum. At least one of the participating vehicles skidded in approximately 27% of the cases. No distinction was made between participating vehicles. Trucks and motorcycles were taken as well as cars.

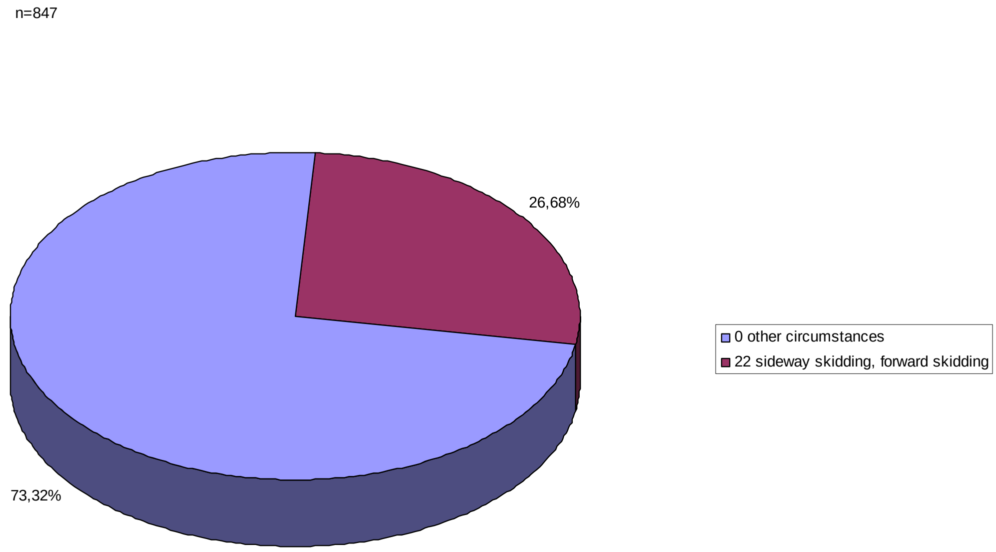



Fig. 12: Accident circumstance sideway skidding, forward skidding

Austrian statistics differentiate 105 accident types which are summarised in ten main groups.

- 0 – Single vehicle accidents
- 1 – Collision between two vehicles driving in the same direction
- 2 – Accidents with on-coming traffic
- 3 – Collision when making u-turn or turn to left/right – same direction
- 4 – Collision when making u-turn or turn to left/right – opposing direction
- 5 – Orthogonal accidents at junctions which are crossing
- 6 – Orthogonal collision at junctions turning left/right
- 7 – Accidents with stopped or parked vehicles two or more parties
- 8 – Pedestrian accidents
- 9 – Other accidents with two or more parties

As it could be seen in the next figure for the accident circumstance sideway and forward skidding close to 53% of the accidents only one vehicle was involved and in about 37% of the cases it was an accident with on-coming traffic. The third group includes accidents with two vehicles driving in the same direction with a portion of ~7%. The other groups with about 3,3% could be neglected.

Only accident cases in the category *“0 – single vehicle accidents”* were taken into account which correspond with the CARE group C.

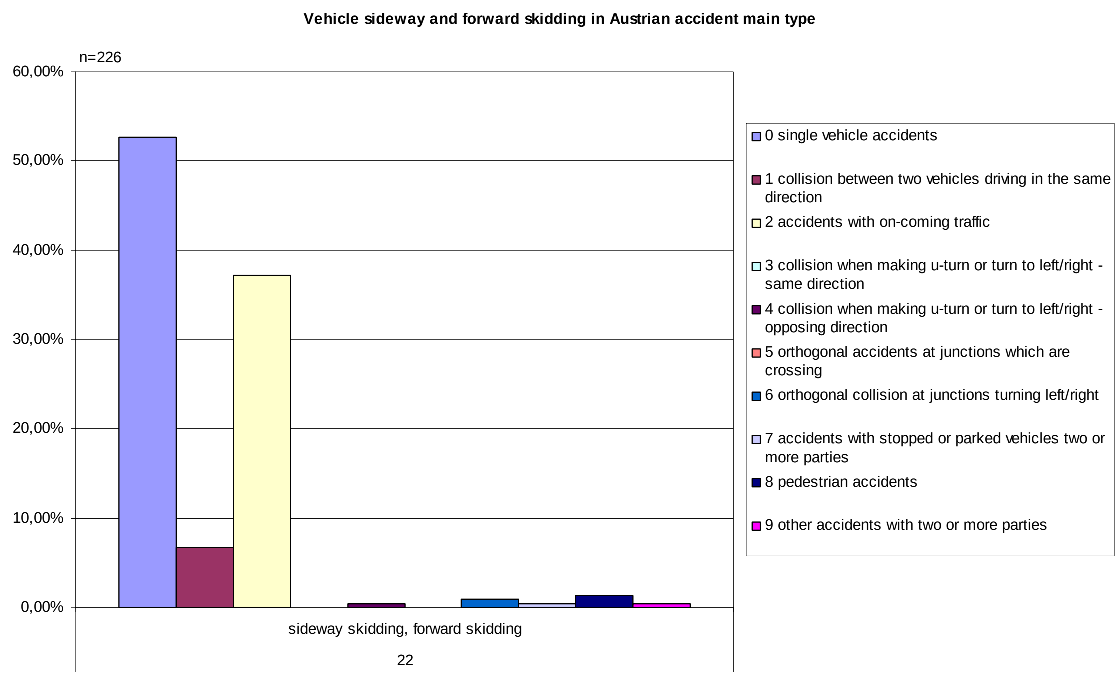



Fig. 13: Accident main group Austria and circumstance sideway skidding, forward skidding

Gathering single vehicle accident cases from ZEDATU it was figured out that documentation of accidents varied in quality. Particularly pictures taken from scene and vehicles were inadequate. For a huge number of single vehicle accidents documentation had poor quality, especially when only the driver was involved. Reason was found in Austrian’s legislation. There is no law to punish self-injuries – hence little effort is taken by the police in investigating single car accident thoroughly. In many cases no photogrammetric analysis of the accident scene has been performed and the documentation of photos is bad too.

The next picture gives an idea of the participating vehicles in *"single vehicle accidents"*. 73% were cases with vehicles of the category M1 (for carriage of passengers; not more than 8 seats (in add. to drivers seat); max. mass <= 3.5 to.) Another huge share are 2-wheelers with approximately 21% (L1 - Two-wheeled vehicle, engine cylinder capacity <= 50ccm, max. design speed <= 50 km/h, L3 - Two-wheeled vehicle, engine cylinder capacity > 50ccm, max design speed > 50 km/h and bicycles). Only car accidents were for interest in this study.

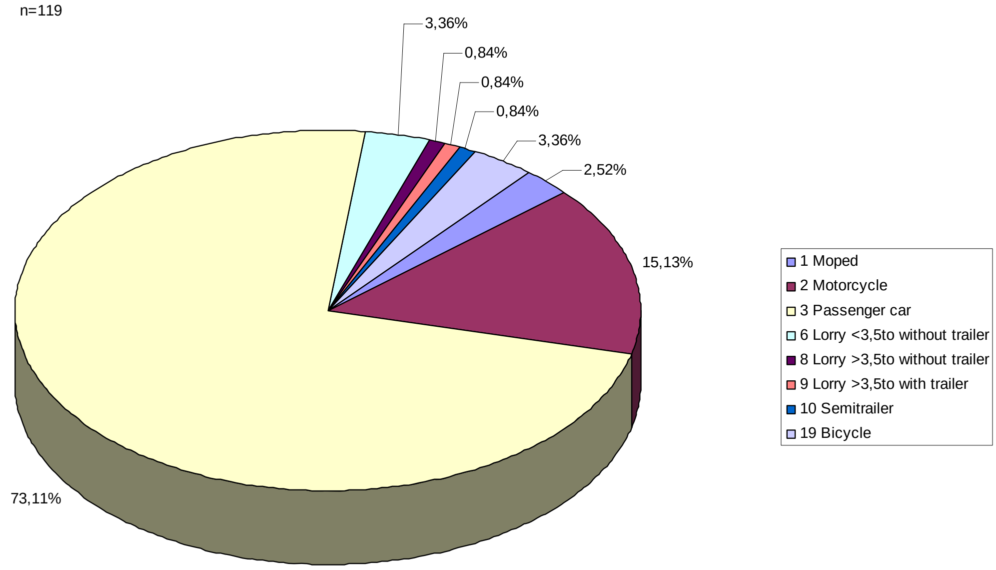



Fig. 14: Accident main group 0, parties and circumstance sideway skidding, forward skidding

Detailed investigation has been made for following categories which describe single vehicle accidents:

- 011 single vehicle accidents - leaving road to the right side - straight section
- 012 single vehicle accidents - leaving road to the right side - right bend
- 013 single vehicle accidents - leaving road to the right side - left bend
- 021 single vehicle accidents - leaving road to the left side - straight section
- 022 single vehicle accidents - leaving road to the left side - right bend
- 023 single vehicle accidents - leaving road to the left side - left bend
- 031 single vehicle accidents - leaving road at a junction - all junctions possible
- 061 single vehicle accidents - rear end collision - obstacle, secured zone
- 091 single vehicle accidents - other

Category 012, 013, 022 and 023 will match CARE group C - C13 (*Single vehicle accidents in a bend - going either side of the road*) respectively. 011 and 021 match CARE group C subgroup C11 (*Single vehicle accident - leaving straight road - either side of the road*). The other tree Austrian categories are not for interest within this study.

Very interesting is that most of the single vehicle accidents ~33% occurred on straight roads and the cars left the road to the right. There is no big difference between single vehicle accidents leaving road to right in a left bend ~15% and leaving road to left in a right bend ~14%. The situation for single vehicle accidents leaving road to right in a right bend ~10% and leaving road to left in a left bend ~8% is similar. 15% of single vehicle accidents happened on straight roads where the vehicle was leaving the road to the left.
In sum 87 cases met the criterion *"single vehicle accident"*, *"passenger car"* and *"sideway skidding, forward skidding"* in this analysis picture.

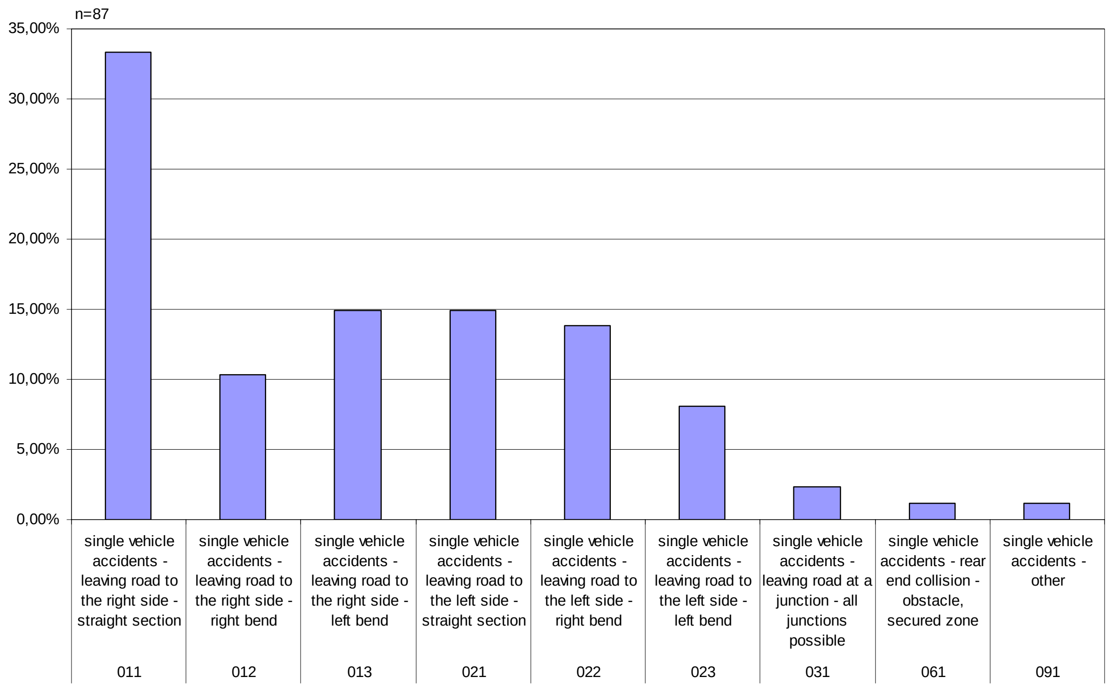



Fig. 15: Categories of single vehicle accidents

Another interesting point was to find out the characterisation of the accident scene. 113 accidents met the criterion *"single vehicle accident"*, *"passenger car"* and *"sideway skidding, forward skidding"*. 37% (41 cases) of the single vehicle accidents occurred in bends. For a huge portion of accidents approx. 17% the police couldn't characterize the accident scene, the information was missing respectively. If Fig. 15: Categories of single vehicle accidents and Fig. 16: Characterization of the accident scene are compared a discrepancy can be found. In Fig. 15 the accident type were coded and in Fig. 16 the characteristic of the accident scene were coded. One accident type could have more than one accident scene characteristics. An accident could happen on a bridge and in a bend when leaving the bend to right. Therefore this mismatch can be explained.

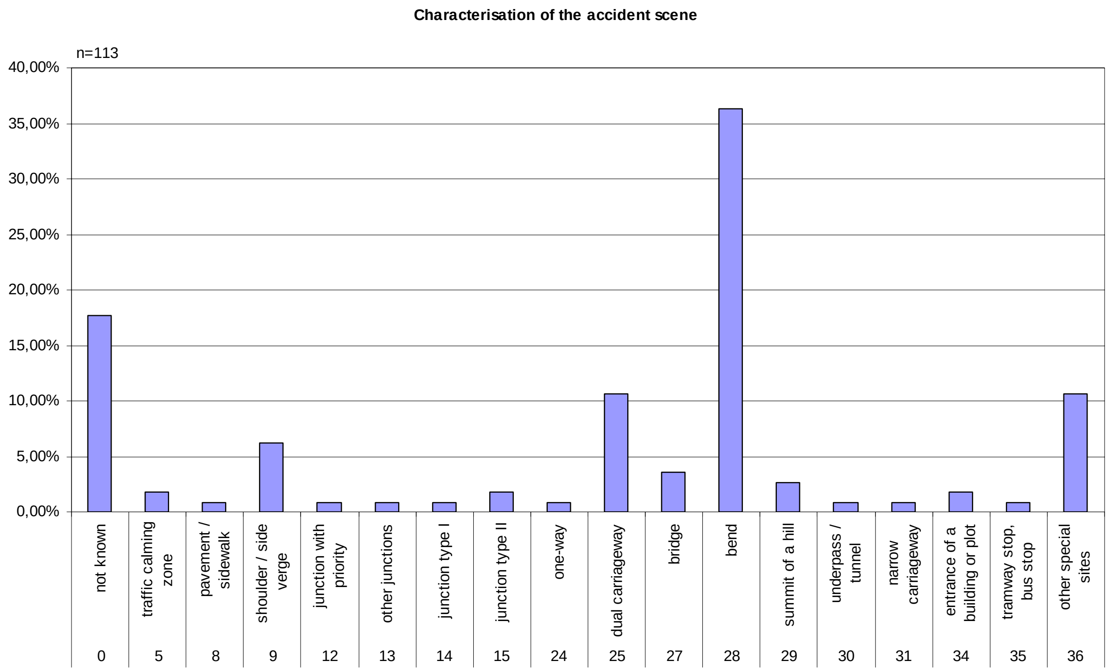



Fig. 16: Characterization of the accident scene

Additional 20 cases could be found in ZEDATU which met all the criterions but not all necessary information was present. As already mentioned above single vehicle accidents are not well documented and so nine cases were added to task 1.3.

Even if there were only fatalities investigated AIS coding was made.

## 5.1 Injury analysis

Injuries were merely analyzed from PENDANT database. As it can be seen in next picture most of the occupants in single vehicle accidents were driver ~63% and about 26% front seat passenger. Close to 11% were passengers of the second row.

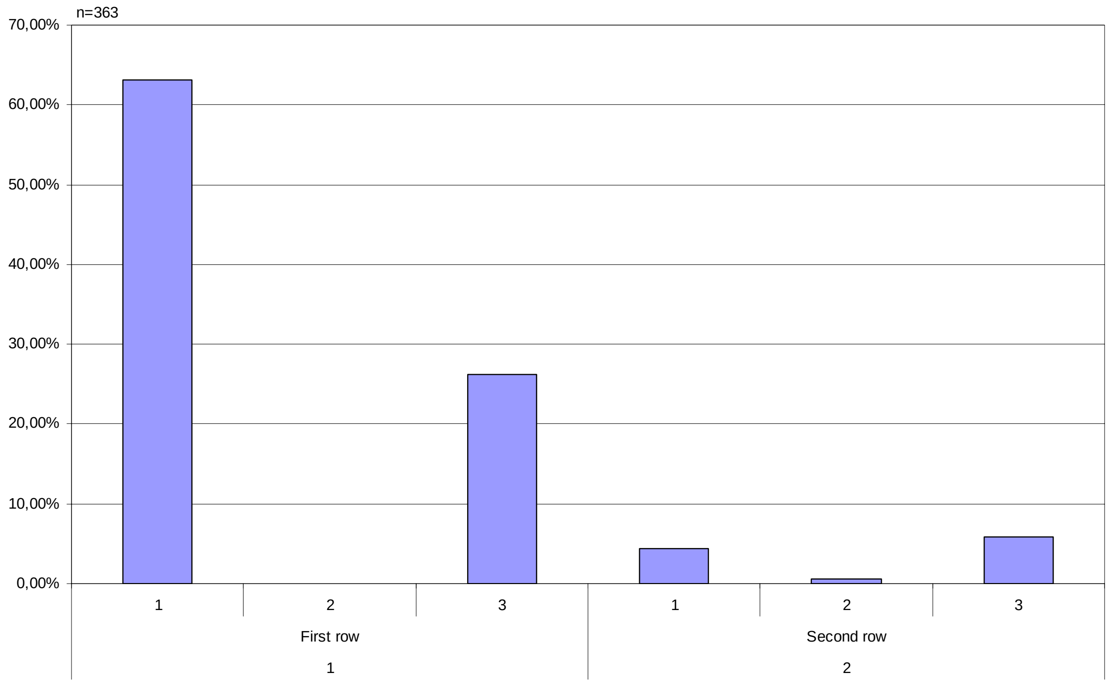



Fig. 17: Number of occupants participating in single vehicle accidents CARE subgroup C

Find in the diagram the maximum injury severity of all occupants in single vehicle accidents of CARE subgroup C1. 336 occupants were involved and the injury severity was known – AIS were coded respectively. Most of them only had minor injuries or weren't injured at all. A small fraction was fatalities in C11 and C13.

