Admir Zukancic

Development of an assessment method for Advanced Driver Assistance Systems

Generating scenarios for Emergency Brake Assist tests and evaluations

Diploma Thesis
to achieve the academic degree Diplom-Ingenieur Maschinenbau

Graz University of Technology

Faculty of Mechanical Engineering and Economic Sciences

Institute of Automotive Engineering

Member of [FSI]

Director: Univ.-Prof. Dipl.-Ing. Dr.techn. Peter Fischer

Supervisor: Univ.-Doz. Dipl.-Ing. Dr.techn. Arno Eichberger

Graz, November 2013

Restricted access until 2015

Acknowledgement

First I would like to thank all the people who helped me finish my diploma thesis.

Especially I would like to thank my supervisor Univ.-Doz. Dipl.-Ing. Dr. techn. Arno Eichberger. He has been a huge help for me with his knowledge and contribution.

Further I would like to thank Dipl.-Ing. Peter Wimmer from the Virtual Vehicle Research Center for supporting me during this project and also offering me his knowledge and time.

A special thank goes also to Univ.-Prof. DI Dr. Ernst Stadlober for helping me out in questions about statistical approaches.

I also like to thank Dipl.-Ing. Dr.techn. Ernst Tomasch for his help with getting required data from the ZEDATU database.

Last but not least I want to thank my parents for supporting me through all the years. It has been a long and sometimes rough journey, but they have always backed me up and been a huge help.

Statutory Declaration

Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig verfasst, andere als die angegebenen Quellen/Hilfsmittel nicht benutzt, und die den benutzten Quellen wörtlich und inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Graz, am ……………………………………………………………………………….

(Unterschrift)

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and I have explicitly marked all material which has been quoted either literally or by content from used sources.

………………………….. ………………………………………………………

(Date) (Signature)

Abstract

Advanced Driver Assistance Systems (ADAS) are nowadays widely spread. Their task is to support the driver in critical as well as non critical situations. This work deals mainly with the application of the Emergency Brake Assist (EBA) with focus on pedestrian and rear end collisions. In order to test and evaluate such systems there are different approaches. One approach would be to perform simulations. However to be able to perform a simulation the basic crash scenario and its parameters have to be known. This thesis deals with the definition and creation of such scenarios. These generated scenarios and their parameters are the basis to a new assessment methodology, which rates the field effectiveness of a system instead of the effectiveness that it has in a certain collision scenario set up. As a first step to achieve this, data from previous projects and macroscopic databases was gathered and researched. From this step basic test scenarios were derived that could be used in simulations. Further the needed parameters for these scenarios such as environmental conditions or driving speeds and distances were deduced. With these results a scenario generator was programmed using the technical simulation programme MATLAB. This scenario generator outputs the parameters for a required number of scenarios and for the selected type (pedestrian or rear end collision). The generated scenarios were exported to IPG Carmaker and tested there. After a general test of 100 scenarios of each type, two scenarios, one from each type, were picked out. In these two scenarios variations in the EBA systems were made and the outcome of this was compared to each other in reference of collision outcome and resulting impact speed.

Kurzfassung

Fahrerassistenzsysteme (FAS) sind heutzutage weit verbreitet und dienen dazu den Fahrer in kritischen als auch in nicht kritischen Situationen zu unterstützen. In dieser Arbeit soll speziell die Anwendung des Notbremsassistenten, im Englischen „Emergency Brake Assist (EBA)“, betrachtet werden. Der Focus wird hierbei auf Fußgänger- und Auffahrunfälle gelegt. Um diese zu testen und zu bewerten gibt es mehrere Möglichkeiten, wie zum Beispiel die Möglichkeit einer Simulation. Um jedoch eine Simulation durchführen zu können bedarf es des allgemeinen Aufbaus des Szenarios und dessen Parameter. Diese Arbeit beschäftigt sich mit dieser Definition der Szenarien und ihrer Erzeugung. Diese erzeugten Szenarien und Parameter bilden die Basis für eine Bewertungsmethodik, welche die tatsächliche Feldeffektivität eines Systems beurteilt, anstatt der Effektivität die das System in einem bestimmten Versuchsaufbau hat. Dazu wurden zunächst Daten aus verschiedenen Forschungsprojekten und globalen Statistiken zusammengetragen und ausgewertet. Aus dieser Auswertung konnten dann Grundszenarien hergeleitet werden, die schließlich in Simulationen nachgestellt werden sollten. Weiters wurden aus diesen Daten die Rahmenbedingungen für diese Szenarien festgelegt. Diese Rahmenbedingungen werden durch verschiedene Parameter dargestellt, die einerseits äußere Bedingungen wie zum Beispiel Umwelteinflüsse, aber auch grundlegende Simulationsparameter, wie Geschwindigkeiten und Abstände, beinhalten. Aus diesen Ergebnissen wurde in MATLAB ein „Szenariengenerator“ programmiert. Dieser gibt Szenarienparameter für eine gewünschte Anzahl an Szenarien des geforderten Typs (Fußgänger oder Auffahrunfall) aus. Die dadurch entstandenen Szenarien wurden dann im IPG Carmaker überprüft und anschließend wurde jeweils ein Szenario der beiden verschiedenen Typen ausgewählt. Dort wurden Veränderungen in der Eingriffsstrategie des Notbremsassistenten vorgenommen und die Ergebnisse mit einander verglichen im Hinblick auf Unfallausgang und resultierende Aufprallgeschwindigkeit.

Contents

Acknowledgement i
Statutory Declaration ii
Abstract iii
Kurzfassung iv
Contents v
Abbreviations viii
Symbols ix
1. Introduction 1
1.1 Scope and goal of this work 1
1.2 Traffic accidents 2
1.3 Active and passive safety 4
1.4 From NCAP to Beyond NCAP and the ViF approach 5
1.4.1 NCAP 5
1.4.2 Virtual Vehicle Research Center (ViF) approach 7
1.5 Evaluation of Advanced Driver Assistance Systems 8
1.6 Traffic and accident statistics for the EU 11
2 Basics 14
2.1 Accident research 14
2.1.1 Accident Statistics 14
2.2 Statistics of pedestrian and rear-end collisions 15
2.2.1 Pedestrian collision 15
2.2.2 Rear end collisions 19
2.3 Advanced Driver Assistance Systems 19
2.3.1 Components 20
2.4 Overview of the different testing methods 24
2.4.1 ADAC 24
2.4.2 RCAR (AEB group) 28
2.4.3 ASPECSS 33
2.4.4 ASSESS 35
2.4.5 NCAP 37
2.4.6 CAMP 40
2.4.7 eValue 42

2.4.8 vFSS ... 45
3 Methodology ... 50
3.1 Development environment ... 50
3.2 Generating a manoeuvre catalogue from other projects ... 50
3.2.1 Car to car collision ... 51
3.2.2 Car to pedestrian collision ... 55
3.3 Parameters derived from global statistics ... 59
3.3.1 Pedestrian scenarios ... 60
3.3.2 Rear end collisions ... 60
3.4 Choice of parameters ... 60
3.4.1 Rear end collision ... 61
3.4.2 Pedestrian collision ... 63
3.5 Classification into dependent and independent parameters ... 64
3.5.1 Car to car collision ... 65
3.5.2 Pedestrian collision ... 66
3.6 Dependencies ... 66
3.6.1 Driving speeds (v_{ego} and v_{target}) ... 66
3.6.2 Deceleration ... 71
3.6.3 Surface ... 71
3.7 Checking the speed distributions ... 71
3.7.1 Testing under the assumption of normal distribution ... 72
3.7.2 Design of experiments (DoE) ... 73
3.7.3 Mixed distribution ... 73
3.8 Combination of the parameters to accident scenarios ... 74
4 Results ... 75
4.1 Result from the scenario generator ... 75
4.1.1 Car to car collision ... 76
4.1.2 Pedestrian collisions ... 86
4.2 Results from IPG Carmaker ... 92
4.2.1 Car to car collision ... 92
4.2.2 Pedestrian collision ... 95
5 Discussion ... 97
6 Summary ... 99
6.1 Conclusion ... 99
6.1.1 Rear end collision ... 99
6.1.2 Pedestrian collision ... 99