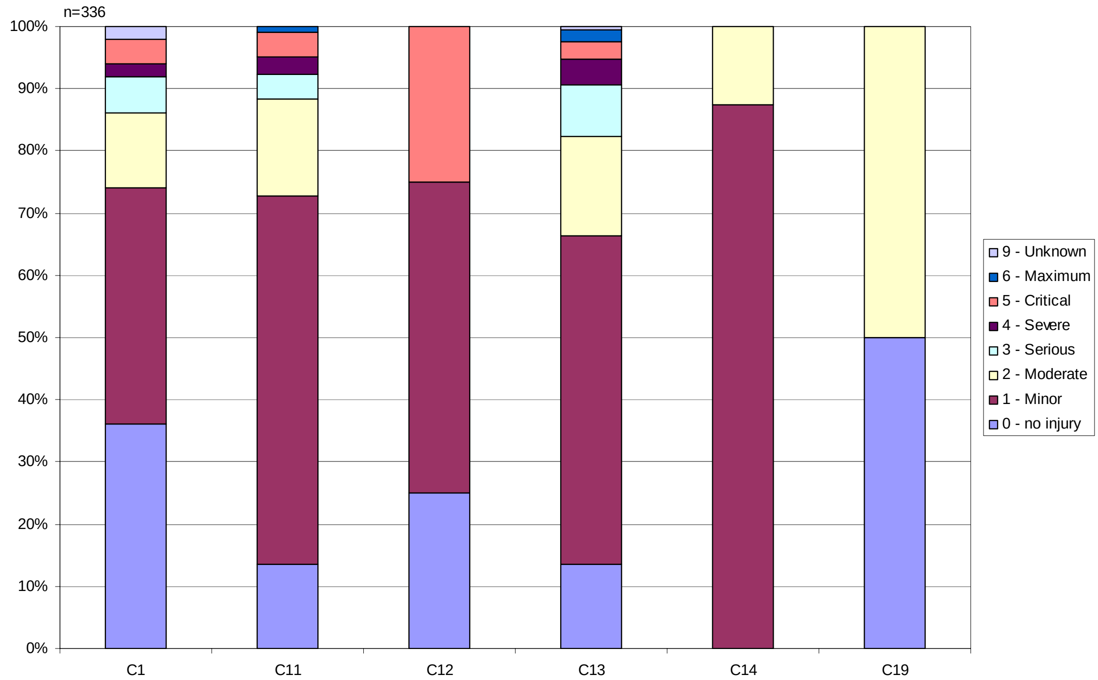



Fig. 18: Injury severity of occupants in single vehicle accidents

The injury situation of driver and front seat passenger have been analysed in the two figures afterwards. Most of the driver was minor injured. A small number wasn't injured at all or only had moderate injuries. In category C13 approximately 20% had AIS 3+ injuries and in C1 15%.

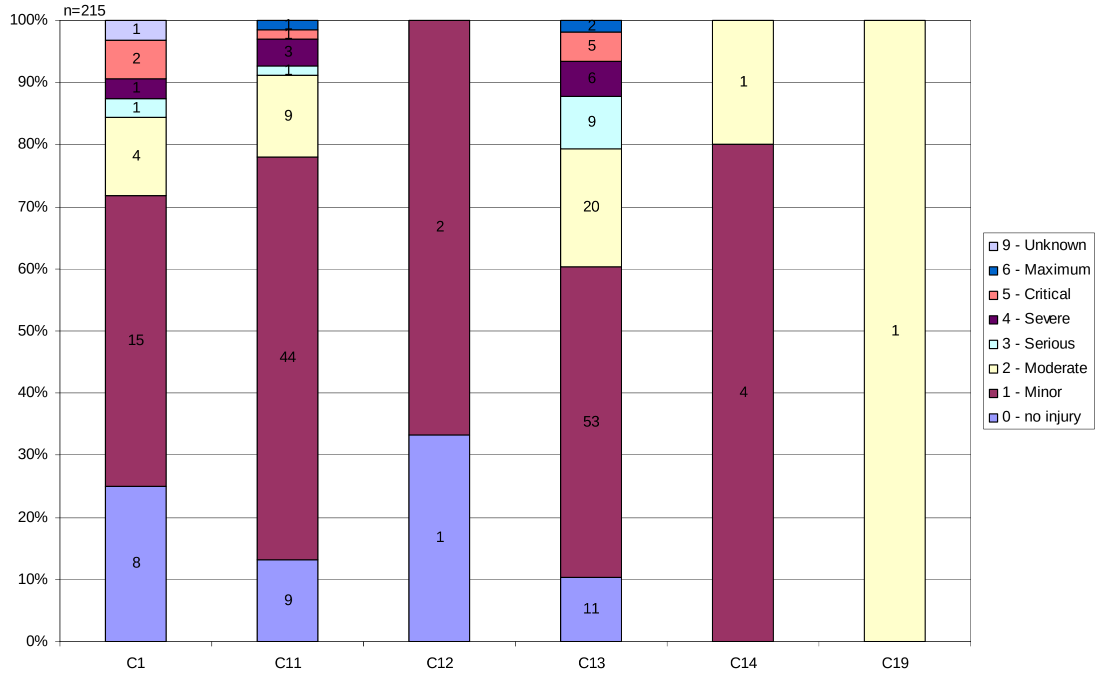



Fig. 19: Injury severity of driver

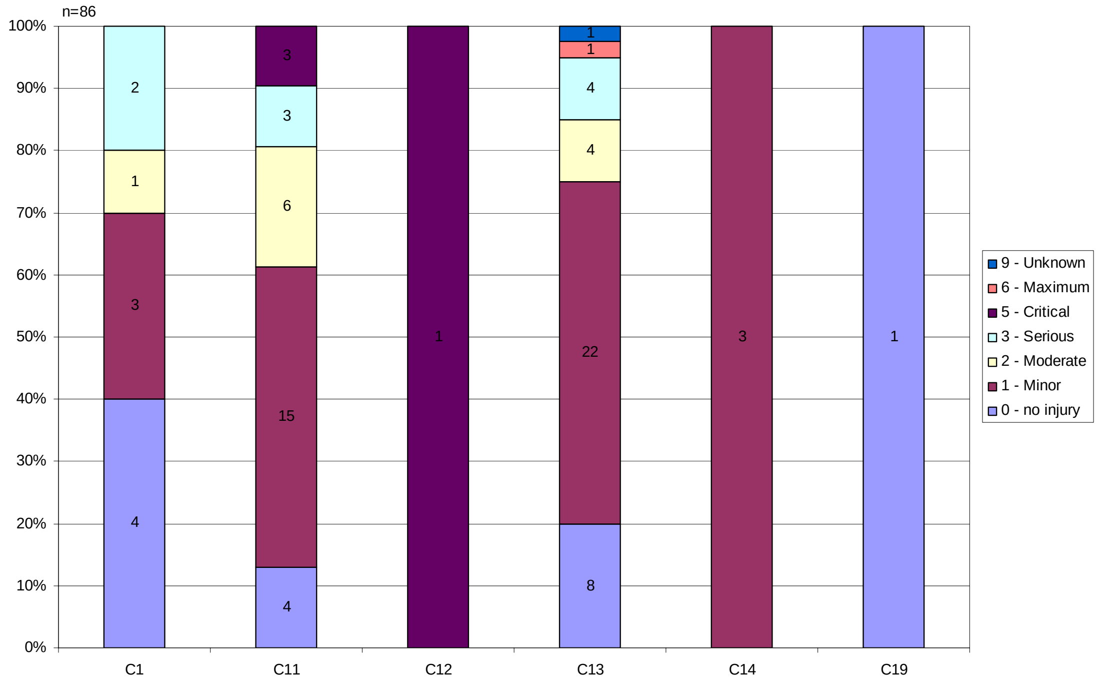



Fig. 20: Injury severity of front seat passenger

## 5.2 Single vehicle accident analysis

It was introduced to look for cases which were already reconstructed with PC Crash. Unfortunately only a view partners are familiar with this program. Anyway even if they were working with PC Crash they used other methods too and for this task most of the appropriate cases wasn't reconstructed with PC Crash. Therefore all cases had to be reconstructed twice. At first it was necessary to reconstruct the accidents in general and second with the assumption that the car was equipped with ESP.
Within PC Crash the reconstruction can be performed over 2D or 3D drawing or digitized and rectified photograph in an interactive graphical environment. For an effective presentation of the results, 3D animations can be created directly from the calculated results. Different road conditions can be simulated as well [7].
Due to the fact that many vehicles are already equipped with ESP such tool was implemented in the software. PC Crash includes two different tyre models: Linear tyre model and TM-Easy. The TM-Easy tire mode allows non-linear tire effects to be modelled, including differences between lateral and longitudinal parameters [7].
For the reconstruction of the accidents the tire model TM-Easy of PC Crash was used.

### 5.2.1 Categorization of single vehicle accidents

The accidents caused by a chain of circumstances were categorized on the basis of on-scene material and regarding street section into bends or straight roads. It was seen that within the analysed cases the driver tried to avoid an accident and counter steered n-times. In many cases the vehicle started skidding and no intervention by the driver could stabilize the car.
In most of the cases the accident was initiated by an emergency manoeuvre of the driver (pulling the steering wheel). The driver tried to avoid leaving the road to the side or a collision with an obstacle on the road.

In principle subsequent picture provides the categories of single vehicle accidents.

Within the *skidding* category the vehicle started skidding due too high velocity. No counter steer was made by the driver. In the following example the accident resulted in a collision with a tree. At a certain point the yaw angle increased to a level where no intervention by the driver is possible anymore and the accident can't be avoided.

In the categories of *counter steer* the drivers pulled the steering wheel because leaving the road to the verge or avoid a collision with an obstacle on the road. In most of the cases inattention by the driver resulted in such emergency manoeuvre. Depending on the experience and the velocity of the vehicle counter steering occurred n-times but resulted in accidents anyway.

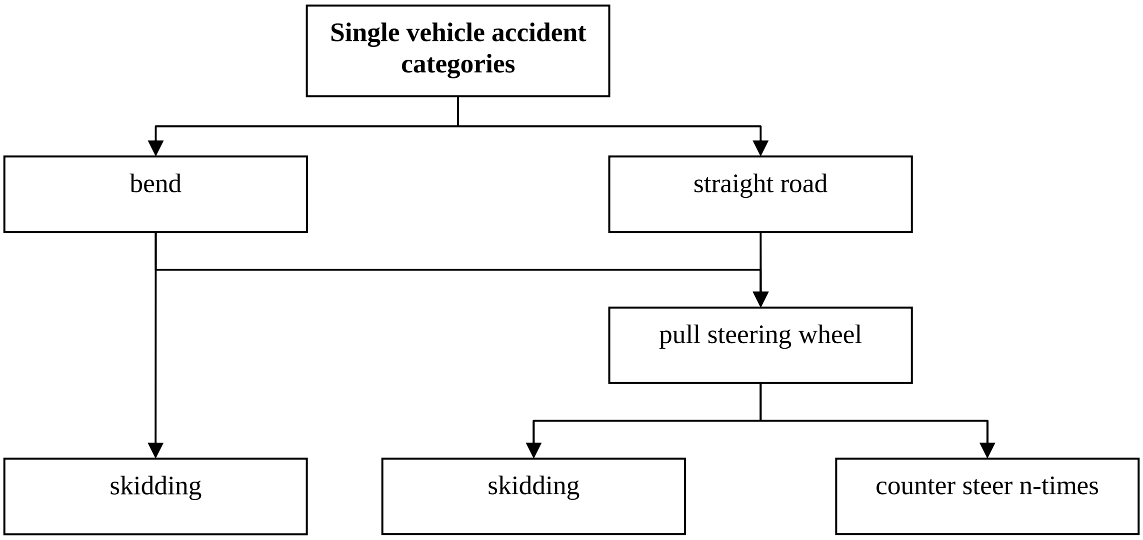
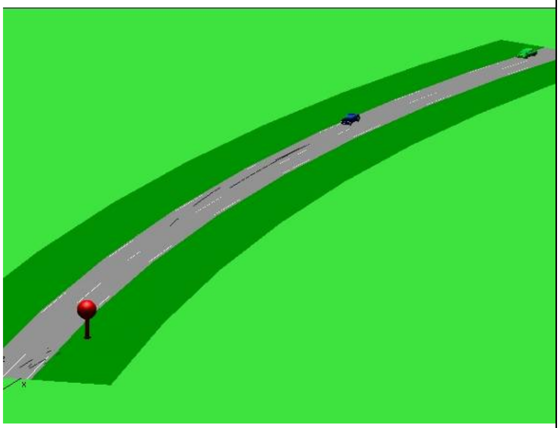
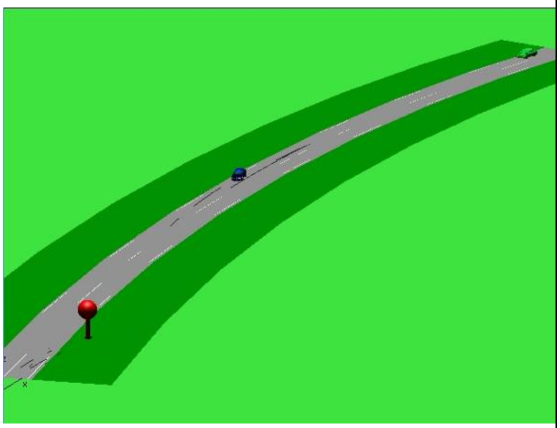
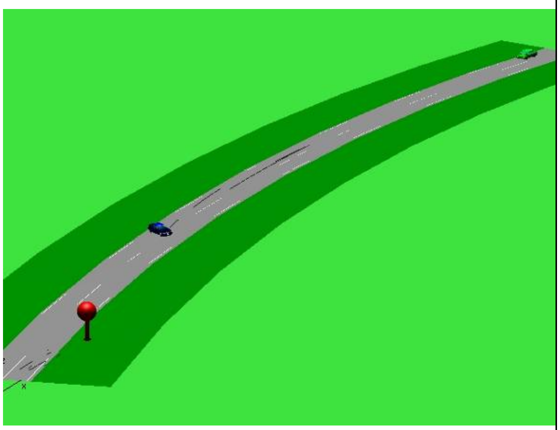
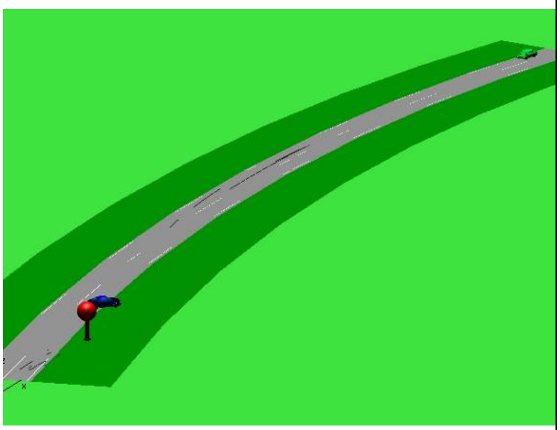



Fig. 21: Single vehicle accident categories

## a) Skidding

| **Skidding** | |
|---|---|
| position when sliding of vehicle begins | increasing of yaw angular velocity and angle |
|  |  |
| vehicle starts skidding | collision with the tree can't be avoided any-more |
|  |  |

For the accidents where the driver didn't pull the steering wheel the characteristic of yaw angle is illustrated in the subsequent pictures. At the left hand side ESP was off and at the right hand side ESP was on. In such cases the vehicle started sliding probably on roads with low friction (wet, icy roads, etc.) the yaw angle increased and the driver didn't counter steer or it wasn't possible anymore because the angle exceeded the thresholds already. Breaks in the curves indicate collisions with obstacles, mainly trees, poles, etc.

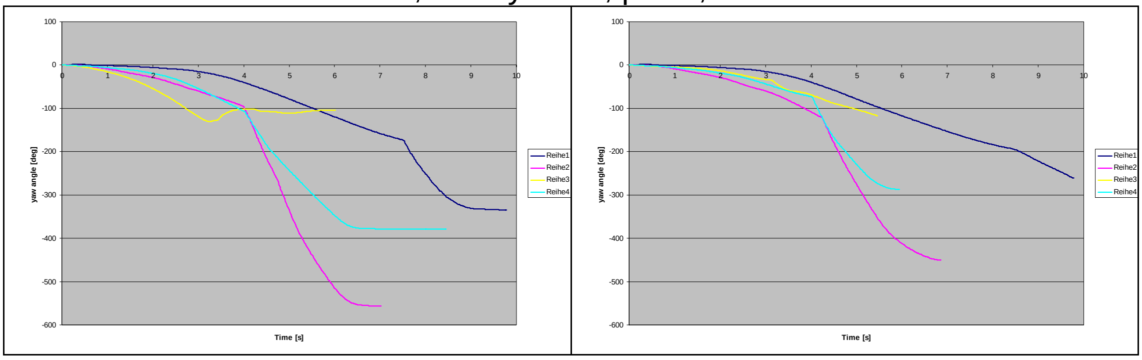



Fig. 22: Yaw angle no pulling steering wheel and skidding in a bend

Loss of vehicle control isn't only a function of yaw angle. Yaw angular velocity needs to be taken into account too. Collisions with obstacles distinguish jumps in the graph. The yellow line characterises a rollover. Vehicle skidded and the yaw angle increased finally the wheels got stuck at the soil and the rollover occurred. As it can be seen in the right picture the accidents couldn't be prevented as the jump in the charts indicate. For the yellow accident the rollover could be prevented but the vehicle still skidded.

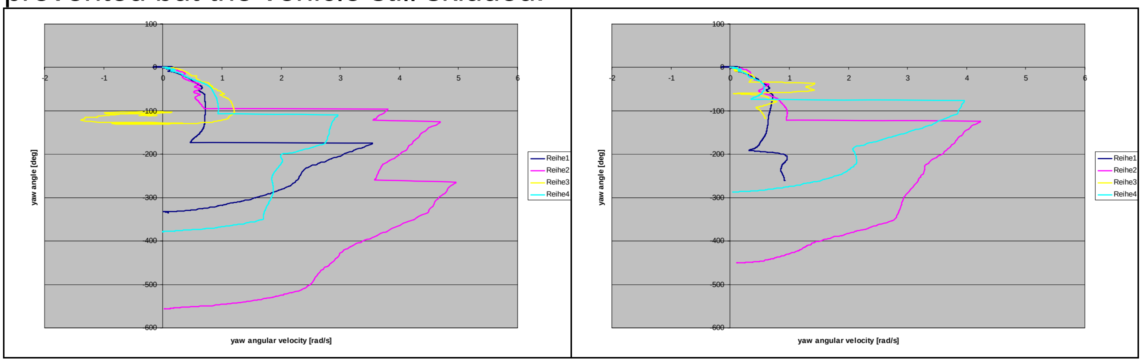



Fig. 23: Yaw angle vs. angular velocity no pulling steering wheel and skidding in a bend

Successive diagrams demonstrate the characteristic charts of skidding accidents in bends and on straight road sections whereby the driver pulled the steering wheel and skidding occurred afterwards. Again break in the graphs identify collision points. Even if there was an emergency manoeuvre of the driver the graph doesn't reflect this situation in a good shape.

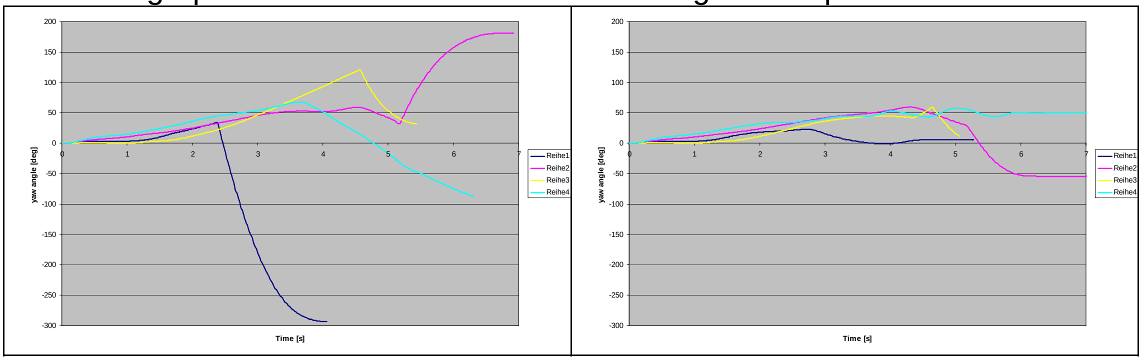



Fig. 24: Yaw angle pulling steering wheel and skidding in a bend

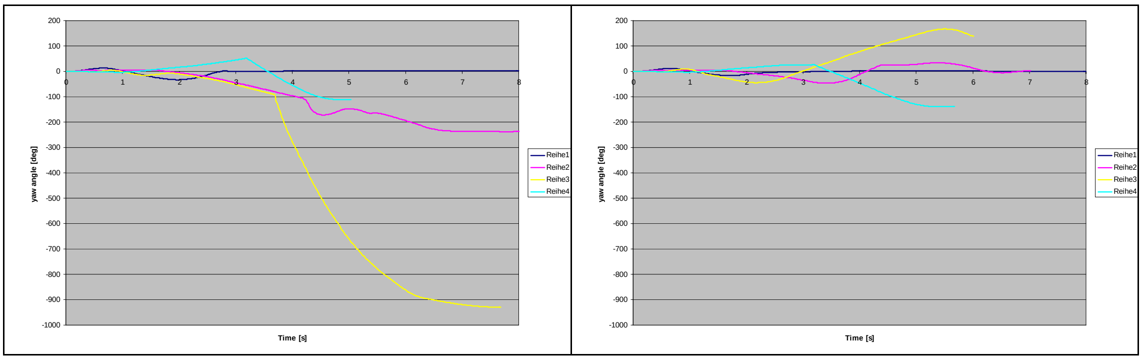



Fig. 25: Yaw angle pulling steering wheel and skidding on a straight road

As already mentioned indicates jumps in the charts a collision. All cases had an impact at one point. ESP reduced in these cases angular velocity and yaw angle but couldn't prevent the accidents.

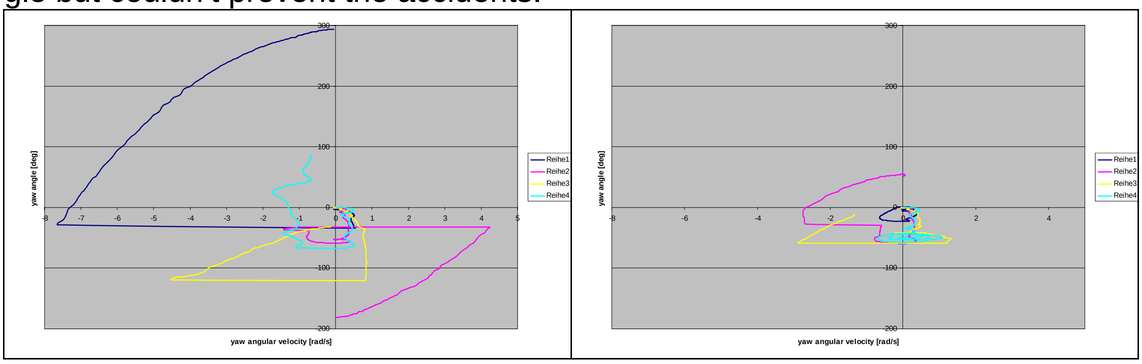



Fig. 26: Yaw angle vs. angular velocity pulling steering wheel and skidding in a bend

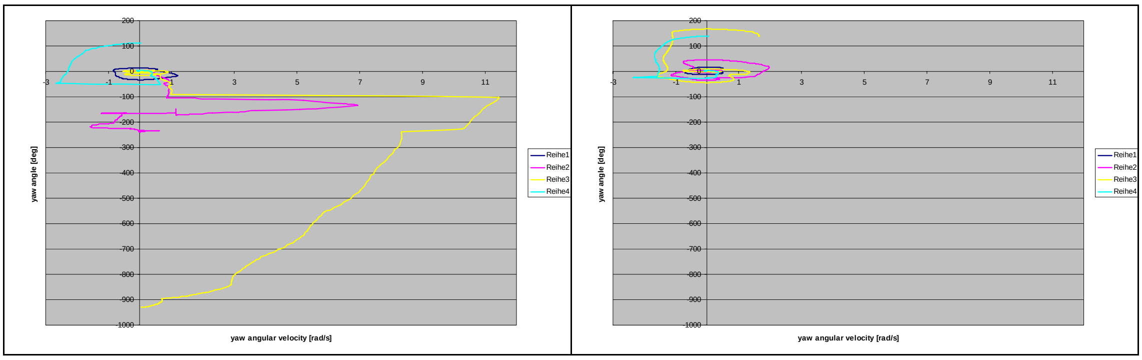
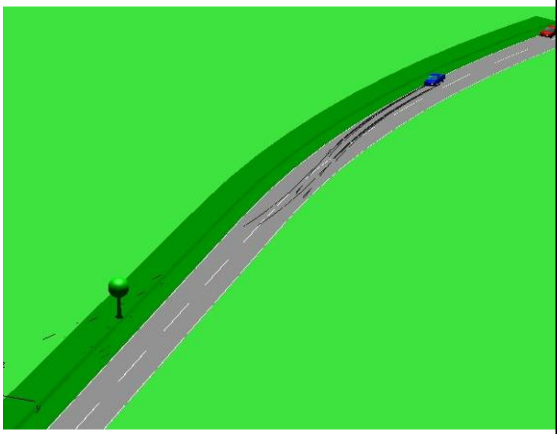
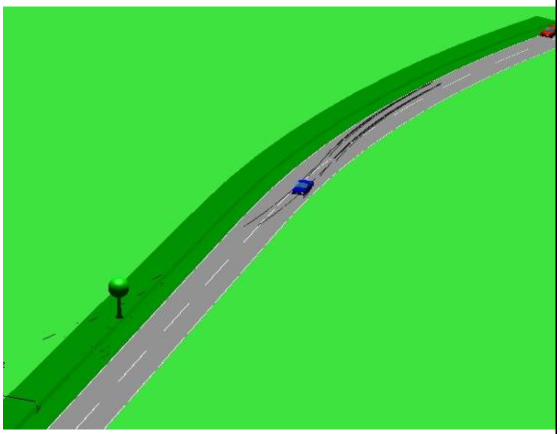
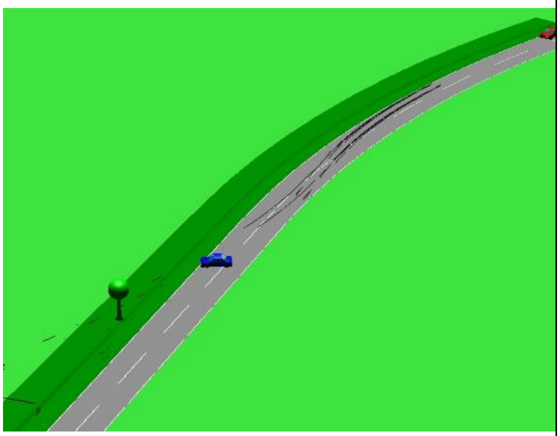
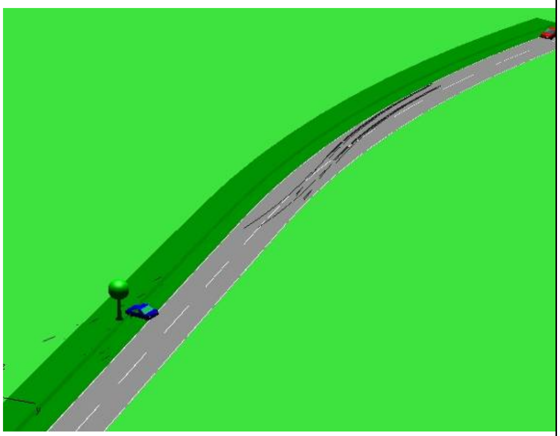
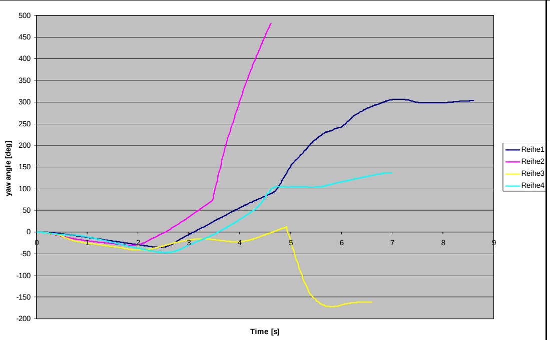



Fig. 27: Yaw angle vs. angular velocity pulling steering wheel and skidding on a straight road

b) Counter steer 1x

| **Counter steer 1x** | |
|---|---|
| position where driver pulled the steering wheel to get out of the verge | driver had to counter steer to avoid leaving the road to at the offside |
|  |  |
| due to too aggressive counter steer manoeu-vre the vehicle started skidding | prevention of the collision with the tree isn't possible |
|  |  |

After pulling the steering wheel (emergency manoeuvre) the yaw angle increased and the driver had the chance to counter steer. The yaw angle started to increase to the opposite direction very fast and skidding wasn't preventable. Even if ESP reduced the yaw angle and angular velocity collisions occurred with road side infrastructure (tree, pole, post, etc.).



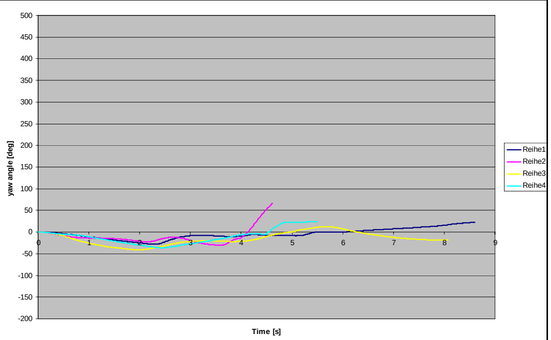




Fig. 28: Yaw angle pulling steering wheel and counter steering 1x in a bend

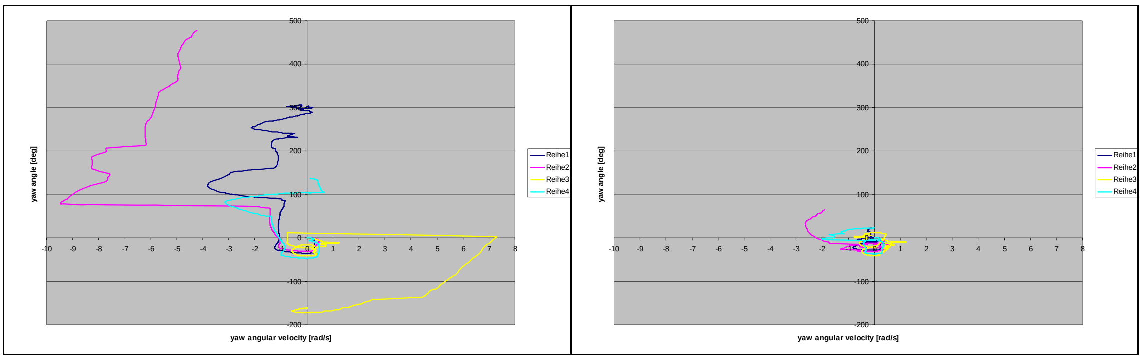



Fig. 29: Yaw angle vs. angular velocity pulling steering wheel and counter steering 1x in a bend

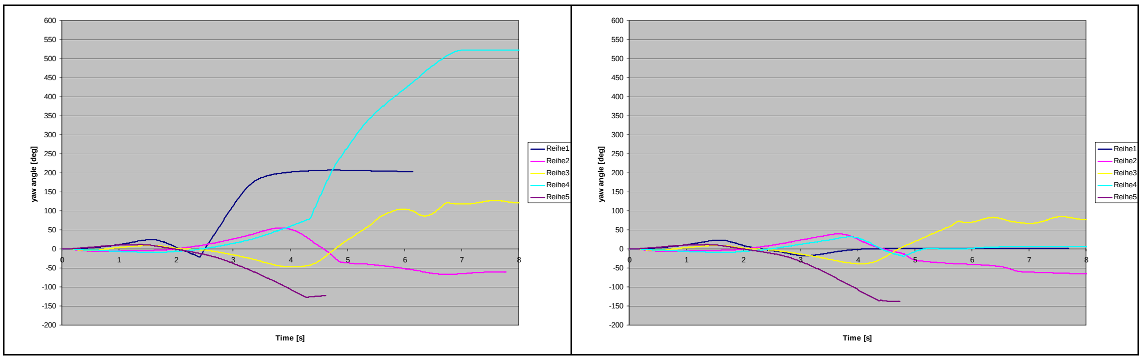



Fig. 30: Yaw angle pulling steering wheel and counter steering 1x on a straight road

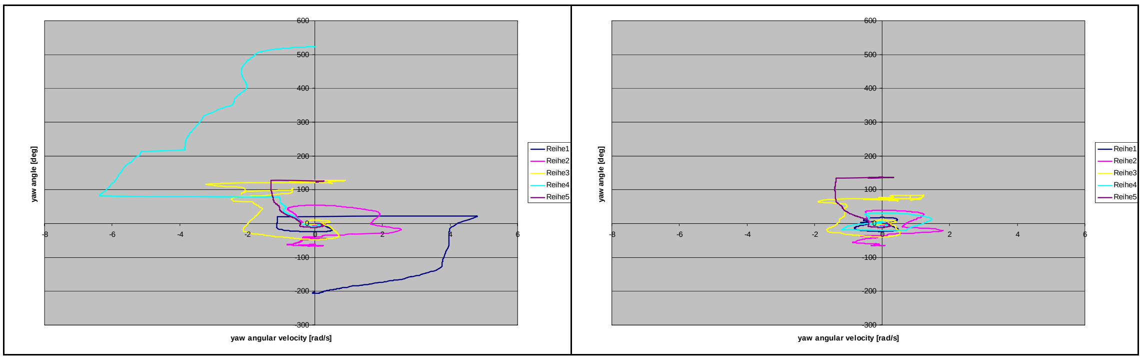
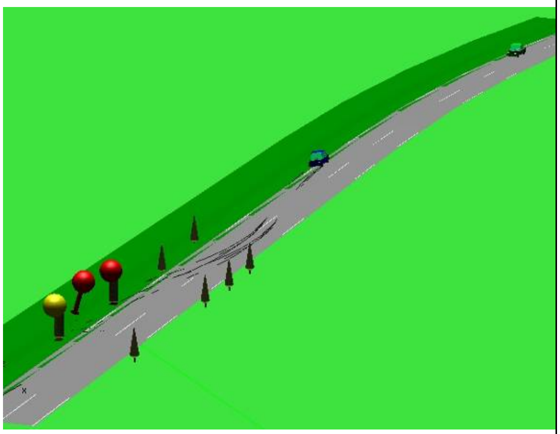
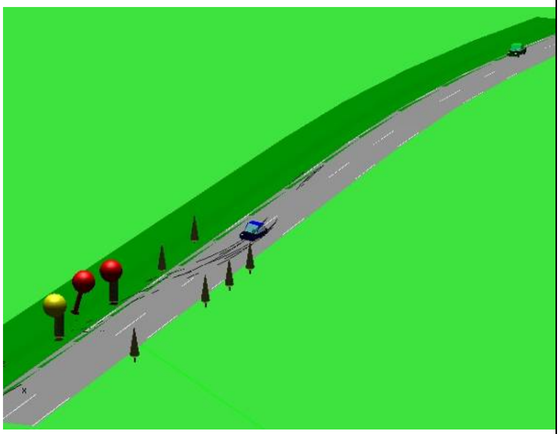
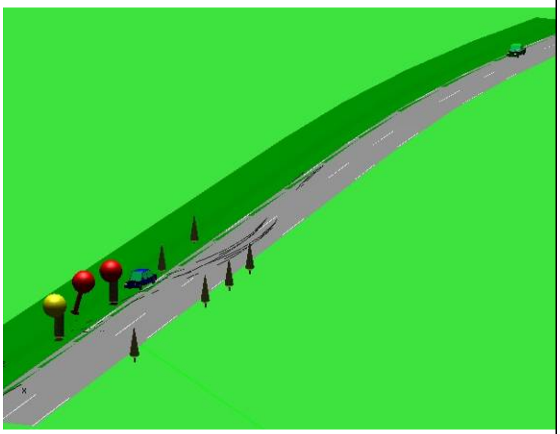
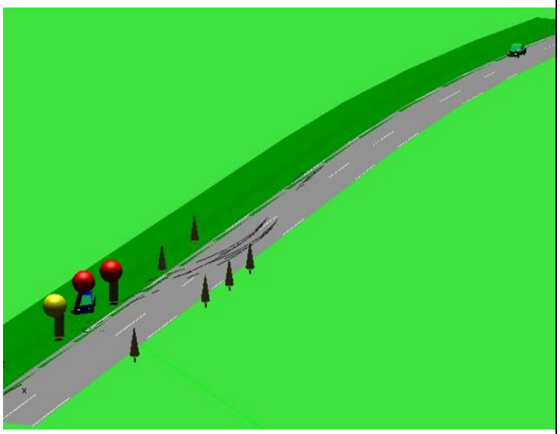



Fig. 31: Yaw angle vs. angular velocity pulling steering wheel and counter steering 1x on a straight road

## c) Counter steer 2x

| **Counter steer 2x** | |
|---|---|
| position where driver pulled the steering wheel to get out of the verge | driver had to counter steer to avoid leaving the road to at the offside |
|  |  |
| due to too aggressive counter steer manoeu-vre the vehicle came into the verge again – tried to counter steer a second time | After driving to the embankment it wasn't possible to avoid the accident. Additional many trees were present too. |
|  |  |

Only in one case counter steering 2x occurred.