6.2 Outlook 100
List of Figures I
List of Tables.. IV
Bibliography.. VI
A. Appendix XII

Abbreviations

ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
AEBS	Advanced Emergency Braking Systems
ANN	Artificial Neural Networks
DoE	Design of experiments
EBA	Emergency Brake Assist
ESC	Electronic Stability Control
EU-25	EU-15 + CY, CZ, EE, HU, LV, LT, MT, PL, SK, SI
EU-27	EU-25 + BG, RO
FAS	Fahrerassistenzsystem
FOT	Field Operational Tests
Gpkm	Passenger Transport Demand
GUI	Graphical User Interface
NCAP	New Car Assessment Programme
NDS	Naturalistic Driving Study
RCAR	Research Council for Automobile Repairs
RCS	Radar Cross Ratio
TTC	Time To Collision
ViF	Virtual Vehicle Research Center

Symbols

Parameters und constants

A	Amplitude
c_i	Model coefficients
f_0	Frequency
G_D	Directive Antenna Gain
H	Hypothesis
s_{init}	Initial Distance
v_{ego}	Driving speed of the ego car
v_{impact}	Impact speed
v_I	Impact speed
v_{target}	Driving speed of the target car
Δv	Relative speed between ego and target car
α	Significance level
φ	Phase
μ	Friction coefficient
σ	Radar Cross Ratio

Variables

Ea	Adjusted effectiveness
E_S	Effectiveness
$f(x)$	Density function
i	Vehicle make and model
IR	Involvement rate
n	Scope of the sample
P	Intensity
p	Share on total cases

p	P-value
R	"Crude" odds ratio
RR	Risk ratio
S	Specific safety system
S^2	Empirical variance
X	Random variable
$\bar{X}$	Arithmetic mean
x	Involvement of the vehicles
x	Factors
xe	Accident involvement
y	Exposure of vehicles
y	Response
ε	Deviation
μ	Mean value
σ^2	Variance

1. Introduction

1.1 Scope and goal of this work

Traffic has increased worldwide over the past few decades dramatically. According to the IRTAD Road Safety Annual Report 2013 the number of vehicles and the number of kilometres driven in Austria has increased by almost 60% since 1990 which leads to a number of 738 vehicles per 1000 inhabitants. Despite this development the number of fatal injuries in Austria has decreased between 1990 and 2011 by 69% [1]. One of the reasons for this is the development of new and the continuous improvement of the already existing safety systems by the vehicle manufacturers.

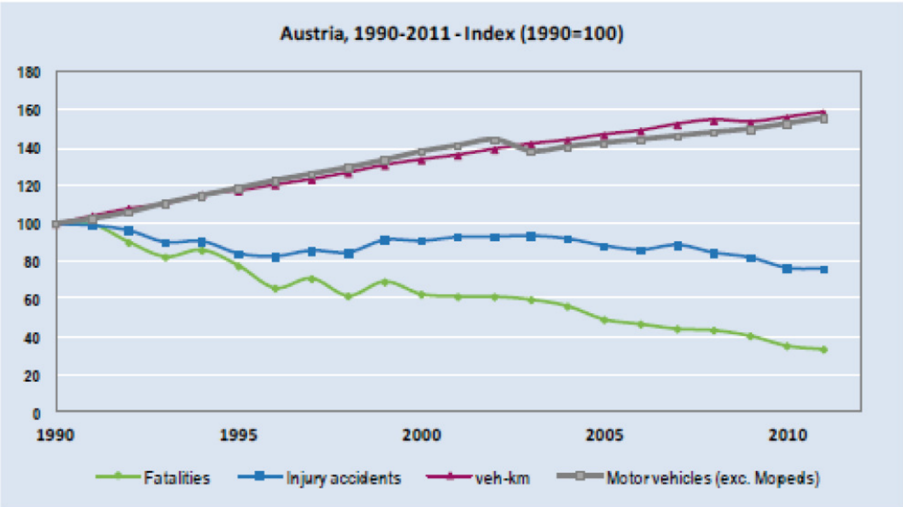

Figure 1 Reported road fatalities, injury crashes, motorised vehicles and vehicle-kilometres [1]

In the last few years Advanced Driver Assistance Systems (ADAS) have been gaining more and more importance, bearing a high potential of crash avoidance and mitigation of crash consequences. The number of cars equipped with such systems is rising and so is the need of adequate testing and assessment methods. Real hardware tests are quite expensive and time consuming. Thus testing via simulations is gaining more and more significance. Also, these simulated tests can be carried out in rather early phases of the development process. Different combinations of safety systems and test settings are realizable with a comparatively low level of effort.

One way to test ADAS would be field data based simulations in which different scenarios, containing different parameters, are set. The definition of the scenarios and parameters could be exported from real accidents by analysing accident databases. This would provide a bigger variability of scenarios and should represent the real life situation more accurately.

This work deals mainly with the problems of car to car rear end collisions and car to pedestrian collisions with the focus on Emergency Brake Assist (EBA) systems. The goal is to generate scenarios based on real accident data that cover a wide range of possible situations. Therefore basic scenarios referring to rear end collisions and pedestrian collisions were derived from previous projects. After this, the influencing parameters, such as weather conditions, driving speed etc. were determined and implemented in the test scenarios. The results of this were scenarios referring to the previously named collision types under many different circumstances. With this approach it was possible to generate a wider range of scenarios including conditions not regarded by most of the previous projects. This offers the possibility to actually rate safety system in regard to their field effectiveness. The current testing and assessment procedures performed by other projects, test and rate the systems in fixed set ups, with a few variations in certain parameters. Therefore the results of these tests are only valid for those set ups. Although they make the systems comparable to each other, since they are all tested under the same conditions, they do not represent the actual field effectiveness. In order to test and rate the field effectiveness, much more set ups have to be reviewed. These set ups result from the scenario generator programmed in this work. This scenario generator provides a basis for the further methodology of assessing the field effectiveness of safety systems. This methodology is part of a project currently running at the Virtual Vehicle Research Center (ViF), aiming to rate the actual field effectiveness of safety systems, as described in paragraph 1.4.2. A similar approach is taken by the Beyond NCAP programme, as described in paragraph 1.4.1.

The results were exported to IPG Carmaker, which is a vehicle dynamics simulation software, where different simulations were run. At the end, two scenarios of those exported were chosen and the settings concerning the EBA system were varied. The results of those variations were reviewed and discussed in regards of crash outcome and resulting impact speed.

1.2 Traffic accidents

About 1.24 million people die worldwide every year in road traffic accidents, plus another 20 to 50 million suffer from non fatal injuries [2]. According to this study traffic injuries are estimated to be number eight on the list of death causes globally and the leading cause for deaths of people aged 15-29 years. While the number of fatal accidents in some high income countries is decreasing, the high increase of traffic accidents in low- and middle income countries is leading to an overall global increase of traffic fatalities and injuries. This is due to the fact that these countries have a rapid increase of motorisation. The rates of injuries in low- and middle income countries are twice as high as those of high income countries. Latest trends show that road traffic injuries will become the number 5 on the list of death causes by 2030 [3].