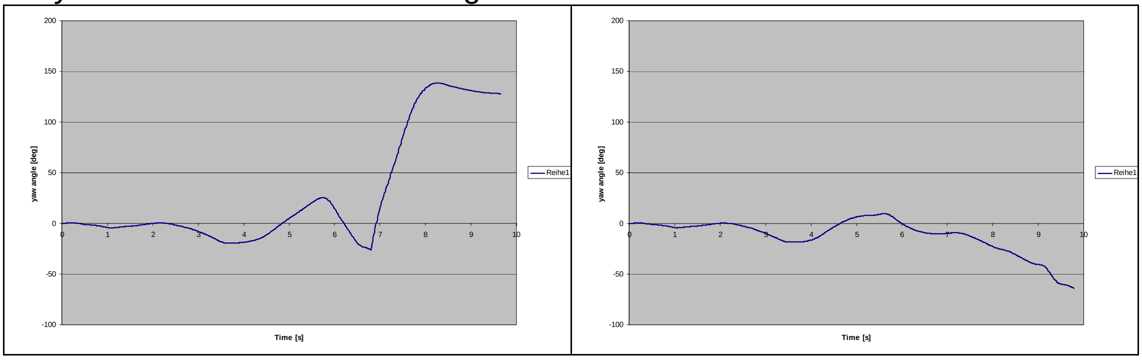



Fig. 32: Yaw angle pulling steering wheel and counter steering 2x on a straight road

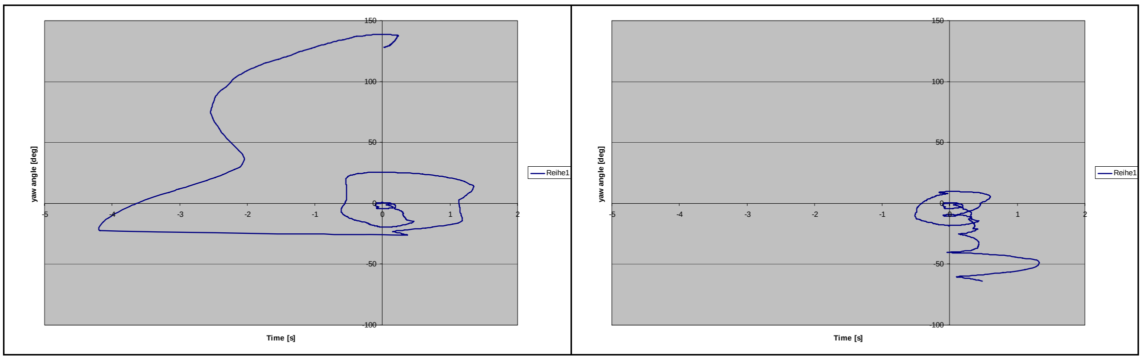
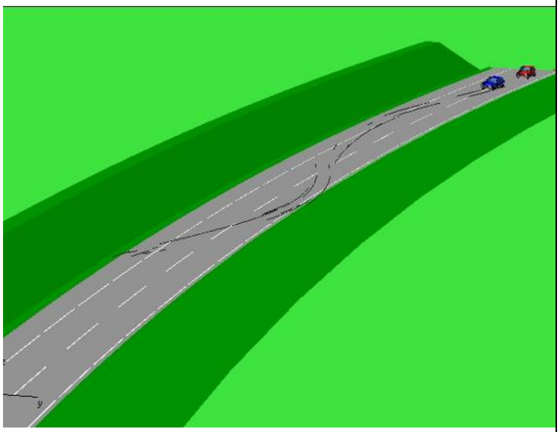
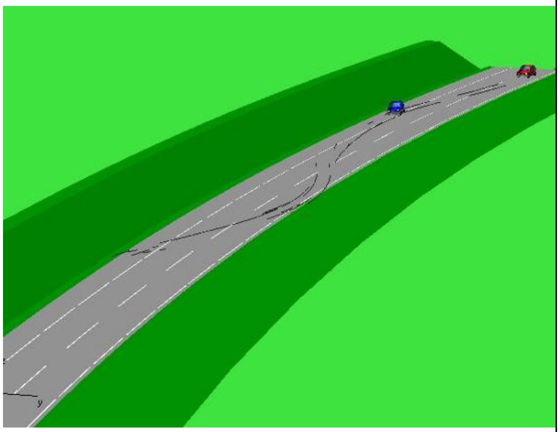
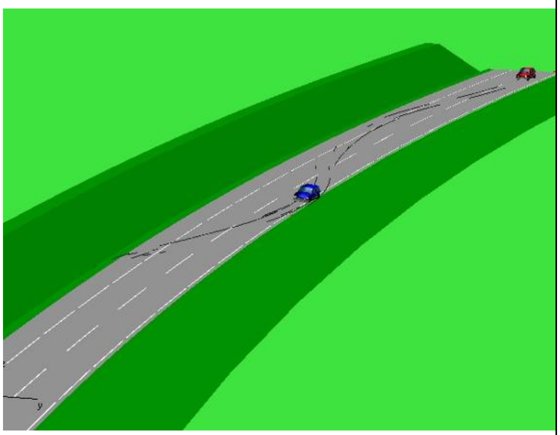
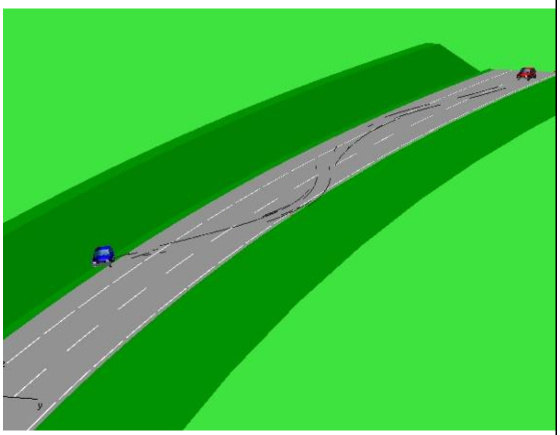
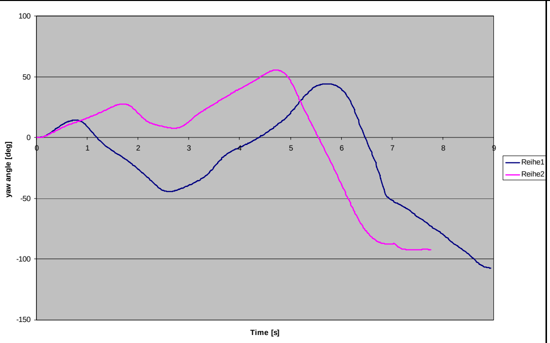



Fig. 33: Yaw angle vs. angular velocity pulling steering wheel and counter steering 2x on a straight road

## d) Counter steer 3x

| **Counter steer 3x** | |
|---|---|
| position where driver pulled the steering wheel to avoid collision with an obstacle | driver had to counter steer to avoid leaving the road to at the nearside |
|  |  |
| due to too aggressive counter steer manoeu-vre the vehicle came into the verge– tried to counter steer a second time | At this point the driver had to counter steer the third time. Unfortunately the wheels got stuck at the soil and a rollover occured |
|  |  |



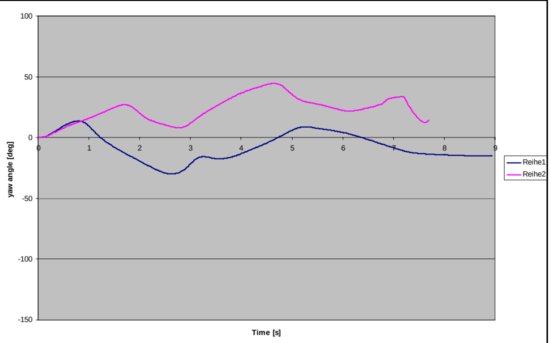




Fig. 34: Yaw angle pulling steering wheel and counter steering 3x

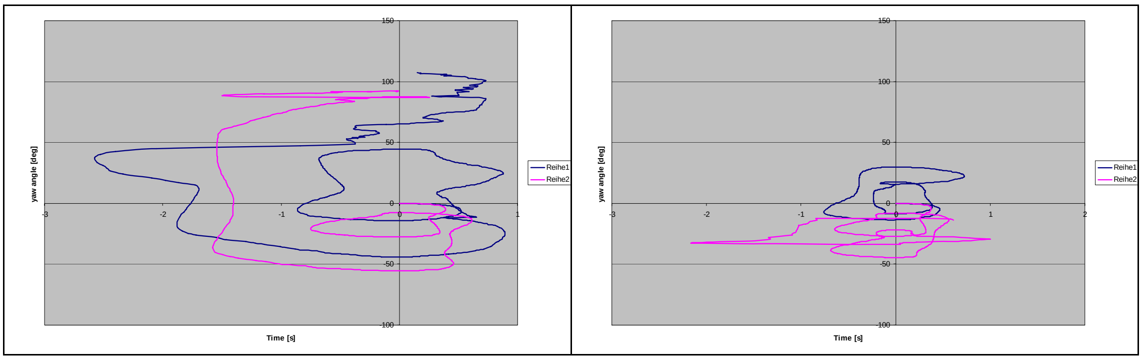



Fig. 35: Yaw angle vs. angular velocity pulling steering wheel and counter steering 3x

Subsequent table gives an idea of the number of cases with the steering behaviour of the drivers.

| | pull steering wheel | skidding | counter steer 3x | counter steer 2x | counter steer 1x | |
|---|---|---|---|---|---|---|
| bend | no | 4 | | | 1 | 5 |
| | yes | 4 | 1 | | 3 | 8 |
| bend result | | 8 | 1 | | 4 | 13 |
| straight road | no | 1 | | | | 1 |
| | yes | 5 | 1 | 1 | 5 | 12 |
| straight road result | | 6 | 1 | 1 | 5 | 13 |
| | | 14 | 2 | 1 | 9 | 26 |

Tab. 6: Accident sequences

Emergency manoeuvres were caused due to inattention and vehicle went to the verge and the driver tried to alter the course. The driver pulled the steering wheel and had to counter steer to avoid leaving the road offside or started skidding and lost the control completely.
Especially in bends and high speed the vehicle started skidding and the driver lost control and finally hit a tree or post or even resulted in a rollover.
In five cases the driver could counter steer but resulted in an accident anyway. For accidents on straight sections obstacles on the road and inattentiveness of the drivers were responsible for emergency manoeuvres. In seven cases it was possible to counter steer. If the vehicle started to skid no intervention from driver was possible anymore.

### 5.2.2 General single vehicle accident analysis

As already mentioned 26 cases have been analysed finally. Within this selection it was found out that 13 single vehicle accidents occurred in a bend and had an impact at one point and 13 cases on straight roads. No distinction was made if this impact happened at the beginning of the sequence or at the end. Two cases got stuck mostly at the soil and rolled over within a bend and four on straight road sections.

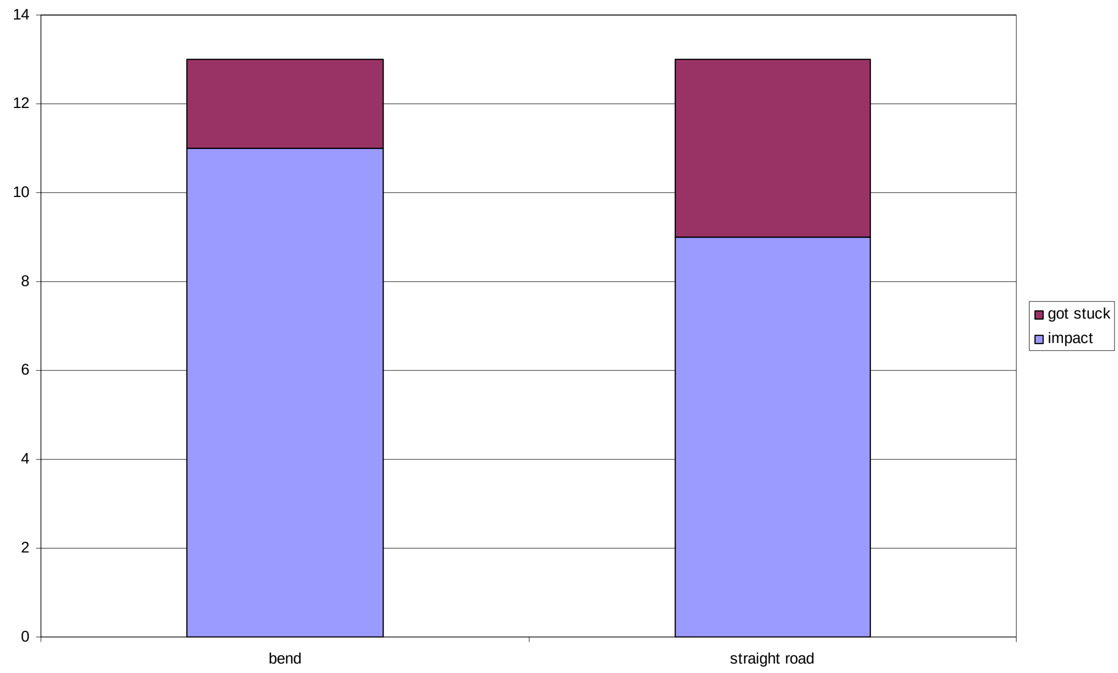



Fig. 36: Street section and impact category

It was found out that in every case were the wheels got stuck the vehicle had a rollover. No matter if there was a bend or the accident happened on a straight road. For accidents within a bend were an impact appeared too three resulted in a rollover.

Dangerous situations occur if the vehicle left the road and got stuck in the verge. These accidents resulted in rollovers.

Nine of the cases on straight roads had an impact at one point.

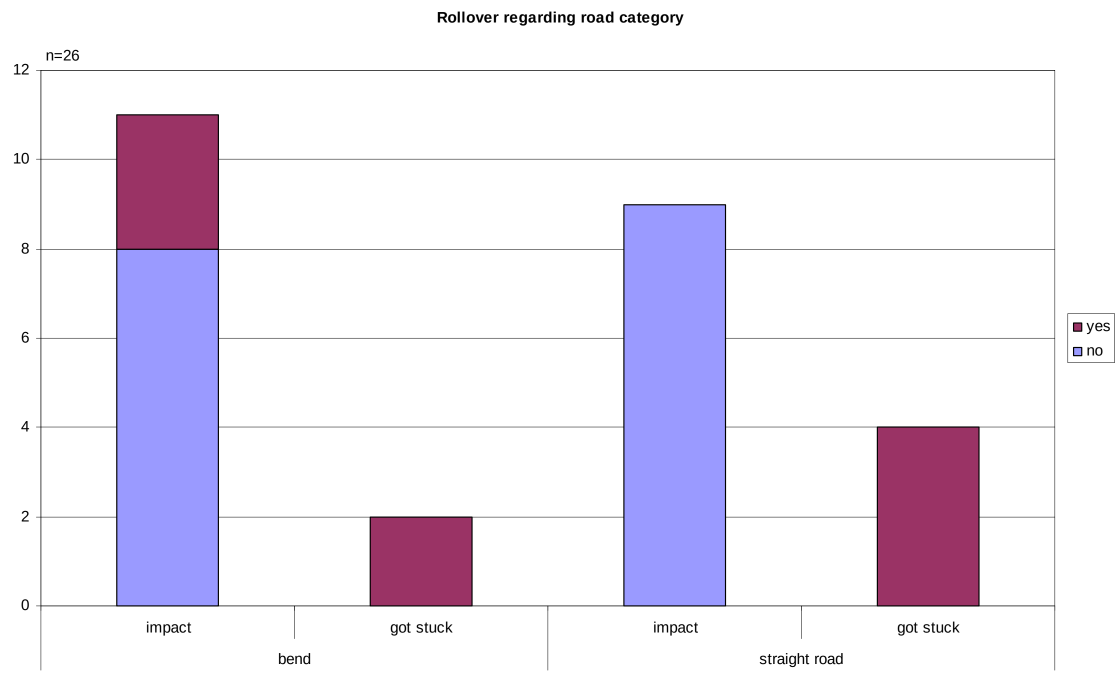



Fig. 37: Rollover and road category

In a more detailed picture three rollover accidents proceed in bends after an impact, two cases before a contact occurred with an obstacle and for another two cases a rollover happened without a collision.
On straight roads one single vehicle accident had a contact before the rollover happened and for three cases no collision arose. The vehicles started to slide got stuck at the soil when they were leaving the road or had a contact with the kerbstone which produced the rollover.

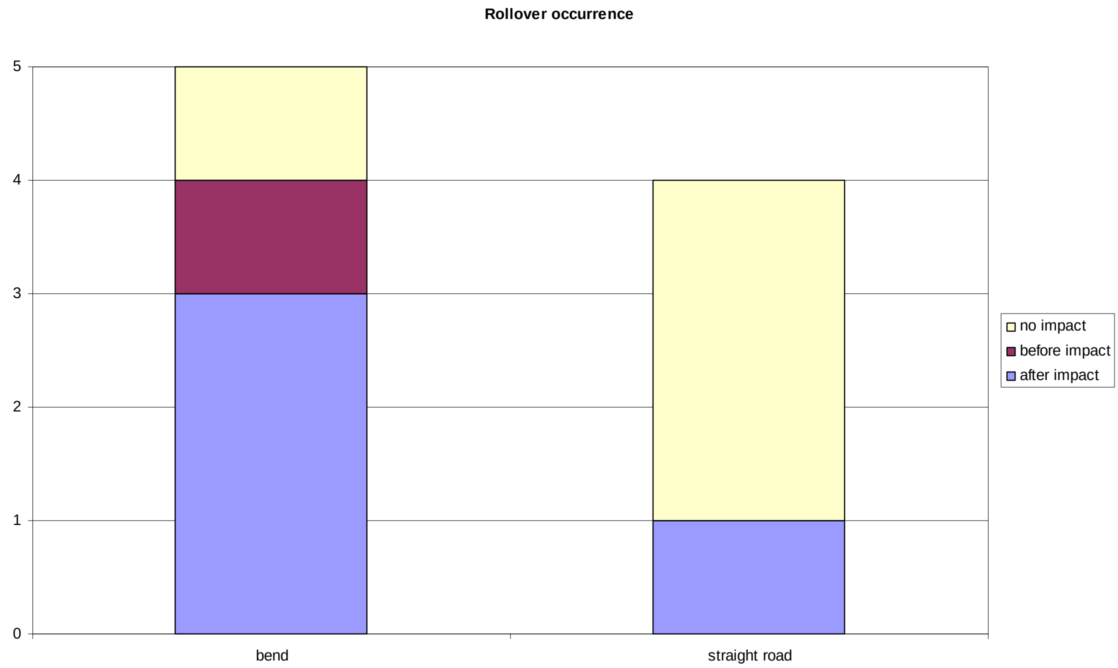



Fig. 38: Rollover proceeded

Following chart represent the street section versus the impact obstacle. As a result of single vehicle accidents in bends the main collision partners are trees and poles/posts which occurred in nine cases. In comparison most collisions happened on straight roads with road side barriers – six cases. No distinction within the type of barriers has been made. Three of the single vehicle accidents on straight roads resulted in an impact with a tree and a further two with soil where apparently a rollover followed. One single vehicle accident could be found which impacted the embankment and resulted in a rollover.

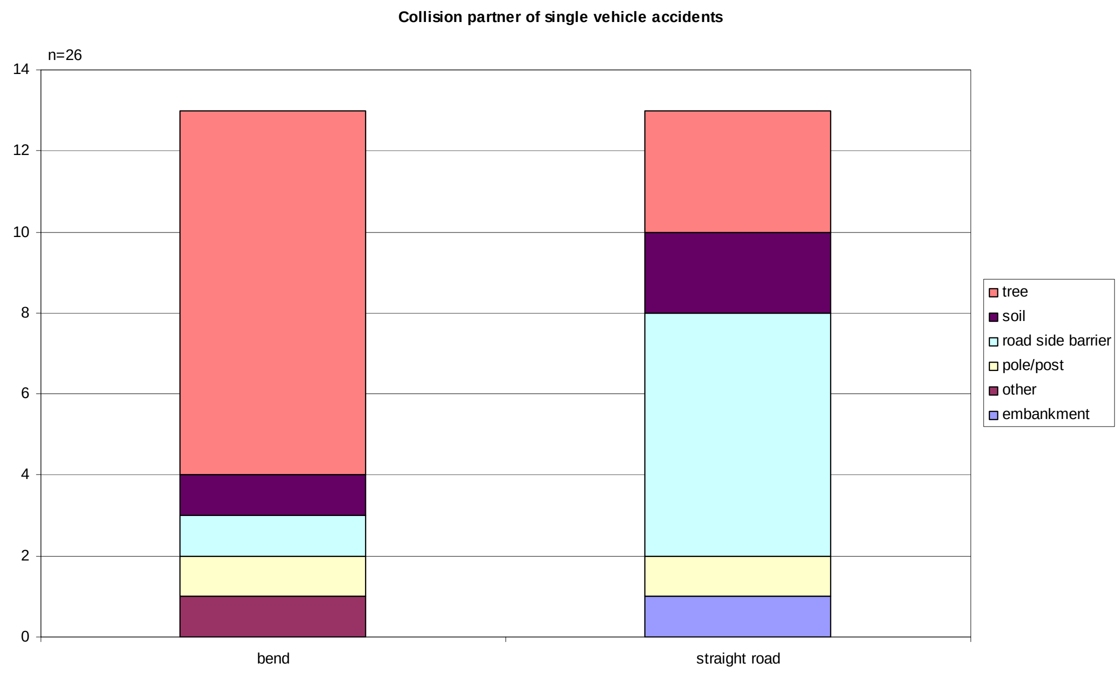



Fig. 39: Street section and collision partner

### 5.2.3 Analysis with assumption vehicle equipped with ESP

The number of vehicles equipped with ESP in road traffic is increasing. Therefore it is necessary to implement tools into reconstruction software which allows simulation of vehicles which are equipped with ESP. PC Crash already has this feature and reconstruction of accidents is rather simple if good evidence of on-scene is available but needs reconstruction practise anyway.

For reconstruction of the single vehicle accidents where the vehicles were equipped with ESP following assumptions had to be made:

- identical vehicle path for both reconstructions (first without and second with ESP)
- equal sequences duration
- equal braking pedal position

Of course that won't match the full accident reality but only with those assumptions it was possible to reconstruct the accidents.

In the software the angular velocity is controlled. Target angular velocity is calculated by actual steering angle and driven velocity. This angular velocity is compared to the actual angular velocity of the vehicle. If a specified threshold exceeds the difference of target/actual angular velocity individual wheels are slowed down depending if the vehicle is under or over steering.
The control factor (intensity of the additional braking) and the cycle time of the ESP can be handled.

| | |
|---|---|
| $r = \max\left( r_{act}, \frac{v^2}{a_{\max} \cdot \mu} \right)$ | Equation 1 |
| $\omega_{Soll} = \frac{v}{r}$ | Equation 2 |
| $\omega_{Diff} = \omega_{Soll} - \omega_{ist}$ | Equation 3 |
| $\Delta F_B = \left\| \omega_{Diff} \cdot k \right\|$ | Equation 4 |

In addition a maximum permitted lateral acceleration could be pretended. The system restricts the target angular velocity to the maximum controllable value [6].

The possibilities to prevent an accident with ESP equipped vehicles is analysed in the next diagram. In bends four cases could have been avoided and on straight roads ESP would have prevented an accident in four cases.
If it wasn’t possible to avert the accident ESP could lead to a different impact configuration. Instead of a side collision a frontal impact happened.
In case of leading to slight accidents the change of velocity Delta-V could have been decreased significantly but in some cases impact velocity decreased as well.
To summarize up to 30% (eight of 27) of single vehicle accidents would have been prevented if the vehicle were fitted with ESP. Of course the results are limited in case of the low number of accidents.

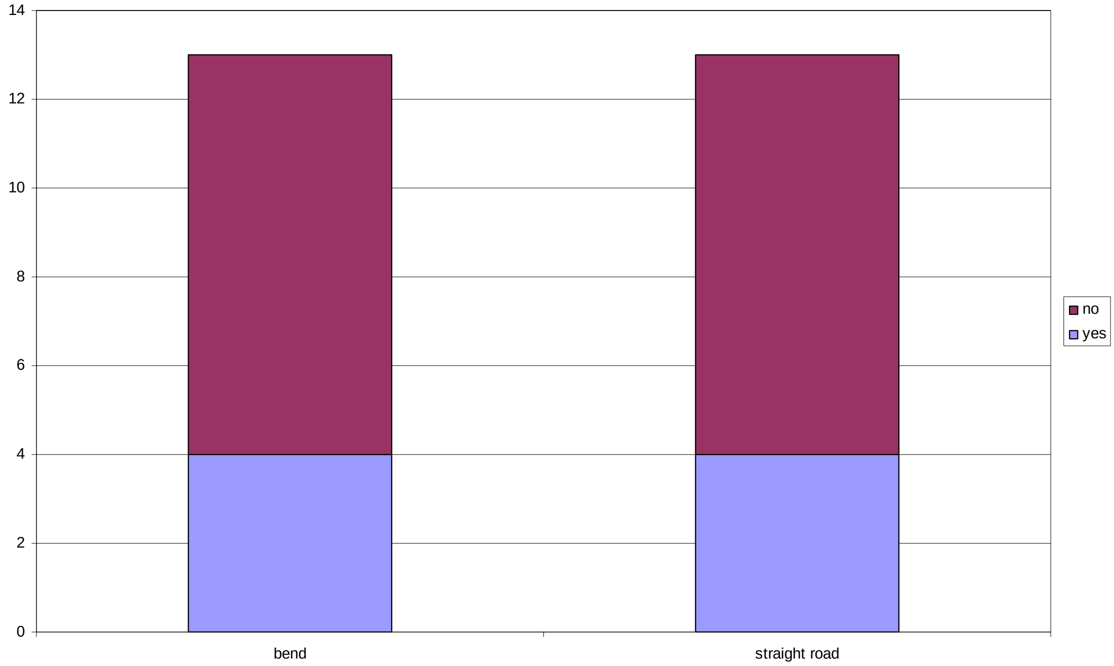



Fig. 40: Accident prevention in bends and on straight roads

### 5.2.4 Analysing of Delta-V in comparison to MAIS

Due to the low number of cases which could have been reconstructed and finally analysed it was necessary to find a possibility for estimating injury reduction when ESP led to a different collision configuration. Accident reconstruction allows calculation of Delta-V which is a good indicator for injury. Of course not only Delta-V has influence to injuries. Severe injuries are also caused by intrusions. Especially when there is a discrepancy in weight or the gap between the ages of the acting vehicles is to big e.g. post EuroNCAP vehicle vs. pre EuroNCAP vehicle. In such scenarios it could happen that the older one would be completely destroyed whereby the new car only have minor to moderate damage.

As it could be seen in the next diagram Delta-V in comparison to MAIS of the vehicle is analysed. Only the maximum injury severity of the participating vehicles was taken into account. For multiple contacts the maximum Delta-V of the vehicle was used. The picture represents all cases where the accident was reconstructed and injury severity was filled in.
Injury severity is increasing with increasing Delta-V. In the second row a critical injury occurred which developed from intrusion when analysing the special case in detail.

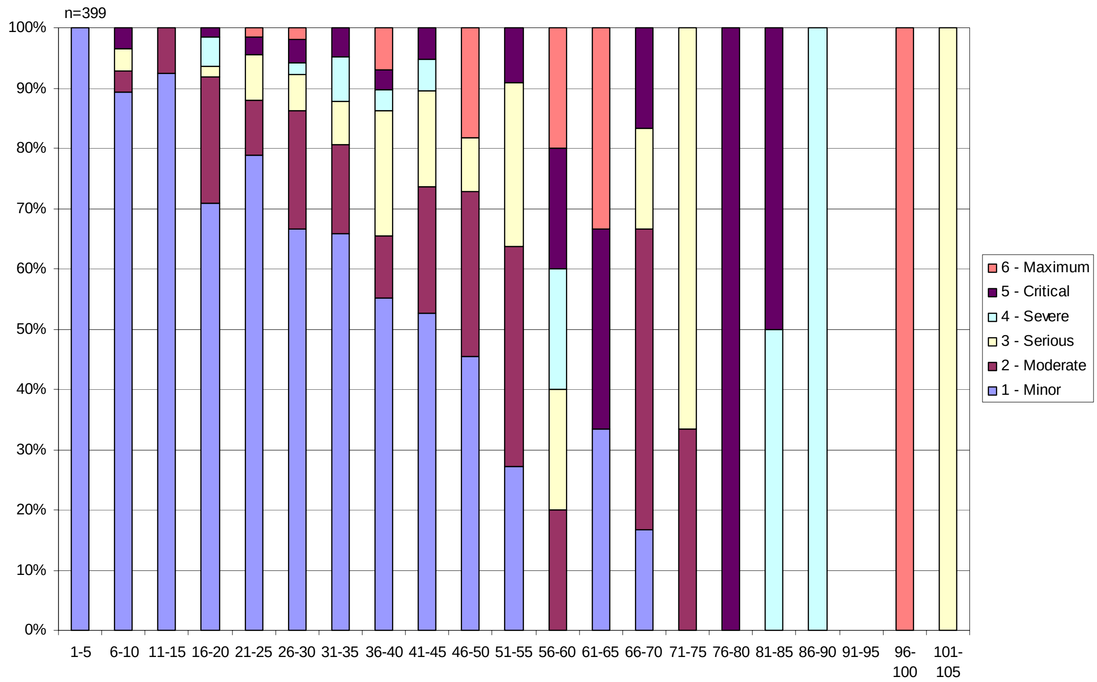



Fig. 41: Delta-V in comparison to MAIS

Subsequent figure gives the detail information of Delta-V in relation to MAIS within CARE subgroup C1. For change of velocity less than 26 [kph] only minor injuries occurred. In a small portion of cases moderate, severe and critical injury took place.

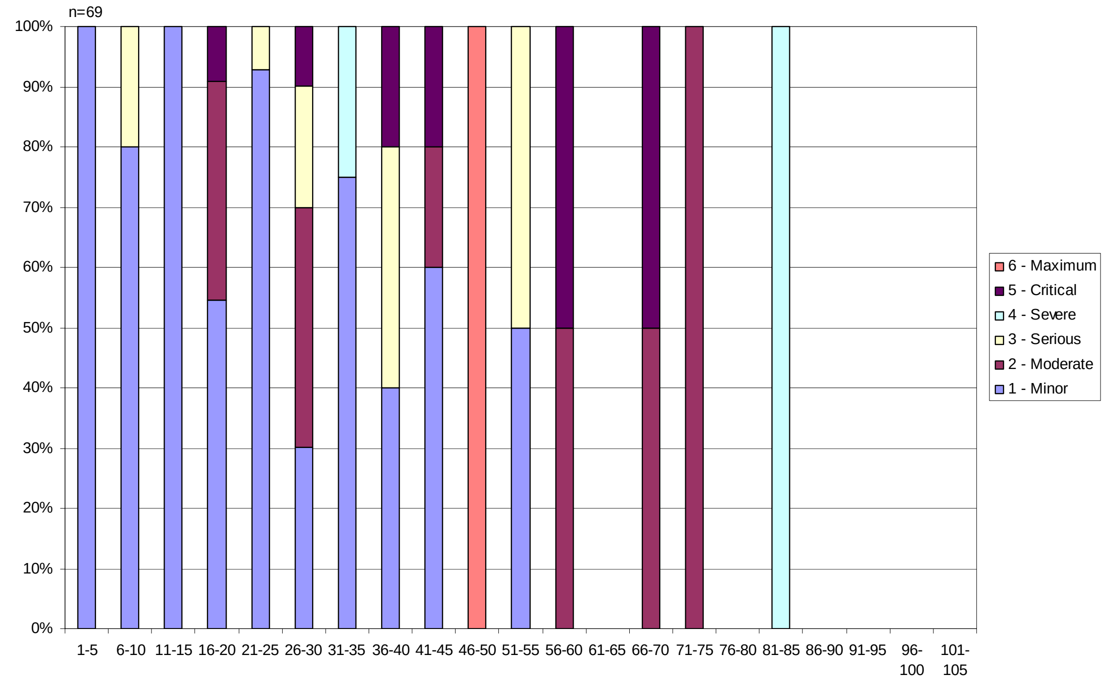



Fig. 42: Delta-V vs. MAIS Care subgroup C1

The following figures show the distribution amongst the categories within CARE subgroup C1 and maximum injury severity.

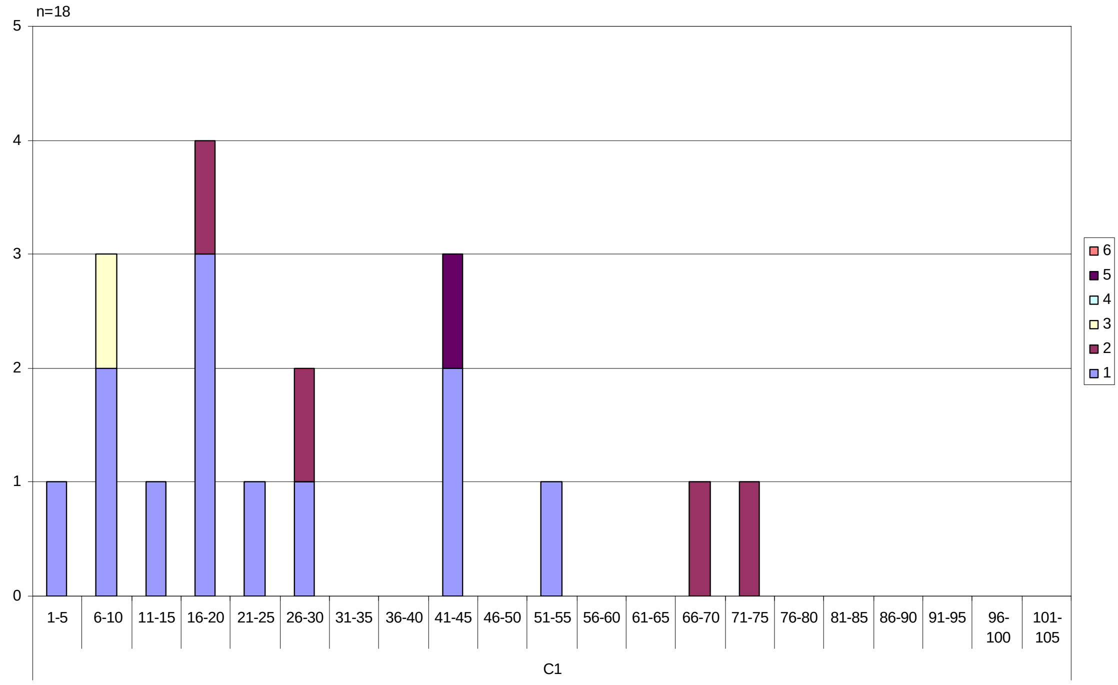



Fig. 43: MAIS - C1 - Single vehicle accidents without obstacles on the road

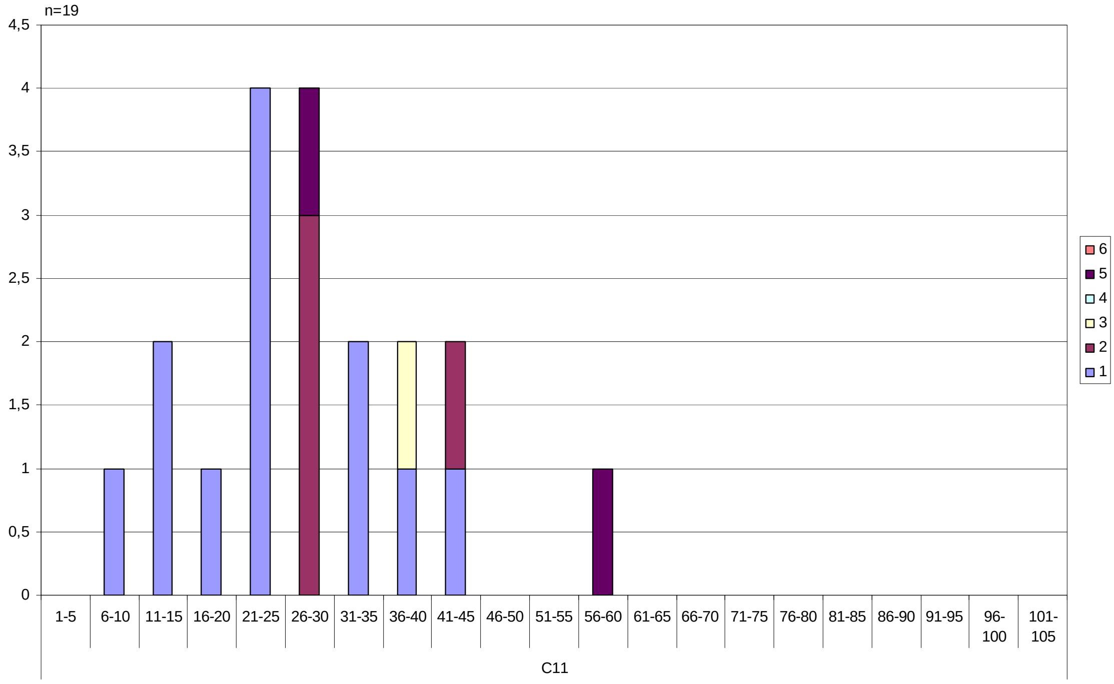



Fig. 44: MAIS - C11 - Single vehicle accident - leaving straight road - either side of the road