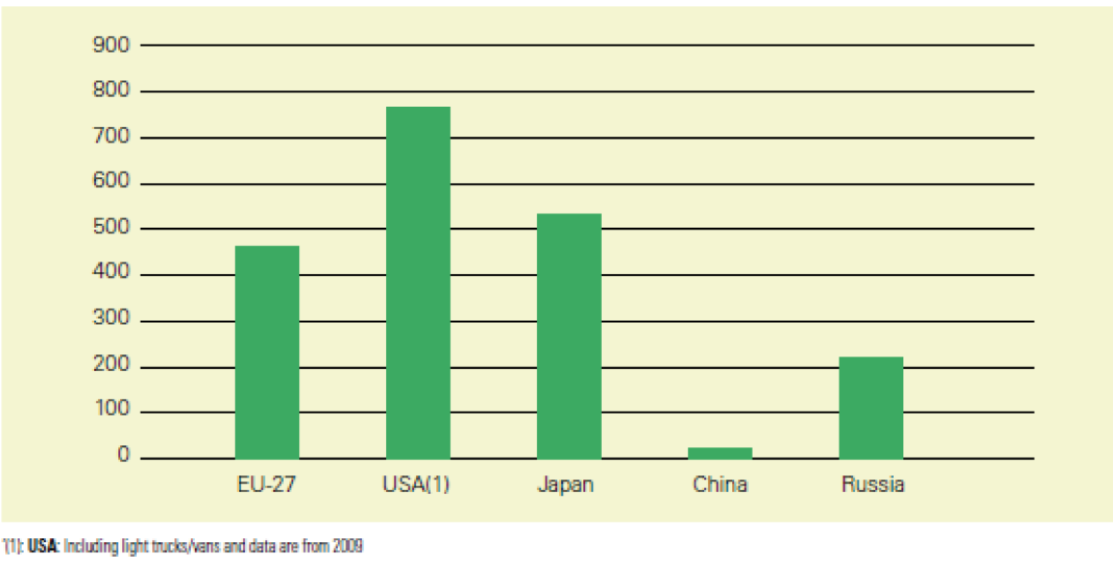

Figure 2 Comparison EU-27/World - 2010 (passenger cars/1000 inhabitants) [4]

EU

Every year in the EU about 34 000 people die in road traffic accidents while more than 1.1 million get injured. This leads to estimated costs of approximately 140 billion Euros [5].

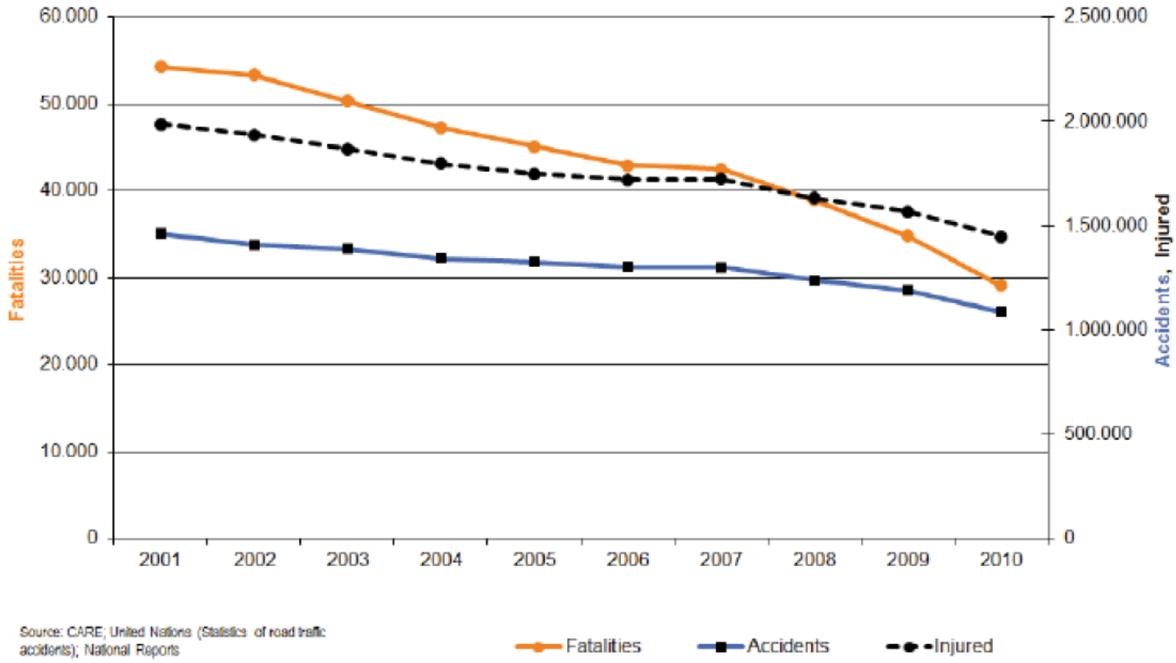

Figure 3 Annual number of fatalities, injury accidents and injured people (EU-27), 2001-2010 [6]

In the White Paper "European transport policy for 2010: time to decide", the EU Commission has set the target to half the number of road traffic fatalities in 2010. The following Figure 4 shows the progress made so far, but the number of fatalities has been slower decreasing than expected. A decrease of 6.7 % per year would have been needed to reach the goal, but the reduction between 2000 and 2007 only decreased by 3.6% per year, which means that the number would need to fall by 20% in 2010 to reach the goal [7].

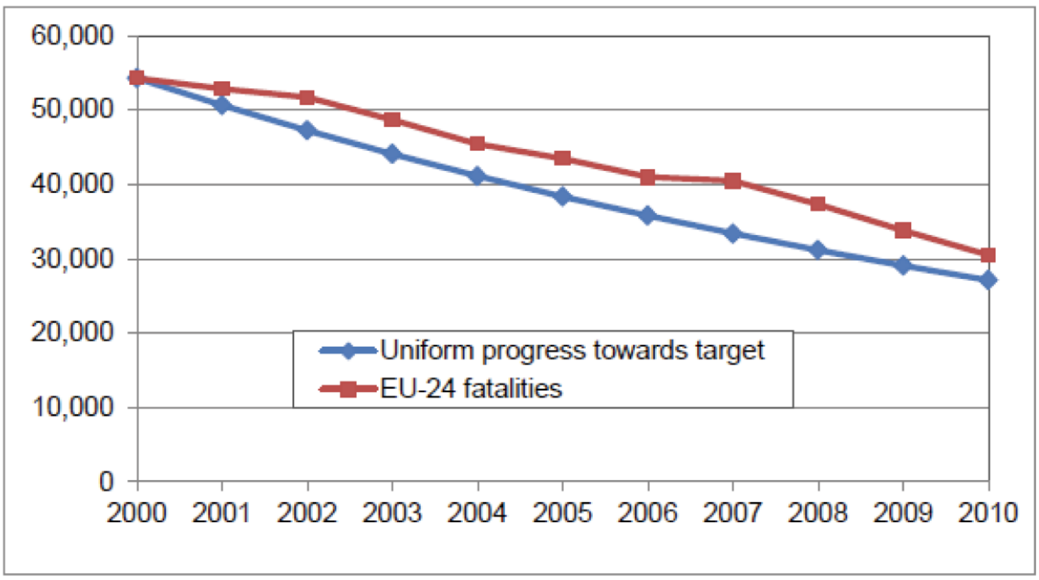

Figure 4 The number of road accident fatalities in the EU-24, 2000-2010, compared with the trend required to reach the 2010 objective [8]

1.3 Active and passive safety

The most common classification of vehicle safety, as stated in [9], is the separation into active safety and passive safety. In detail this means:

- Active safety: Measures for avoiding a collision;
- Passive safety: Measures for reducing the consequences of a collision.

However there is a trend of replacing these two classifications with the more precise terms primary and secondary safety and in some publications a tertiary safety for post crash treatment is defined [10].

- Primary safety: Measures for avoiding a collision or decreasing collision severity;
- Secondary safety: Mitigation of the consequences to the human in an accident;
- Tertiary safety: Refers to rescue systems and immediate injury treatment.

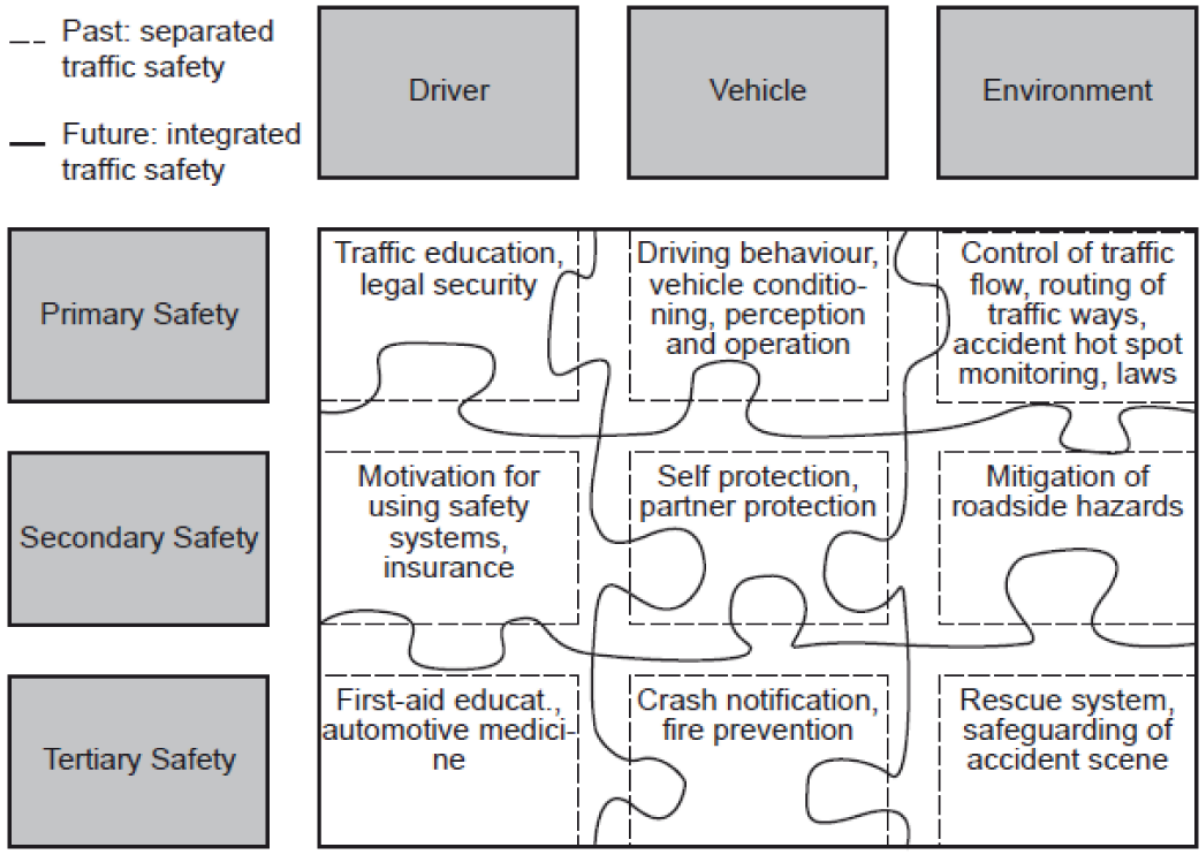

Figure 5 Aspects of traffic safety and examples for safety measures [10]

To evaluate the possible safety benefit of these systems there are various testing methods and tests performed by different institutions worldwide. Probably the best known hardware test is the NCAP test which is performed worldwide.

1.4 From NCAP to Beyond NCAP and the ViF approach

1.4.1 NCAP

NCAP

The Euro NCAP test is one of the most known crash tests in Europe. It was established in 1997 and is composed of seven European Governments as well as motoring and consumer organisations in each European country [11]. The fact that many car manufacturers use the Euro NCAP test as part of their marketing strategies shows its influence on the manufacturers and the consumers.

However the Euro NCAP test has been mainly testing secondary safety systems in the past. With the upcoming trend of active and integrated safety systems, which include all of the three safety systems mentioned earlier, the need for new testing and assessment methods is rising. At the moment secondary and tertiary safety systems do not directly go into the NCAP star rating.

NCAP Advanced

Therefore in 2010 the Euro NCAP advanced was introduced. This rewards car manufacturers which provide new safety technologies that demonstrate a scientifically proven safety benefit for the consumer and society. Most of these technologies can be referred to the primary safety sector. Each technology nominated by a car manufacturer has to be delivered with an evidence of its safety benefits. This evidence is further reviewed by a panel of objective experts. Through analysing the way in which the technology has been developed, tested and validated and from real-world experience, if possible, the system’s performance and expected effectiveness is determined [12].

Beyond NCAP

The following explanations about Beyond NCAP are taken from [13].The Beyond NCAP methodology is an addition to the current assessment process. Unlike the normal NCAP testing and similar to the NCAP advanced, the process is based entirely on the assessment of scientific evidence provided by the manufacturer. The Beyond NCAP assessment method is displayed in Figure 6.

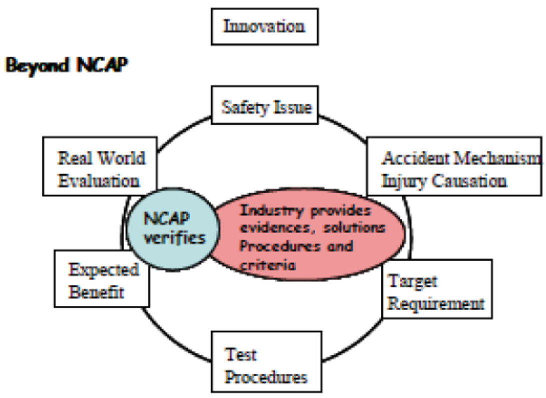

Figure 6 The Beyond NCAP assessment method [13]

Innovation

The first part of the dossier includes a description of the components and the system’s functionality. Based on the provided information, the dossier will identify if:

- The system is addressing primary and/or secondary and/or tertiary systems;
- A system with similar functionality has been assessed before;
- The system can be assessed with regular procedures (and hence whether it is already covered by the star rating) or if a new procedure is required.

Safety Issue

The main goal here is to identify the relevance of the safety issue that the safety system aims to address. The effectiveness and any possible side effects are not considered at this point. The main aspect is to identify the problem at large and the potential size of the safety benefit that the innovation addresses in the context of the EU-27.

The field of application of the safety system has to be defined based on the specifications provided in the first part. This information is then judged on the:

- Reliability of the methods;
- Validity of the used data sources.

If the used methods are reliable and the used data sources are representative, then this will result in an agreement on the potential safety benefit.

Accident mechanism/ Injury causation

In this point the injury/crash mechanisms causing the problem to be addressed by the innovation are defined.

Therefore a detailed understanding of the accident mechanism and/or injury causation is required to guarantee a correct definition of the target requirement and technical assessment in a later stage. This investigation will identify:

- The accident mechanism and/or injury mechanism;
- The driver behaviour (if applicable, for instance for ADAS systems);
- The injury risk or transfer functions identifying the main accident parameters governing the system's effectiveness;
- The reliability and the validity of the data;
- The methods and the tools proposed.

This should lead to the key parameters contributing to the accidents and their outcomes. Further it should result in the knowledge of which parameters will be used or have to be controlled by the system to deliver the benefit.

Target requirement

These are the requirements set by the manufacturer on the important system parameters identified in the previous section. These are the basis for the criteria used in the test(s) of the system. The target requirement has to be defined in a way, so that it is possible to know what the innovation is expected to do (e.g. keep the car in the desired lane). The output from this is the:

- Definition of the target requirement(s) in relation to methods and tools;
- Understanding of the relationship between criteria and the system's benefit.

Test procedure

This part presents the methods of the manufacturer with which he has verified that the system works in the intended situations and the in the designed manner. Evidence is wanted that the system meets the manufacturer's own targets and/or to estimate the technical efficiency on the basis of test series carried out. The test methods and target requirements used for the assessment the system are reviewed considering:

- Methods and tools used;
- Source and independence of data;
- Reliability and validity of the results;
- Criteria used;
- Assessment procedure and results.

The testing can be done experimentally, by computer simulation or by both. For ADAS systems, driver simulator studies are relevant to quantify the effectiveness of the Human Machine Interface.

Expected benefit

After all the previous points an expected benefit of the innovation can be calculated. In the assessment process the following is considered:

- Available methods / accepted methods;
- Accident data used;
- Inclusion of any side effects (e.g. driver adaptation);
- Potential level of dissemination (for information only);
- Market share (for information only);
- Expected benefit evaluation.