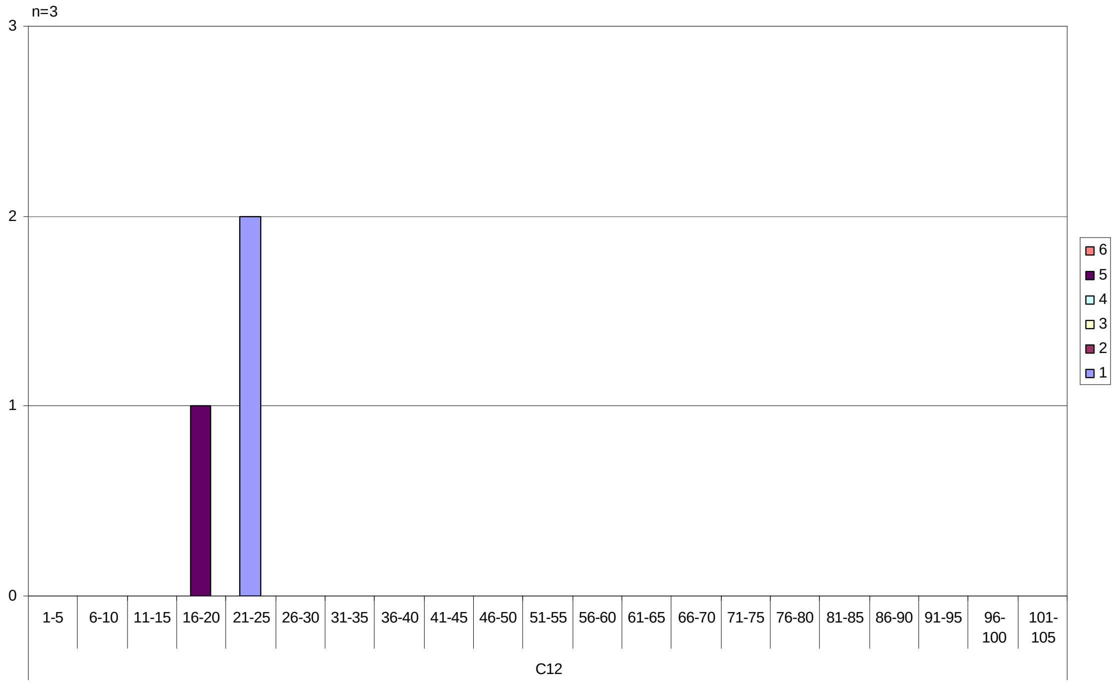



Fig. 45: MAIS - C12 - Single vehicle accidents on the road (often two-wheelers)

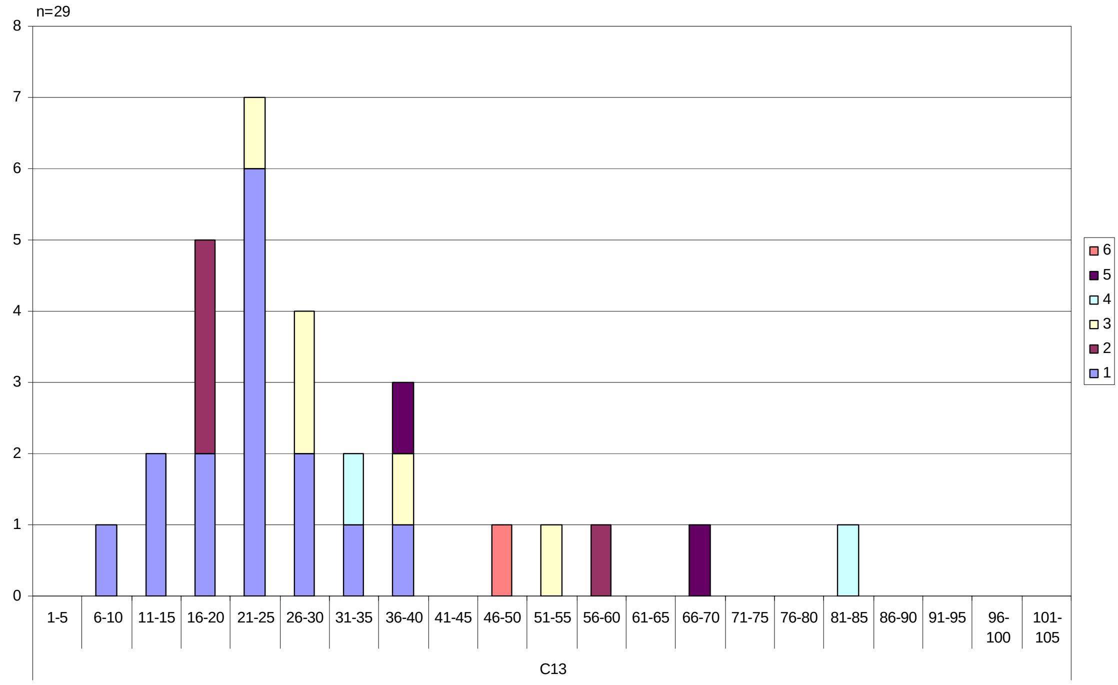



Fig. 46: MAIS - C13 - Single vehicle accidents in a bend - going either side of the road

Next pictures show the distribution amongst the categories within CARE sub-group C1, impact configuration according CDC code 3 and maximum injury severity.

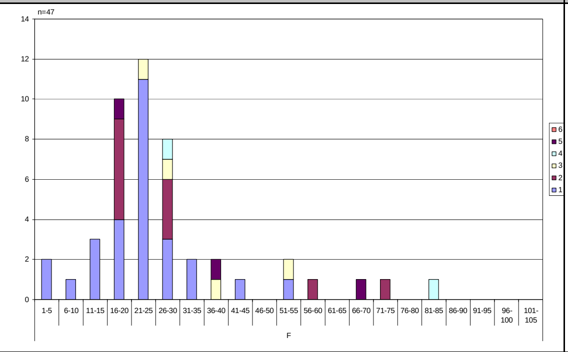
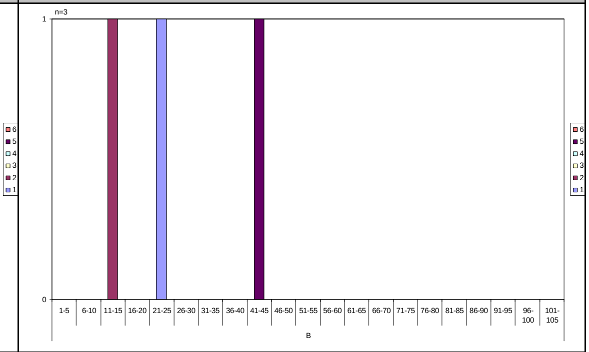
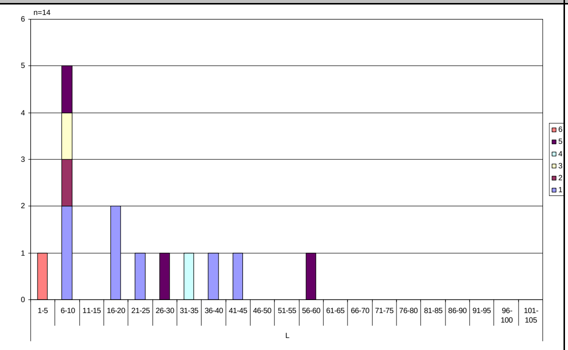
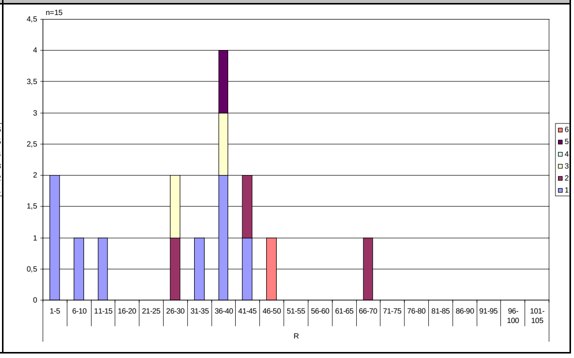
| CDC3 - Front | CDC3 - Back |
|---|---|
|   |   |
| **CDC3 - Left** | **CDC3 - Right** |
|   |   |

Fig. 47: Injury severity regarding CDC column 3 and Delta-V in single vehicle accidents

In comparison injury severity of all frontal and side impact accidents are provided in next figures.

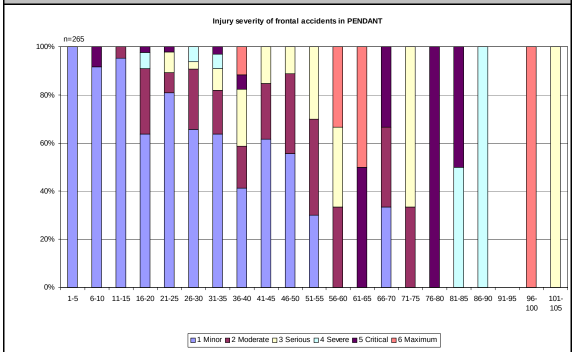
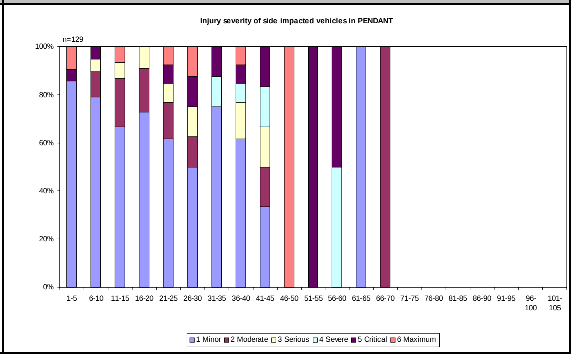
| CDC3 - Front | CDC3 – Left and right |
|---|---|
|   |   |

Fig. 48: Injury severity regarding CDC column 3 and Delta-V all recorded accidents

For accidents which couldn't be prevented ESP led at least to another impact configuration:

*a) Sliding*
Accident couldn't be avoided and sliding still occurred

*b) Leading to slight impact*
This might be a frontal collision with a low Delta-V or a sliding collision with a road side barrier or a tree/pole/post.

*c) Leading to frontal collision*
For accidents were drivers tried to prevent the accident and had to counter steer - resulted in side impacts with road side barriers or trees/poles/posts. ESP didn't prevent the accident but led to a frontal collision.

*d) Other*
This category is for those accidents which couldn't be coded with the other three types.

Following abbreviations were used in the next two tables:
n/a not applicable
ai after impact
bi before impact
ni no impact

Next two tables provide an impression of certain parameters of reconstructed single vehicle accidents. First picture shows the cases which could be prevented by ESP. Second table explain those accidents which were not avoided or led to different impact configuration respectively.

| without ESP | | | | | | with ESP | | | |
|---|---|---|---|---|---|---|---|---|---|
| **impact location** | **PDoF** | **speed limit** | **Roll-over** | **Delta–V [kph]** | **oc-cured** | **impact location** | **PDoF** | **Delta–V [kph]** | **Rollo-ver** |
| F | 01 | 120 | no | 51 | n/a | Prevented by ESP | | | |
| L | 10 | 50 | yes | 22 | ai | | | | |
| L | 11 | 70 | no | 8 | n/a | | | | |
| L | 02 | 100 | no | 55 | n/a | | | | |
| R | 11 | 80 | yes | 7 | ai | | | | |
| R | 08 | 100 | no | 32 | n/a | | | | |
| T | 00 | 100 | yes | n/a | ni | | | | |
| T | 00 | 130 | yes | n/a | ni | | | | |

| without ESP | | | | | | with ESP | | | |
|---|---|---|---|---|---|---|---|---|---|
| **impact location** | **PDoF** | **speed limit [kph]** | **Roll-over** | **Delta -V [kph]** | **oc-cured** | **impact location** | **PDoF** | **Delta -V [kph]** | **Rollo-ver** |
| F | 01 | 50 | no | 11 | n/a | R | 02 | 5 | no |
| F | 01 | 70 | yes | 44 | ai | L | 11 | 15 | no |
| F | 11 | 130 | no | 27 | n/a | L | 10 | 9 | no |
| F | 01 | 130 | no | 40 | n/a | L | 09 | 4 | no |
| L | 08 | 70 | yes | 20 | ai | F | 12 | 52 | no |
| L | 10 | 100 | no | 37 | n/a | L | 10 | 4 | no |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| L | 08 | 130 | no | 74 | n/a | L | 08 | 64 | no |
| L | 11 | 999 | no | 58 | n/a | L | 10 | 8 | no |
| R | 02 | 50 | no | 29 | n/a | R | 01 | 8 | no |
| R | 02 | 70 | no | 49 | n/a | F | 01 | 70 | no |
| R | 12 | 80 | no | 49 | n/a | F | 12 | 70 | no |
| R | 02 | 100 | no | 57 | n/a | F | 01 | 67 | no |
| R | 01 | 100 | no | 66 | n/a | R | 02 | 5 | no |
| R | 08 | 100 | no | 66 | n/a | R | 02 | 6 | no |
| R | 07 | 999 | no | 39 | n/a | F | 01 | 23 | no |
| T | 03 | 50 | yes | 20 | bi | F | 12 | 50 | no |
| T | 00 | 70 | yes | n/a | ni | M | 00 | n/a | yes |
| T | 00 | 100 | yes | n/a | ni | M | 00 | n/a | yes |

The diagram shows the cases where an accident still occurred but led to different collision type. Blue column frontal impacts happened. Side impacts occurred in column red and cyan and if multiple impacts arose it was coded with an m, yellow column. Multiple impacts are mostly for rollovers.

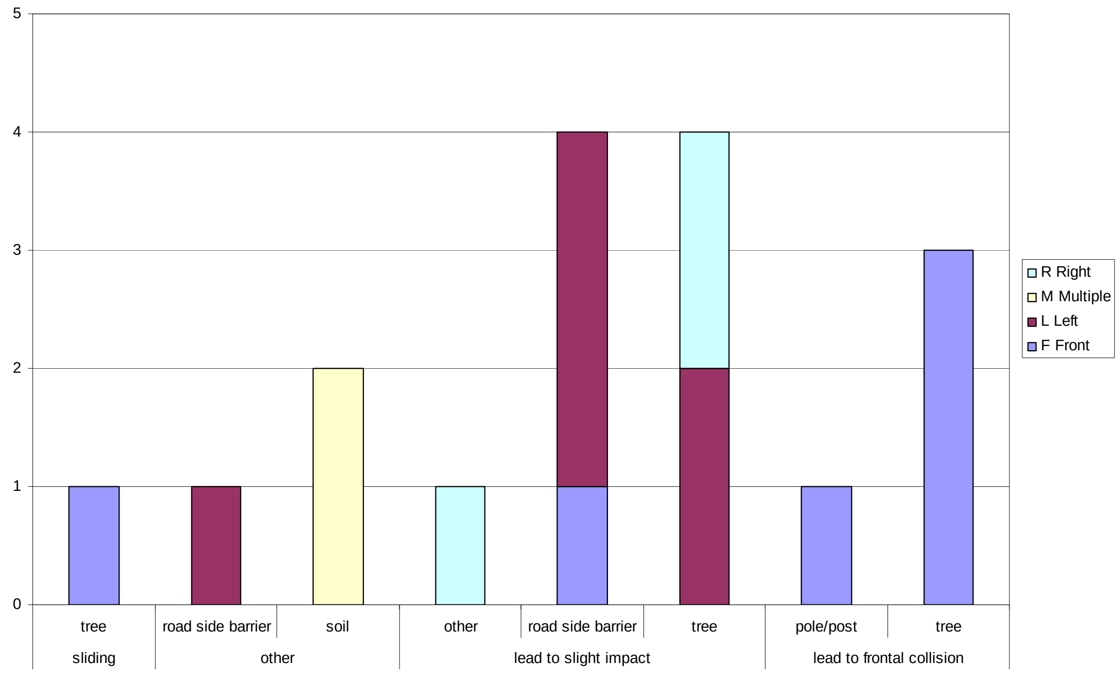



Fig. 49: No accident prevention with ESP

Frontal impacts led to side impacts whereby change of velocity Delta-V decreased as well as impact velocity. Accidents which couldn't be prevented and had side impact configuration resulted mainly in side impacts with a lower change of velocity Delta-V. In some cases side impacts developed with ESP in frontal collisions but in this cases Delta-V increased. Accidents in which the wheels got stuck at the soil ESP wasn't able to avoid a rollover.

Comparing the results of single vehicle accidents equipped with ESP and the analysis of Delta-V vs. MAIS it could be seen that injury severity will decrease. Of course not only Delta-V is responsible for injuries. Intrusions or body contact with the chassis has an influence too. But estimating injury reduction on basis of Delta-V is a good approach for analysing the small number of available data.

By definition a full impact [7] is defined as one in which there is no relative movement between the vehicles at the impulse point at the end of the compression phase. In a sliding impact [7], the two vehicles do not reach a common velocity at the impulse point during the impact. In such a case a contact plane has to be defined, along which the two vehicles slide. The impulse point must lie in this plane. Following assumptions apply:

- No relative movement between the vehicles occurs at the impulse point at the end of the compression phase in the direction normal to the contact plane.
- The direction of the momentum transfer is limited by an inter-vehicle friction coefficient (μ).
- The ratio between compression and restitution impulse is again defined by the coefficient of restitution.

For analysing injury severity from Delta-V the previous figures were taken into account and subsequent table has been produced. According to the impact location and Delta-V estimated MAIS (Fig. 48) were filled in. The second MAIS row show the injury severity which really occurred in those accidents – they reflect the real accident situation. In the right part of the table the relevant values are shown which are the results from an accident reconstruction with the assumption that the vehicle was equipped with ESP.

It can be seen that an estimation of injury severity is very difficult. Due to the small number of cases Delta-V don't reflect injury severity and estimation via Delta-V is more or less impossible. The increment of Delta-V was selected with 5 [kph] to assess injury severity more detailed.

Whereby MAIS varies from 1 to 4 with a Delta-V of 27 for frontal impacts MAIS could be 1 with a higher Delta-V anyway.

| without ESP | | | with ESP | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| im-pact loca-tion | Delta-V | MAIS hos-pital | im-pact loca-tion | Delta-V | Injury severity probability [%] | | | | | |
| | | | | | MAIS 1 | MAIS 2 | MAIS 3 | MAIS 4 | MAIS 5 | MAIS 6 |
| F | 11 | 3 | R | 5 | 86 | 0 | 0 | 0 | 5 | 9 |
| F | 44 | 1 | L | 15 | 66 | 20 | 7 | 0 | 0 | 7 |
| F | 27 | 1 | L | 9 | 79 | 11 | 5 | 0 | 5 | 0 |
| F | 40 | 2 | L | 4 | 86 | 0 | 0 | 0 | 5 | 9 |
| L | 58 | 1 | L | 8 | 79 | 11 | 5 | 0 | 5 | 0 |
| L | 20 | 1 | F | 52 | 30 | 40 | 30 | 0 | 0 | 0 |
| L | 37 | 1 | L | 4 | 86 | 0 | 0 | 0 | 5 | 9 |
| L | 74 | 999 | L | 64 | 100 | 0 | 0 | 0 | 0 | 0 |
| R | 57 | 1 | F | 67 | 33 | 33 | 0 | 0 | 33 | 0 |
| R | 66 | 2 | R | 5 | 86 | 0 | 0 | 0 | 5 | 9 |
| R | 49 | 2 | F | 70 | 33 | 33 | 0 | 0 | 33 | 0 |
| R | 66 | 4 | R | 6 | 79 | 11 | 5 | 0 | 5 | 0 |
| R | 49 | 2 | F | 70 | 33 | 33 | 0 | 0 | 33 | 0 |
| R | 39 | 999 | F | 23 | 82 | 8 | 8 | 0 | 2 | 0 |
| R | 29 | 3 | R | 8 | 79 | 11 | 5 | 0 | 5 | 0 |
| T | 20 | 1 | F | 50 | 56 | 33 | 11 | 0 | 0 | 0 |
| T | n/a | 1 | M | 0 | n/a | n/a | n/a | n/a | n/a | n/a |
| T | n/a | 3 | M | 0 | n/a | n/a | n/a | n/a | n/a | n/a |

Tab. 7: Estimated MAIS from Delta-V

An estimation of MAIS with Delta-V and impact configuration could be an approach if enough data is present but still other issues (intrusions, body contact, age, constitution, etc.) influences injuries too.