Although the expected benefit is referred to a single vehicle, information on the potential level of dissemination of the system and the market share is requested. This additional information will not affect the expected benefit of the system but these numbers can be taken as an indicator of the manufacturer's confidence in the system.

Real world evaluation/experience

The final step is the real world evaluation. This is the best way to verify the true effects of the safety system in real world conditions. These results may distinguish from the expected benefits in many ways. Information learned in this step can be used as input for the next development loop. The best method for real world evaluation is the a posteriori analysis. But this method is found to be complicated and time consuming especially for avoidance systems. This leads to the conflict of good quality real world evaluation process and the need of rapid answers. For systems recently introduced or not yet available there might be no data available to perform a real world study. For these systems results from fleet studies, feedback from consumers or simulation may provide some information on the real world benefit.

1.4.2 Virtual Vehicle Research Center (ViF) approach

The scenario generator resulting from this work will be implemented in a current project of the Virtual Vehicle Research Center (ViF). The following short description of the project is taken from [14], where also further information is stated.

This project deals mainly with the testing and evaluation of primary, secondary and integrated vehicle safety systems by using numerical simulations. The method developed in this project includes a definition of scenarios and safety system variants, a fully automated numeric simulation of those scenarios and an automated evaluation of those. The evaluation is based on commonly used injury criteria known from secondary safety system assessment.

In the next section a short overview of evaluation methods for Advanced Driver Assistance Systems will be presented.

1.5 Evaluation of Advanced Driver Assistance Systems

One of the most importing things is the assessment of the benefit the traffic safety system bears. For this there have been two main methods developed [15]:

- A priori (evaluating the system before its introduction)
- A posteriori (i.e. evaluating the system after its introduction)

A priori

This method analyses accidents that have already happened to determine what amount could have been avoided or for which amount could the collision severity have been decreased. The advantage is that the system does not have to be developed or introduced to the market. The disadvantage is that several assumptions have to be made, for example in terms of functionality and fleet penetration [10]. For the a priori effectiveness assessment, five different methods were selected in the TRACE project [15].

- **Target population times efficiency approach**
  This is a useful method if the functionality of a future system is not yet fully defined. First, accidents where the system could have been beneficial are identified and the maximum efficiency of the system is determined. The technological limitations of the system are estimated, often by expert prediction. An example of such a limitation could be sensor range and acquisition time.
- **Automatic case-by-case analysis**
  The requirement for this is that the system has to be sufficiently specified, so that it can be modelled. After this two simulations of the same scenario(s) are run. One with and the other without the analysed system. The effectiveness is shown in the difference between the two simulations of each scenario.
- **Case-by-case analysis within database**
  This is similar to the automatic case-by-case analysis with the difference that besides the analysed system the accident has also to be modelled. Actual accidents from an in-depth database are used. From this a reduction of injury risk can be estimated from the number of avoided accidents or the number in which the system reduced injury severity. This data can be projected from the in-depth database to national statistics.
- **Artificial Neural Networks (ANN)**
  Artificial Neural Networks are modelling techniques able of modelling complex and highly non linear functions. They are mostly used for solving problems of predictions, classification or control. One example of use is the approach to detect driving patterns with less chance of causing fatal or severe injuries [16].

- **Decision tree model**
  Decision trees are mathematical models with sequences of branching operations. It is used in similar applications as the ANN. In [17] it was used to analyse important factors influencing fatal injuries.

A posteriori

This investigation assesses the effectiveness of safety systems after their introduction by investigating accident databases. There are also several methods for a posteriori investigations, the two most important are [18]:

- **Comparison between observed and expected number of involved vehicles**
  This methodology requires several steps. In the first step two vehicle fleets have to be selected. These fleets have to include different vehicle make and model i, one of them with the specific safety system (S) and the other without (0). In the next step the different involvement of the two sets of vehicles is observed. This may be done with respect to e.g. fatal accidents, $x_{i,0}$, $x_{i,S}$. Furthermore, the exposure of the vehicles in terms of the number of registered cars or driven kilometres is observed, $y_{i,0}$, $y_{i,S}$. From this the involvement rate IR for both sets is calculated by

$$IR_{i,0} = \frac{x_{i,0}}{y_{i,0}}, \tag{1-1}$$

$$IR_{i,S} = \frac{x_{i,S}}{y_{i,S}}. \tag{1-2}$$

Then, the expected number of accident involvement $xe_{i,S}$ for vehicle i equipped with S is calculated by

$$xe_{i,S} = IR_{i,0} \cdot y_{i,S}. \tag{1-3}$$

In the end a so-called risk ratio $RR_{i,S}$ is calculated by

$$RR_{i,S} = \frac{x_{i,S}}{xe_{i,S}}. \tag{1-4}$$

The risk ratio means the following:

- $RR < 1$ → The system is beneficial
- $RR = 1$ → The system has no effectiveness
- $RR > 1$ → The system would increase the investigated accident type

However, there might be problems with the results because they can be influenced, since different time periods are analysed (i.e. before and after the introduction of the safety system). In [19], a correction by the following relations is proposed

$$IR_{i,1} = \frac{x_{i,1}}{y_{i,1}}, \tag{1-5}$$

$$xe_{i,2} = IR_{i,1} \cdot y_{i,2}, \tag{1-6}$$

$$CR_i = \frac{xo_{i,2}}{xe_{i,2}}, \tag{1-7}$$

$$RRa_{i,S} = \frac{RR_{i,S}}{CR_i}. \tag{1-8}$$

In this $IR_{i,1}$ is the involvement rate of the considered vehicle i in the time period 1. The number of involvements in a certain scenario and the number of registered vehicles is represented by $x_{i,1}$ and $y_{i,1}$. Furthermore $xe_{i,2}$ is the expected number of involvements of vehicle type i in time period 2 and $xo_{i,2}$ is the actually observed number. Symbol $y_{i,2}$ is the number of vehicles in time period 2 and CR_i is the control ratio. The control ratio expresses if there is a difference because of the fact that the vehicles in time period 2 are newer than the vehicles in time period 1. The CR_i is calculated regardless of the considered safety system. Finally the adjusted risk ratio can be calculated, with respect to safety system S of the vehicle model i. The database in which the investigation is done has to be very large because the subsamples with respect to a specific make, model and safety system can be hardly compared to the total number of cases in the database.

- **Evaluation of relative crash risk**
  This method was mainly used for a posteriori assessment of the effectiveness of safety systems in the TRACE project [18]. As stated in [20] it is based on a comparison of a case and a control group. In a first step two examples are selected, vehicles equipped (S) and unequipped (0) with a safety system. Then a pertinent case group (p) and a control group (c) are selected. The case group must contain accidents where the analysed safety system could have shown a benefit and the control group must include a sample for which the safety system should be of low influence.

The "crude" odds ratio $R_{1,S}$ reads

$$R_{1,S} = \frac{\frac{x_{S,p}}{x_{S,c}}}{\frac{x_{0,p}}{x_{0,c}}}, \quad (1\text{-}9)$$

where $x_{S,p}$ and $x_{0,p}$ stand for the numbers of equipped and unequipped vehicles in pertinent cases and $x_{S,c}$ and $x_{0,c}$ are the numbers of vehicles in the control group.
The effectiveness E_S is calculated by

$$E_S = \left(1 - R_{1,S}\right) \cdot 100\ [\%]. \quad (1\text{-}10)$$

This describes the portion of avoided accidents in the case group. The case group is a subset of the accident database depending on the investigated system. However there is a database bias due to the comparison of different model years, so the odds ratio can be corrected by the ratio R_2,

$$R_2 = \frac{\frac{x_{2,p}}{x_{2,c}}}{\frac{x_{1,p}}{x_{1,c}}}, \quad (1\text{-}11)$$

with $x_{1,p}$ and $x_{2,p}$ standing for the numbers of pertinent cases of model year 1 and 2. Variables $x_{1,c}$ and $x_{2,c}$ represent the respective cases in the non-pertinent group.
Variable Ea_S is defined as:

$$Ea_S = (1 - R_S) \cdot 100\ [\%], \quad (1\text{-}12)$$

and represents the adjusted effectiveness of the safety system S, with R_S reading:

$$R_S = \frac{R_{1,S}}{R_2}. \quad (1\text{-}13)$$

One disadvantage of this method is the selection of non-pertinent cases in the database. Another drawback is the assumption that only the selected safety system influences the results. Actually there are other external variables that may affect the analysis. As stated in [21] the consideration of the influence of the external variables may be done with extending the method by using an "adjusted odds ratio" approach based on logistic regression. A detailed description of this can be found in [18].

An advantage delivered by the odds ratio method is that it allows to investigate multiple safety systems, for example vehicles equipped with ABS which are enhanced with ESC. By the additional odds ratio $R_{S1,add}$ the effectiveness $E_{S1,add}$ of the safety system $S1$ in addition to $S2$ is calculated. It compares the number of vehicles equipped with safety system 1 in pertinent and non-pertinent accident scenarios $x_{S1,p}$ and $x_{S1,c}$ to the number of vehicles equipped with safety system 2 ($x_{S2,p}$, $x_{S2,c}$).

$$R_{S1,add} = \frac{\frac{x_{S2,p}}{x_{S2,c}}}{\frac{x_{S1,p}}{x_{S1,c}}}, \quad (1\text{-}14)$$

$$E_{S1,add} = \left(1 - R_{S1,add}\right) \cdot 100\ [\%]. \quad (1\text{-}15)$$

1.6 Traffic and accident statistics for the EU

The following statistics are taken from the ERF European Road Statistics Report 2012 [4]. Table 1 gives an overview of the total transport network in 1000 km and compares different countries with the EU-27.

Table 1 Transport network (in 1000 km) [4]

Region/Type of road	EU-27	USA	Japan	China	Russia
Road network (paved)	5000	4400	968	3056	776
Motorway network	68.2	94.3	7.6	65.1	30
Railway network	212.7	202.4	27	85.5	86

The stock of registered passenger cars in the EU-27 is about 238 762 000, which leads to around 477 passenger cars per 1000 inhabitants. In Germany the stock of registered passenger cars is 42 302 000 with 517 passenger cars per 1000 inhabitants and in Austria the numbers are 4 441 000 registered passenger cars with 528 passenger cars per 1000 inhabitants.

The number of registrations of new passenger cars has decreased in the EU-27 by 5.4% from 2009-2010 and 1.7% from 2010-2011, while in Austria the numbers have increased by 2.9% from 2009-2010 and 8.4% from 2010-2011. The situation in Germany is different where the registrations of passenger cars from 2009-2010 have decreased by 23.4% and increased again from 2010-2011 by 8.8%.

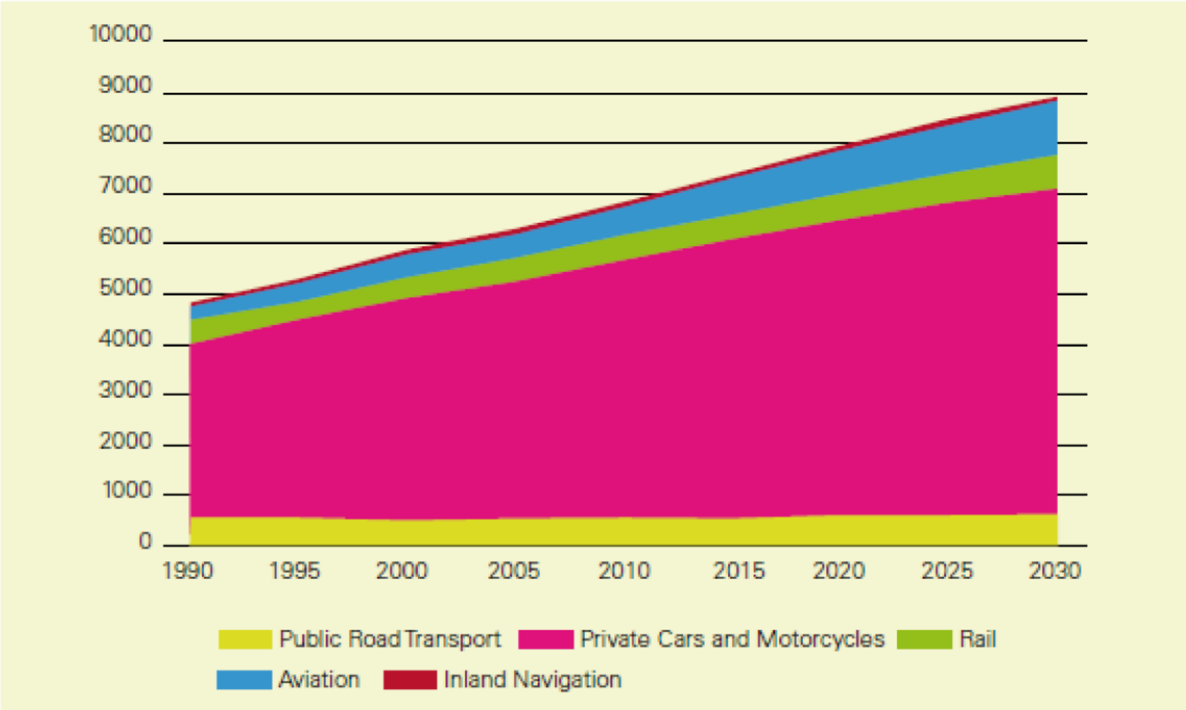

Figure 7 Trends and outlooks in passenger transport demand for the different modes of transport in EU-25 - 1990-2030 (Gpkm) [4]

Figure 7 shows the trends regarding passenger transport modes in the future.

The number of accidents involving personal injury in the EU-27 has decreased by 25.21% from 2000 to 2010 with a decrease of 24.72% in Germany and 16.09% in Austria.

In Figure 8 the road accidents, which involve personal injury, per thousand of population in the EU – 27 are displayed. It can be seen that the number in Germany and Austria is rather high compared to the EU – 27.

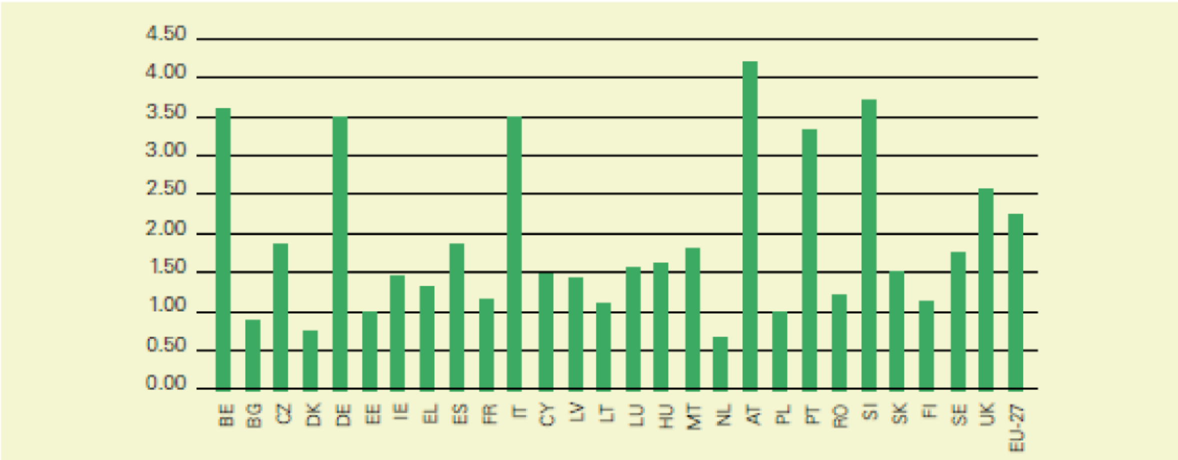

Figure 8 Road accidents involving personal injury per thousand of population EU-27 – 2010 [4]

The road fatalities have even decreased by 42.86% in the EU-27 from 2001 to 2010 with a decrease of 47.71% in Germany and 42.38% in Austria in the same time period. The percentage change in road fatalities between 2001 and 2010 is shown in Figure 9. While the number in Germany is higher than the number in the EU – 27, the number in Austria is lower with about 40%.