# 6 Conclusion

Even though the PENDANT database was focused primarily at passive (or, secondary) safety issues an attempt was made to evaluate the effectiveness of active (or, primary) safety systems, namely Electronic Stability Control Systems.

Besides certain data quality issues and somewhat predictably, difficulties were encountered with availability of required information such as, e.g., exposure. These difficulties are not unique to PENDANT, and workarounds like induced exposure methods exist. However these methods require information on the role of vehicles in the accident (at fault or random opponent), which is not available in PENDANT. This is also true for any kind of pre-crash data - initial speed, longitudinal and lateral acceleration, yaw, braking or steering input, trajectory, etc. Another difficulty is PENDANT’s bias with respect to the vehicle fleet which makes any projection of results to a national or EU level highly problematic.

Investigation of single vehicle accidents in a more detailed way it was figured out that vehicle which were equipped with ESP reduced single vehicle accidents by approximately 30%. According to a study of Masami Aga et al [8] ESP would reduce single vehicle accidents by a portion of 35% and a reduction of head on collisions of 30%. Anders Lie et al [9] investigated accidents in Sweden with low friction from 1998-2004 and found out a positive influence for cars equipped with ESP. Due to the low number of accidents a statistical estimation of accident reduction is not possible and not representative but PENDANT and ZEDATU single vehicle accident sample shows a good correlation with previous studies anyway.

In many cases the impact configuration would have been changed. Side impacts led to frontal impacts. Depending on the road side infrastructure it could lead to minor severe accident or in a few cases even to a more severe one. An estimation of MAIS from Delta-V could be possible if enough cases can be analysed but there are still severe injuries for low Delta-V. Therefore the whole accident situation has to be analysed and impact configuration needs to be analysed as well. Age of the occupants and constitution are other aspects which are important too.

Even if ESP could prevent or lead at least to minor severe accidents the road side infrastructure need to be investigated as well. In many cases trees or poles/posts are too close to the road and not enough safety zone is left. Additional drivers try to avoid collisions with trees even if it would be better to leave the road and try to stop in a meadow or acre. Due to emergency manoeuvres the vehicles started to skid and mostly resulted in side impacts or rollovers. Vehicles came in trouble when they already skidded sideways and the wheels got stuck at the soil.

# 7 Literature

Papers marked in blue are available for download.


1 www.audi.de – 3rd October 2005

2 http://rb-k.bosch.de – 3rd October 2005

3 www.bosch-esperience.de – 3rd October 2005

4 Fahrstabilisierungssysteme, Robert Bosch GmbH, Gelbe Reihe Ausgabe 2004

5 Description of Work, PENDANT, 26th April 2004

6 Simulationen von ESP und Vergleich mit Fahrversuchen: A. Moser, H. Steffan, A. Klose, E. Tomasch, J. Veith; EVU Tagung Oktober 2005

7 PC Crash Technical Manual, DSD, Linz Austria - 2003

8 ANALYSIS OF VEHICLE STABILITY CONTROL (VSC)'S FFECTIVENESS FROMAC-CIDENT DATA, Masami Aga, ToyotaMotor Corporation, Japan Akio Okada, Toyota Techno Service Corporation, Japan; Paper No. 541

9 THE EFFECTIVENESS OF ESC (ELECTRONIC STABILITY CONTROL) IN REDUC-ING REAL LIFE CRASHES AND INJURIES; Anders Lie Swedish Road Administration, Claes Tingvall Swedish Road Administration, Monash University Accident Research Centre; Maria Krafft, Anders Kullgren Folksam Research, Sweden; Paper number 05-0135, 19th International Technical Conference on the Enhanced Safety of Vehicles Conference (ESV) June 2005

10 www.auto-reporter.net – 27th March 2006

11 www.bmw.com

12 Drive and stay alive, www.driveandstayalive.com

13 Electronic Stability Control Coalition, www.esceducation.org

14 www.fiat.co.uk

15 www.ford.co.uk

16 Insurance Institute for Highway Safety, www.iihs.org

17 www.jaguarusa.com

18 National Highway Transport Safety Administration, www.nhtsa.gov

19 www.nissan.co.uk

20 www.Peugeot.co.uk

21 www.safercar.gov

22 www.vauxhall.co.uk

23 Aga, M.; Okada, A.: Analysis of vehicle stability control (VSC) effectiveness from accident data; Paper no 541, Proceedings of the 18th International technical Conference on the Enhanced Safety of Vehicles. NHTSA, Washington DC.

24 Blows S, Ivers IQ, Woodward M, Connor J, Ameratunga S, Norton R (2003) *"Vehicle year and the risk of car crash injury"* Injury Prevention, Vol 9, pp353 – 356.

25 Bosch (2000), "*Automotive handbook",* $5^{th}$ edition

26 Bosch[2] "*New vehicles with an electronic stability programme in Europe*" www.driveandstayalive.com/info%20section/news/individual%20news%article

27 Dang, Jennifer N (2004), *"Preliminary results analyzing the effectiveness of electronic stability control (ESC) systems"*, National Highway Traffic Safety Administration, US Department of Transport, September 2004. Report number DOT-HD-809-790 www.NHTSA.dot.gov

28 Farmer, Charles M (2004), *"Effect of electronic stability control on automobile crash risk"*, Traffic Injury and Prevention 5: 317 – 325, 2004.

29 Giessen, N (2002) *"Current analysis of the accident statistics: Mercedes passenger cars get into fewer accidents"* www.esceducation.org/downloads/mercedes_ESC_study.pdf

30 Sferco R, Page Y, Le Coz J, Fay P (2001) *"Potential effectiveness of the electronic stability programs (ESP) – what European field studies tell us".* $17^{th}$ International Technical Conference on the Enhanced Safety of vehicles. Paper 2001.S2 – 0 – 327, June 4-7, 2001.

31 Tingvall Cl, Krafft M, Kullgren A, Lie A. (2004) *"The effectiveness of ESP (electronic stability programme) in reducing real life accidents"* Swedish National Road Administration, paper number 261. Traffic Injury Prevention, vol 5, pp 37 – 41.

32 Francisco Aparicio on behalf of EEVC WG19: EEVC WG19 ACTIVITIES ON PRIMARY AND SECONDARY SAFETY INTERACTION; Paper Number 05-0462

33 Klaus Langwieder, Johann Gwehenberger, Thomas Hummel, Jenö Bende: BENEFIT POTENTIAL OF ESP IN REAL ACCIDENT SITUATIONS INVOLVING CARS AND TRUCKS; GDV Institute for Vehicle Safety, Munich Germany; Paper Number 150

34 http://www.eevc.org/index.html

35 Francisco Aparicio on behalf of EEVC WG19: EEVC WG19 ACTIVITIES ON PRIMARY AND SECONDARY SAFETY INTERACTION; Paper Number 05-0462

36 Tingvall, C. et al: The effectiveness of ESP (electronic stability programme) in reducing real life accidents. ESV Conference 2003, Nagoya, Japan.

37 Becker, H. et al.: Großzahlenmaterial, "In-Depth" Erhebungen und Einzelfallanalyse, Werkzeuge zur Verbesserung der Fahrzeugsicherheit im Volkswagenkonzern (Large number material, in-depth studies and single case analysis – tools for improvement of vehicle safety at Volkswagen Group). 1. Dresdner Tagung, „Verkehrssicherheit interdisziplinär", 27.-28. June 2003 (in German).

38 Langwieder, K. et al: Benefit potential of ESP in real accident situations involving cars and trucks. ESV Conference 2003, Nagoya, Japan.

39 Langwieder, K.: Unfallvermeidungspotenzial durch ESP bei Lastkraftwagen (Accident prevention potential of ESP in trucks. Automobiltechnische Zeitschrift 5/2003, p.504-510 (in German).

40 Langwieder, K.: Characteristics of car accidents in the pre-crash phase. SAEJ Automotive Engineering Exhibition, May 1999, Yokohama, Japan.

41 N.N.: Aktuelle Analyse der Unfallstatistik: Mercedes-Personenwagen verunglücken seltener. (Current Analysis of Accident Statistics: Mercedes cars get into fewer accidents). DaimlerChrysler Press release, 26 November, 2002.

# Appendix A

### Accident Type – CARE Plus Dataset

Five main groups of accident type configurations:

- Accidents with pedestrians (group A)
- Accidents with parked vehicles (group B)
- Single vehicle accidents (group C)
- Accidents with at least two vehicles and no turning (group D)
- Accidents with at least two vehicles and turning (group E)

Each main group is classified into subgroups defining more detailed classification of the accident circumstances. These subgroups are spilt into sub subgroups and so on.

In the following **R** and **L** connected to the pictograms are referring to right hand driving and left hand driving countries.

The following table should give an overview how to code accidents in PENDANT and subsequent projects.

**Example:** D11 R

***D*** ***11*** ***R***

R: Right hand driving countries

11: Consecutive number (depending on level)

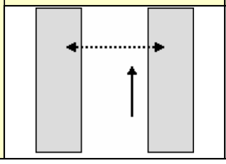
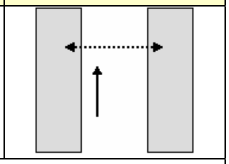
D: Accidents with at least two vehicles and no turning (group D)

In the next table the CARE codes with pictures are specified:

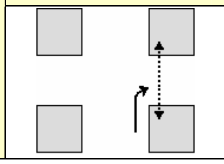
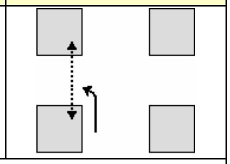
# Level 2

## Accidents with pedestrians (group A)

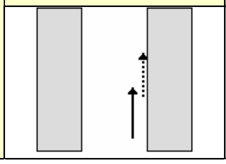
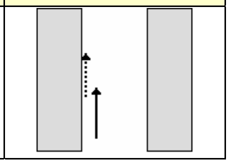
**Pedestrian crossing street - no turning of vehicle**

| | R | L |
|---|---|---|
| **A1** |  |  |

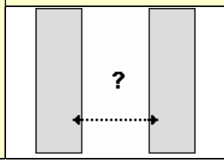
**Pedestrians crossing - turning of vehicle**

| | R | L |
|---|---|---|
| **A2** |  |  |

**Pedestrian walking along the road or stationary in the road**

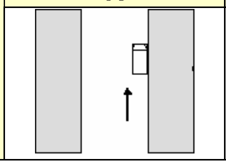
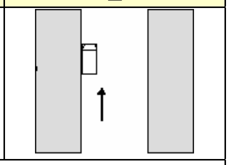
| | R | L |
|---|---|---|
| **A3** |  |  |

**Pedestrian others**

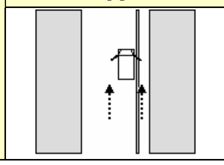
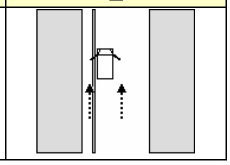
| | | |
|---|---|---|
| **A9** |  | |

## Accidents with parked vehicles (group B)

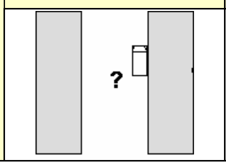
**Hitting parked vehicles either side of the road**

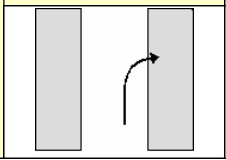
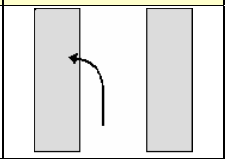
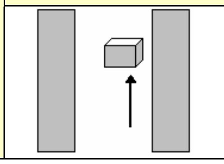
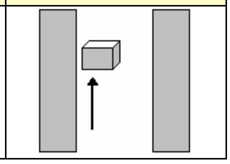
| | R | L |
|---|---|---|
| **B1** |  |  |

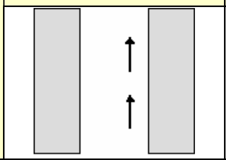
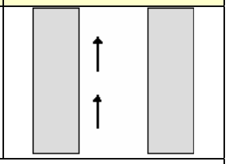
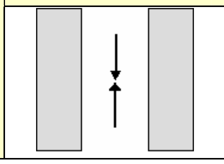
**Accidents with parked vehicles - opening doors**

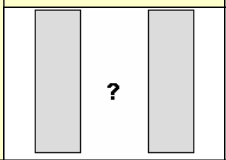
| | R | L |
|---|---|---|
| **B2** |  |  |

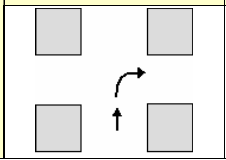
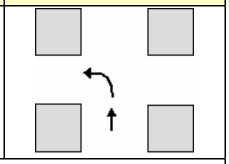
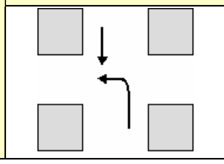
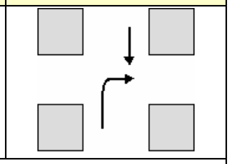
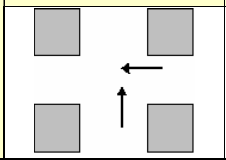
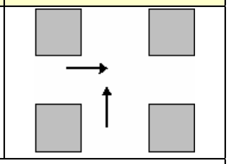
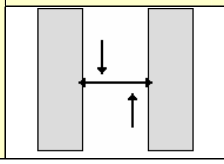
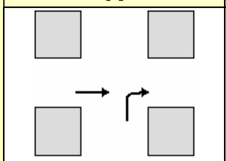
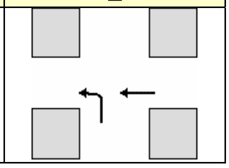
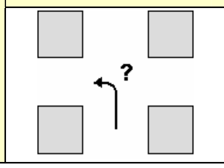
**Other accidents with parked vehicles**

| | | |
|---|---|---|
| **B9** |  | |

| Single vehicle accidents (group C) | | | | | |
|---|---|---|---|---|---|
| Single vehicle accidents without obstacles on the road | | | Single vehicle accidents with obstacles on the road | | |
| | R | L | | R | L |
| C1 |  |  | C2 |  |  |

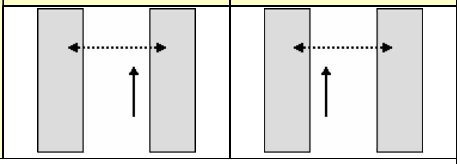
| Accidents with at least two vehicles and no turning (group D) | | | | | |
|---|---|---|---|---|---|
| At least two vehicles - same direction no turning | | | At least two vehicles - opposite direction no turning | | |
| | R | L | | | |
| D1 |  |  | D2 |  | |

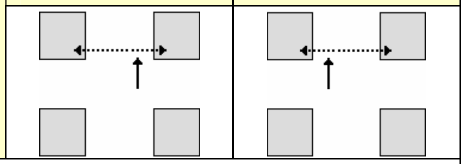
| At least two vehicles - Others no turning | | |
|---|---|---|
| | | |
| D9 |   | |

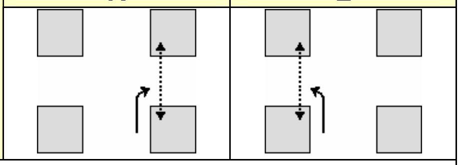
| Accidents with at least two vehicles and turning (group E) | | | | | |
|---|---|---|---|---|---|
| **At least two vehicles - turning or crossing - same road - same direction** | | | **At least two vehicles - turning or crossing - same road - opposite direction** | | |
| | **R** | **L** | | **R** | **L** |
| **E1** |  |  | **E2** |  |  |
| **At least two vehicles - crossing (no turning) - different roads** | | | | | |
| | **R** | **L** | | | |
| **E3** |  |  | **or** |  | |
| **At least two vehicles - turning - different roads** | | | **At least two vehicles - crossing or turning - others** | | |
| | **R** | **L** | | | |
| **E4** |  |  | **E9** |   | |

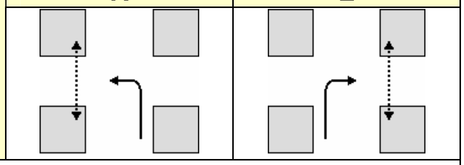
# Level 3

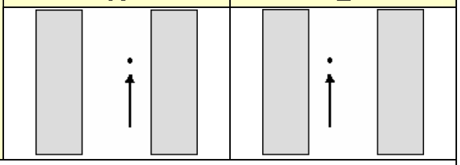
## Accidents with pedestrians (group A)

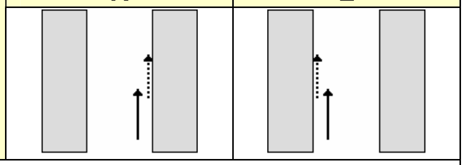
| Pedestrian crossing street outside a junction | R / L |
|---|---|
| A11 |  |

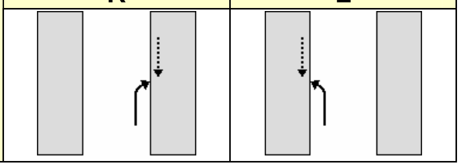
| Pedestrian crossing street at a junction | R / L |
|---|---|
| A12 |  |

| Hitting pedestrian - turning right (left) | R / L |
|---|---|
| A21 |  |

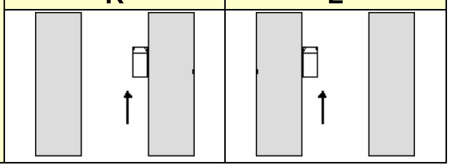
| Hitting pedestrian - turning left (right) | R / L |
|---|---|
| A22 |  |

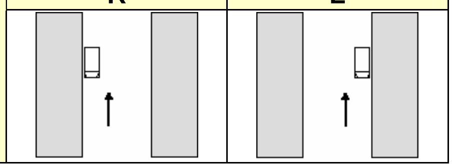
| Pedestrian in the road | R / L |
|---|---|
| A31 |  |

| Pedestrian walking along the road | R / L |
|---|---|
| A32 |  |

| Pedestrians on pavement or bicycle lane | R / L |
|---|---|
| A33 |  |

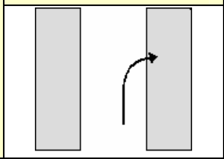
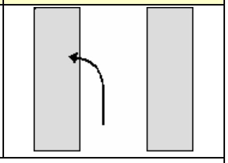
## Accidents with parked vehicles (group B)

| Hitting parked vehicles right (left) side of the road | R / L |
|---|---|
| B11 |  |

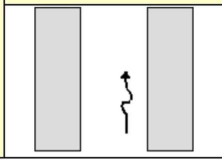
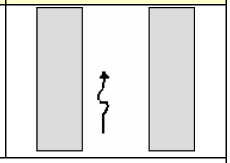
| Hitting parked vehicles left (right) side of the road | R / L |
|---|---|
| B12 |  |