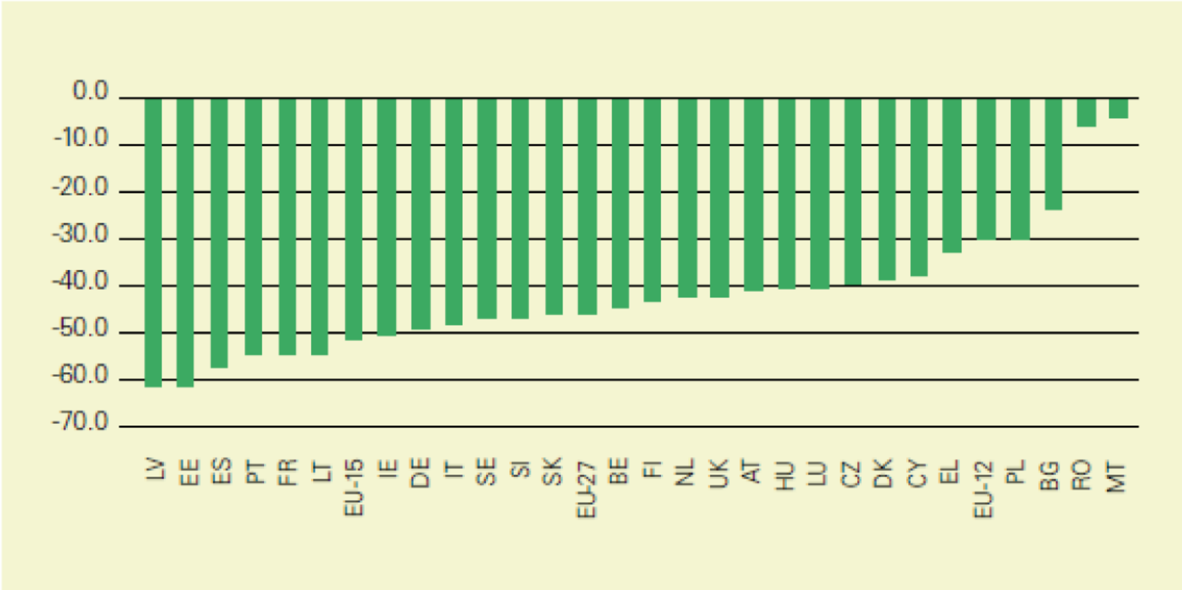

Figure 9 Change in road fatalities between 2001 and 2010 (%) [4]

The evolution of road fatalities in the EU-27 between the year 2000 and 2010 is shown in the following Figure 10. It shows an almost constant decrease of the road fatalities and injured people over the past ten years.

Figure 10 Evolution of road fatalities and injured in EU-27 - 2000-2010 [4]

The three biggest modes of transport groups in road fatalities in the year 2010 in the EU-27 are "Car+Taxi" with 46.38%, followed by "Pedestrians" and "Powered two-wheeler" with 19.80% each.

In the next chapter some basic facts which are important for the further work will be shown. First a general overview about accident research followed by some statistics especially for pedestrian and rear end collisions. At the end a short introduction into ADAS will be provided.

2 Basics

2.1 Accident research

Accident research is one of the keys to understand the circumstances of traffic accidents and to reduce them. According to [9] accident research can be divided into three parts:

- Accident statistics;
- Accident reconstruction;
- Accident analysis.

The basic task of accident research is to get information on accident causation. From this information countermeasures can be derived in order to enhance road safety. Nowadays accident research is also becoming a more and more important economic factor as many car manufacturers have started to implement vehicle safety into their marketing concepts.

The following paragraph provides some details on the accident statistics.

2.1.1 Accident Statistics

As mentioned before, accident statistics are one of the three points of accident research and also a very important basis for the development of new safety systems. Accident statistics can offer various information on accident types and the circumstances that lead to traffic crashes. Basically, accident databases can be divided into two groups as described in [22].

One group are the databases that contain macroscopic data (state statistics). These databases contain a very large number of data, but with a low level of detail. Mostly the accident circumstances (who, where, when) are noticed without any further detailed information. They also contain analyses of trends and development of the road traffic. Macroscopic databases also may provide an evaluation of legal actions taken to increase traffic safety.

The other group of databases contain the microscopic data (in-depth studies). They contain a relative small amount of data compared to the macroscopic databases but offer a much higher level of detail, containing the accident cause as well as identification of accident risks. Further an accident reconstruction is done which delivers the most important physical parameters for the accident and provides the possibility of development of counteractions. These databases also contain detailed information on the vehicles and the vehicle safety systems.

Some examples of macroscopic and microscopic databases are:

- **Macroscopic databases:**
    - National statistics
    - CARE: European Road Accident Database
    - IRTAD: International Road Traffic and Accident Database
    - IRF: International Road Federation
    - UNECE: United Nations Economic Commission for Europe
    - GES: General Estimates System

- **Microscopic databases:**
  - Project based (Europe)
    - PENDANT - Pan-European Co-ordinated Accident and Injury Databases
    - RISER - Roadside Infrastructure for Safer European Roads
    - ROLLOVER - Improvement of rollover safety for passenger vehicles
    - MAIDS - Motorcycle Accidents In-depth Study
    - CHILD - Child Injury Led Design
    - ETAC - European Truck Accident Causation
    - EACS - European Accident Causation Study
    - ECBOS - Enhanced Coach and Bus Occupant Safety
    - SAFETYNET
  - Europe
    - GIDAS - German In-depth Accident Study (DE)
    - FALS - Fatal Accidents Lower Saxony (DE)
    - CCIS - Co-operative Crash Injury Study (UK)
    - OTS - On-The-Spot accident research (UK)
    - VALT Database on fatal accidents (FI)
    - INTACT Investigation Network and Traffic Accident Investigation Techniques (SE)
    - Sports Utility Vehicle study (NL)
    - AAHTWO - Accident Analysis Heavy Trucks TWO (NL)
    - ZEDATU - Zentrale Datenbank zur Tiefenanalyse von Verkehrsunfällen (central database for in-depth analysis of road traffic accidents - AT)
  - USA
    - FARS - Fatality Analysis Reporting System
    - SCI - Special Crash Investigations
  - Australia
    - ANCIS - Australian National Crash In-depth Study
    - CASR - Centre for Automotive Safety Research

In the following paragraph some statistics referring to pedestrian and rear end collisions are presented. As the focus of this work lies in these two collision types, these statistics provide very important basic information.

2.2 Statistics of pedestrian and rear-end collisions

2.2.1 Pedestrian collision

In this paragraph a few statistics from [23] according pedestrian fatalities are given, focusing on the EU, Germany and Austria.

In 2010 about 6000 pedestrians were killed in road traffic accidents in the EU-24. This is about a portion of 20% of all traffic fatalities, with 18% in Austria and 13% in Germany. The number of pedestrian fatalities per million inhabitants is in the EU-24 was 12.3, with a number of 11.7 in Austria and 5.8 in Germany, in the year 2010. As shown in Figure 11, the highest rate of pedestrian fatalities is in the Eastern European countries.