## Single vehicle accidents (group C)

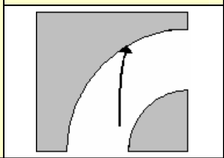
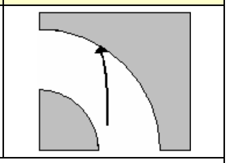
**Single vehicle accident - Leaving straight road - either side of the road**

| | R | L |
|---|---|---|
| C11 |  |  |

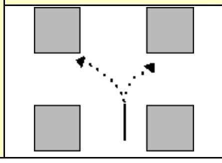
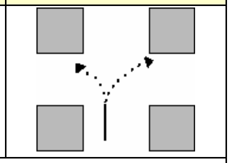
**Single vehicle accidents on the road (often two-wheelers)**

| | R | L |
|---|---|---|
| C12 |  |  |

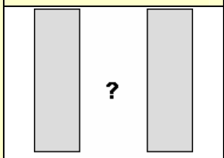
**Single vehicle accidents in a bend - going either side of the road**

| | R | L |
|---|---|---|
| C13 |  |  |

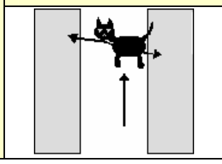
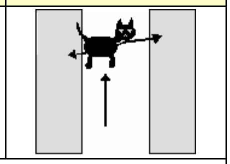
**Single vehicle accidents In junctions or entrances**

| | R | L |
|---|---|---|
| C14 |  |  |

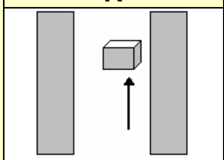
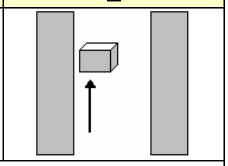
**Single vehicle accidents - others**

| | | |
|---|---|---|
| C19 |  | |

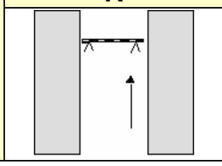
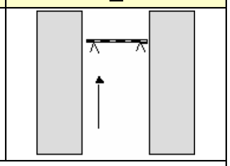
**Single vehicle accidents with animals**

| | R | L |
|---|---|---|
| C21 |  |  |

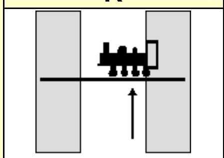
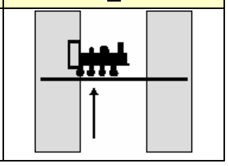
**Single vehicle accidents with obstacles on or above the road**

| | R | L |
|---|---|---|
| C22 |  |  |

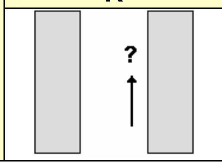
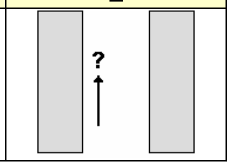
**Single vehicle accidents with roadwork materials**

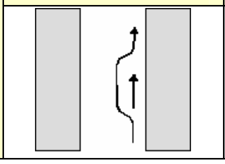
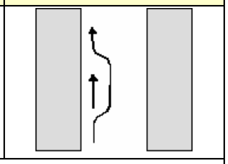
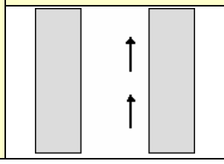
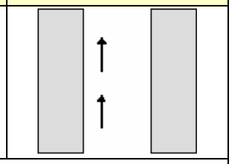
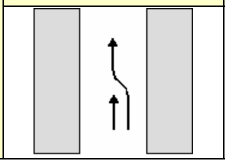
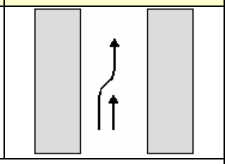
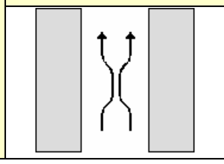
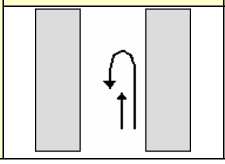
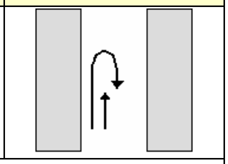
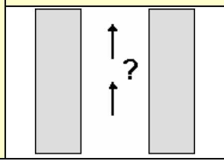
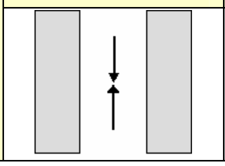
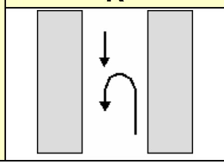
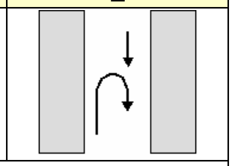
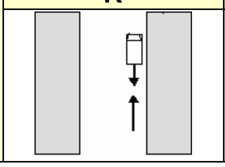
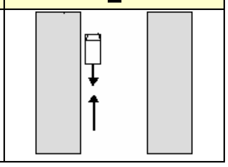
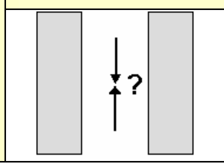
| | R | L |
|---|---|---|
| C23 |  |  |

**Accidents between train and vehicle**

| | R | L |
|---|---|---|
| C24 |  |  |

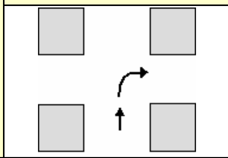
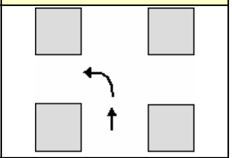
**ingle vehicle accidents with obstacles - others**

| | R | L |
|---|---|---|
| C29 |  |  |

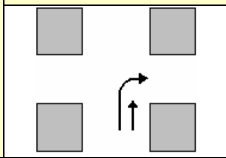
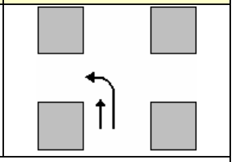
| Accidents with at least two vehicles and no turning (group D) | | | | | |
|---|---|---|---|---|---|
| At least two vehicles - same direction - overtaking | | | At least two vehicles - same direction - rear end collisions | | |
| | R | L | | R | L |
| D11 |  |  | D12 |  |  |
| At least two vehicles - same direction - entering traffic | | | At least two vehicles - same direction - side collision | | |
| | R | L | | | |
| D13 |  |  | D14 |  | |
| At least two vehicles - same direction - U-turn in front of other vehicle | | | At least two vehicles - same direction - others | | |
| | R | L | | | |
| D15 |  |  | D19 |  | |
| At least two vehicles - head on collision in general | | | At least two vehicles - U-turn in front of other vehicle | | |
| | | | | R | L |
| D21 |  | | D22 |  |  |
| At least two vehicles - opposite direction no turning - reversing | | | At least two vehicles - opposite direction no turning - others | | |
| | R | L | | | |
| D23 |  |  | D29 |  | |

## Accidents with at least two vehicles and turning (group E)

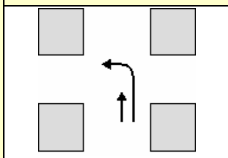
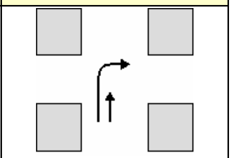
**At least two vehicles - turning or crossing - same road - same direction - rear end collision**

| | R | L |
|---|---|---|
| **E11** |  |  |

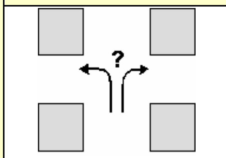
**At least two vehicles - turning or crossing - same road - same direction - turning right (left)**

| | R | L |
|---|---|---|
| **E12** |  |  |

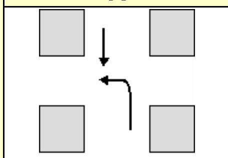
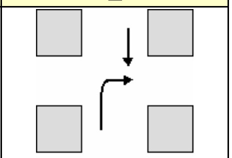
**At least two vehicles - turning or crossing - same road - same direction - turning left (right)**

| | R | L |
|---|---|---|
| **E13** |  |  |

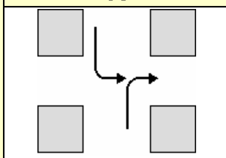
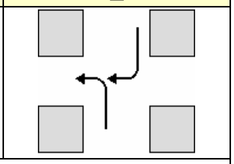
**At least two vehicles - turning or crossing - same road - same direction - others**

| | | |
|---|---|---|
| **E19** |  | |

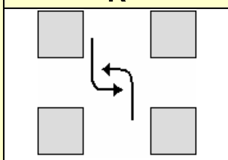
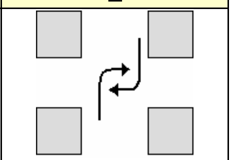
**At least two vehicles - same road - opposite direction - turning left (right) in front of other vehicle**

| | R | L |
|---|---|---|
| **E21** |  |  |

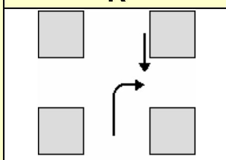
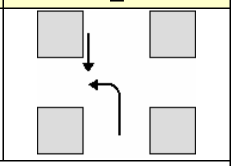
**At least two vehicles - same road - opposite direction - turning into same road**

| | R | L |
|---|---|---|
| **E22** |  |  |

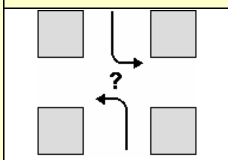
**At least two vehicles - same road - opposite direction - turning into opposite roads**

| | R | L |
|---|---|---|
| **E23** |  |  |

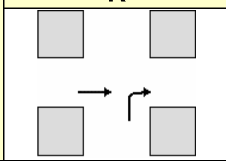
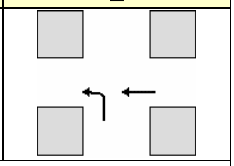
**At least two vehicles - same road - opposite direction - turning right (left) in front of other vehicle**

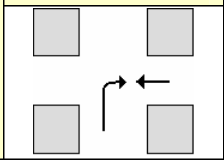
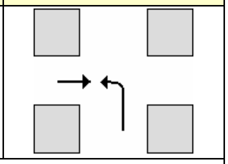
| | R | L |
|---|---|---|
| **E24** |  |  |

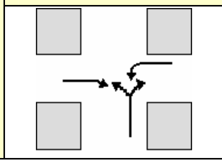
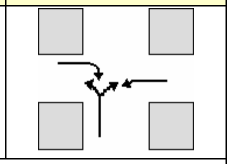
**At least two vehicles - same road - opposite direction - turning others**

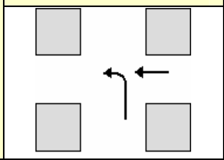
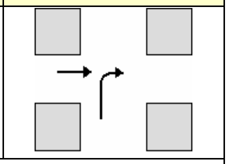
| | | |
|---|---|---|
| **E29** |  | |

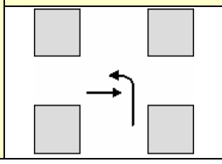
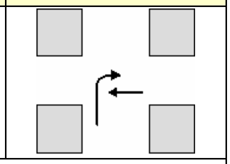
**At least two vehicles - different roads - turning right (left) in front of vehicle from the left (right)**

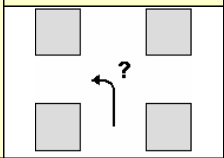
| | R | L |
|---|---|---|
| **E41** |  |  |

| At least two vehicles - different roads - turning right (left) - head on collision | | |
|---|---|---|
| | R | L |
| E42 |  |  |

| At least two vehicles - different roads - both vehicles turning | | |
|---|---|---|
| | R | L |
| E43 |  |  |

| At least two vehicles - different roads - turning left (right) into traffic from the right (left) side | | |
|---|---|---|
| | R | L |
| E44 |  |  |

| At least two vehicles - different roads - turning left (right) into traffic from the left (right) side | | |
|---|---|---|
| | R | L |
| E45 |  |  |

| At least two vehicles - different roads - turning into traffic - others | | |
|---|---|---|
| | | |
| E49 |  | |

# Appendix B

## Case Matrix

| Code | Description | Code | Description |
|---|---|---|---|
| i | impact | L | left |
| g | got stuck | R | right |
| s | sliding | F | front |
| b | bend | M | multiple |
| s | straight | n/a | not applicable |
| 1x | countersteer 1x | | |
| 2x | countersteer 2x | | |
| 3x | countersteer 3x | | |

## Reconstruction case matrix without ESP:

| Case Number | road type | speed limit | impact type | steee-ring | collision partner | Rollo-ver | occu-red | impact veloci-ty | Delta-V | force directi-on | PDoF | impact locati-on | pull stee-ring wheel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case 01 | b | 100 | i | s | tree | no | n/a | 45 | 32 | 135 | 08 | R | no |
| Case 02 | b | 50 | g | 1x | tree | yes | after impact | 64 | 22 | -60 | 10 | L | yes |
| Case 03 | s | 80 | g | 2x | pole/post | yes | after impact | 999 | 7 | -20 | 11 | R | yes |
| Case 04 | s | 100 | i | 1x | tree | no | n/a | 68 | 37 | -45 | 09 | L | yes |
| Case 05 | b | 50 | i | s | kerbstone | no | n/a | 73 | 11 | 28 | 01 | F | no |
| Case 06 | b | 70 | i | 1x | road side barrier | yes | after impact | 66 | 44 | 38 | 01 | F | yes |
| Case 07 | b | 50 | i | 2x | tree | yes | before impact | 22 | 20 | 93 | 03 | T | no |
| Case 08 | s | 70 | i | s | road side barrier | no | n/a | 43 | 8 | -25 | 11 | L | yes |
| Case 09 | b | 100 | g | s | soil | yes | no im-pact | n/a | n/a | 00 | 00 | T | no |
| Case 10 | s | 70 | i | 2x | tree | no | n/a | 60 | 49 | 45 | 09 | R | yes |
| Case 11 | s | 100 | g | 1x | soil | yes | no im-pact | n/a | n/a | 00 | 00 | T | yes |
| Case 12 | b | 100 | i | s | tree | no | n/a | 79 | 57 | 57 | 02 | R | no |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case 13 | s | 70 | g | 1x | soil | yes | no impact | n/a | n/a | 00 | 00 | T | yes |
| Case 14 | s | 130 | i | s | road side barrier | no | n/a | 54 | 27 | -15 | 11 | F | no |
| Case 15 | s | 130 | i | 1x | road side barrier | no | n/a | 98 | 40 | 19 | 01 | F | yes |
| Case 16 | b | 70 | i | 3x | pole/post | yes | after impact | 68 | 20 | -112 | 08 | L | yes |
| Case 17 | b | 100 | i | s | tree | no | n/a | 84 | 66 | 17 | 01 | R | yes |
| Case 18 | s | 130 | i | 1x | road side barrier | no | n/a | 67 | 74 | -111 | 08 | L | yes |
| Case 19 | s | 130 | g | s | embankment | yes | no impact | n/a | n/a | 00 | 00 | T | yes |
| Case 20 | b | 80 | i | s | tree | no | n/a | 58 | 49 | -4 | 12 | R | yes |
| Case 21 | b | 100 | i | s | tree | no | n/a | 67 | 66 | 102 | 08 | R | yes |
| Case 22 | b | 999 | i | 1x | tree | no | n/a | 74 | 58 | -15 | 11 | L | yes |
| Case 23 | s | 999 | i | s | road side barrier | no | n/a | 64 | 39 | 160 | 07 | R | yes |
| Case 24 | b | 100 | i | s | tree | no | n/a | 92 | 55 | 48 | 02 | L | yes |
| Case 25 | s | 120 | i | s | road side barrier | no | n/a | 97 | 51 | 32 | 01 | F | yes |
| Case 26 | s | 50 | i | s | tree | no | n/a | 43 | 29 | 45 | 02 | R | yes |

## Reconstruction case matrix with ESP:

| Case Number | road type | speed limit | impact type | stee-ring | collision partner | Rollo-ver | Pre-venti-on | collision | impact veloci-ty | Delta-V | force directi-on | PDOF | impact locati-on |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case 01 | b | 100 | no i | s | n/a | no | yes | only sliding occured | n/a | n/a | n/a | n/a | n/a |
| Case 02 | b | 50 | no i | 1x | n/a | no | yes | n/a | n/a | n/a | n/a | n/a | n/a |
| Case 03 | s | 80 | no i | 2x | n/a | no | yes | n/a | n/a | n/a | n/a | n/a | n/a |
| Case 04 | s | 100 | i | 1x | tree | no | no | lead to slight impact | 58 | 4 | -45 | 10 | L |
| Case 05 | b | 50 | i | s | other | no | no | lead to slight impact | 57 | 5 | 68 | 02 | R |
| Case 06 | b | 70 | i | 2x | road side barrier | no | no | lead to slight impact | 65 | 15 | -34 | 11 | L |
| Case 07 | b | 50 | i | 2x | tree | no | no | lead to frontal collision | 46 | 50 | -5 | 12 | F |
| Case 08 | s | 70 | no i | 1x | n/a | no | yes | n/a | n/a | n/a | n/a | n/a | n/a |
| Case 09 | b | 100 | no i | n/a | n/a | no | yes | n/a | n/a | n/a | n/a | n/a | n/a |
| Case 10 | s | 70 | i | 3x | tree | no | no | lead to frontal collision | 55 | 70 | 10 | 01 | F |
| Case 11 | s | 100 | g | 1x | soil | yes | no | n/a | n/a | n/a | n/a | 00 | M |
| Case 12 | b | 100 | i | s | tree | no | no | sliding | 77 | 67 | 27 | 01 | F |
| Case 13 | s | 70 | g | 1x | soil | yes | no | n/a | n/a | n/a | n/a | 00 | M |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case 14 | s | 130 | i | s | road side barrier | no | no | lead to slight impact | 62 | 9 | -58 | 10 | L |
| Case 15 | s | 130 | i | 1x | road side barrier | no | no | lead to slight impact | 89 | 4 | -81 | 09 | L |
| Case 16 | b | 70 | i | 3x | pole/post | no | no | lead to frontal collision | 76 | 52 | -6 | 12 | F |
| Case 17 | b | 100 | i | n/a | tree | no | no | lead to slight impact | 95 | 5 | 45 | 02 | R |
| Case 18 | s | 130 | i | 1x | road side barrier | no | no | lead to other impact con-figuration | 60 | 64 | -120 | 08 | L |
| Case 19 | s | 130 | no i | 1x | n/a | no | yes | n/a | n/a | n/a | n/a | n/a | n/a |
| Case 20 | b | 80 | i | 1x | tree | no | no | lead to frontal collision | 72 | 70 | -9 | 12 | F |
| Case 21 | b | 100 | no i | n/a | n/a | no | no | lead to slight impact | 71 | 6 | 45 | 02 | R |
| Case 22 | b | 999 | i | 1x | tree | no | no | lead to slight impact | 68 | 8 | -59 | 10 | L |
| Case 23 | s | 999 | i | s | road side barrier | no | no | lead to other impact con-figuration | 78 | 23 | 41 | 01 | F |
| Case 24 | b | 100 | no i | s | n/a | no | yes | n/a | n/a | n/a | n/a | n/a | n/a |
| Case 25 | s | 120 | i | s | n/a | no | yes | n/a | n/a | n/a | n/a | n/a | n/a |
| Case 26 | s | 50 | i | n/a | tree | no | no | lead to slight impact | 41 | 8 | 20 | 01 | R |