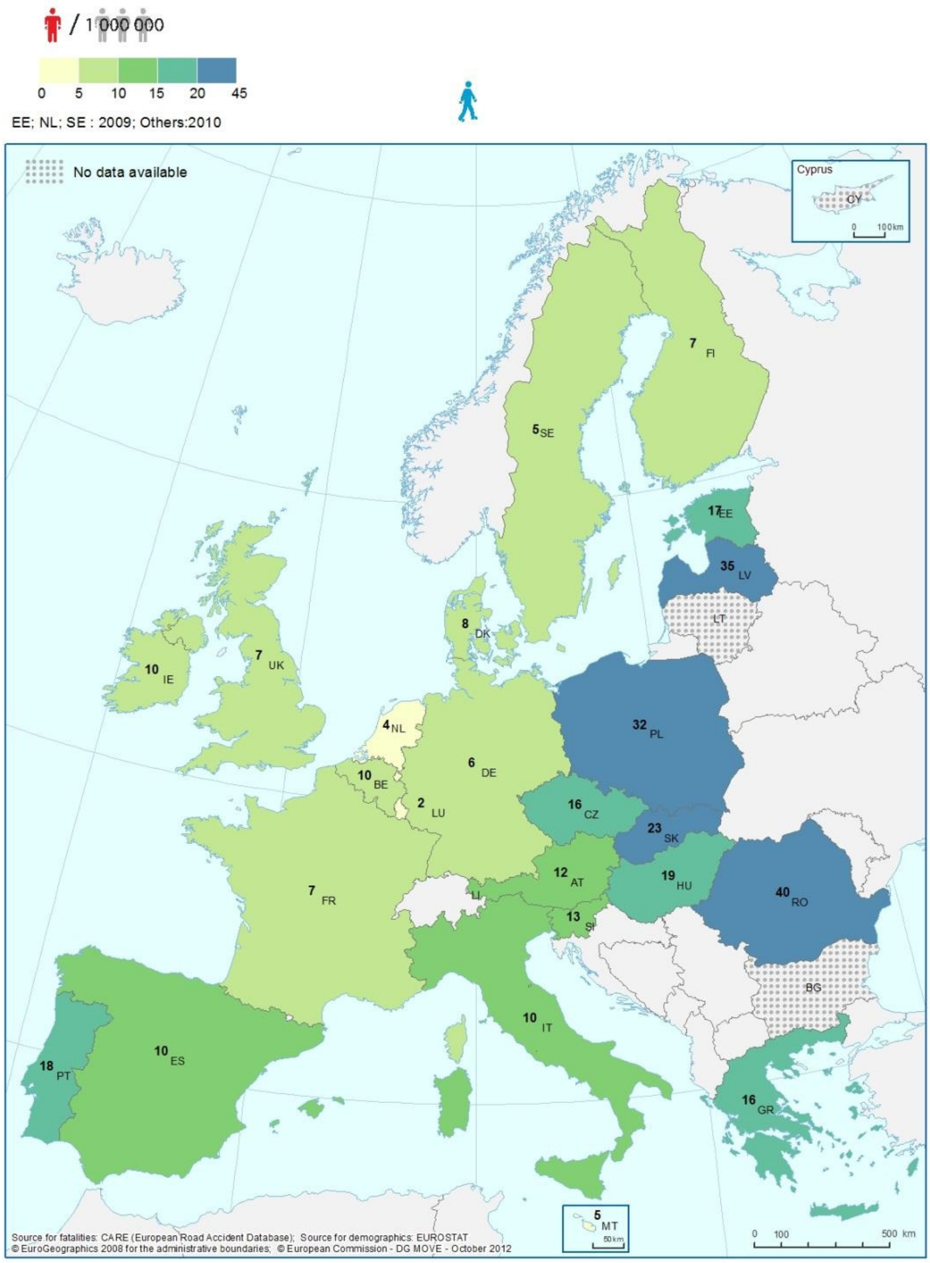

Figure 11 Pedestrian fatalities per million inhabitants by country, 2010 [23]

As the absolute number of pedestrian fatalities has been decreasing over the years, the pedestrian fatalities, as a proportion of all fatalities, have been slightly increasing in the EU-19 as shown in Figure 12.

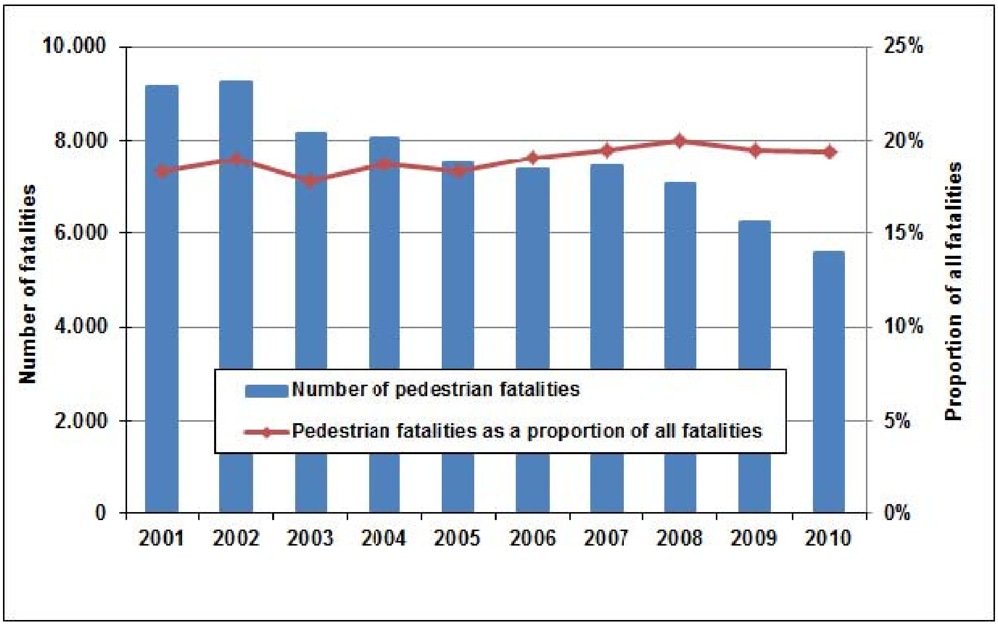

Figure 12 Number of pedestrian fatalities and proportion of total fatalities in EU-19, 2001-2010 [23]

The largest age group in the pedestrian fatalities is formed by the elderly, aged 64 years and older. However this number has also decreased by 31% in the EU-19 between the year 2001 and 2010, see Figure 13.

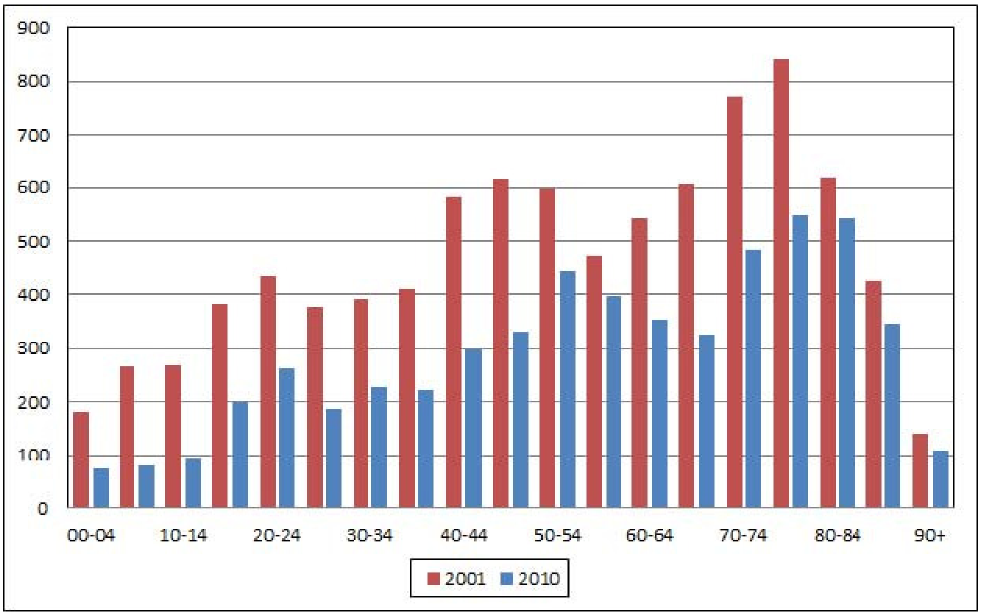

Figure 13 The number of pedestrian fatalities by age group, EU-19, 2001 and 2010 [23]

The proportion of pedestrian fatalities is higher for children and the elderly, than for any other age group, as shown in Figure 14.

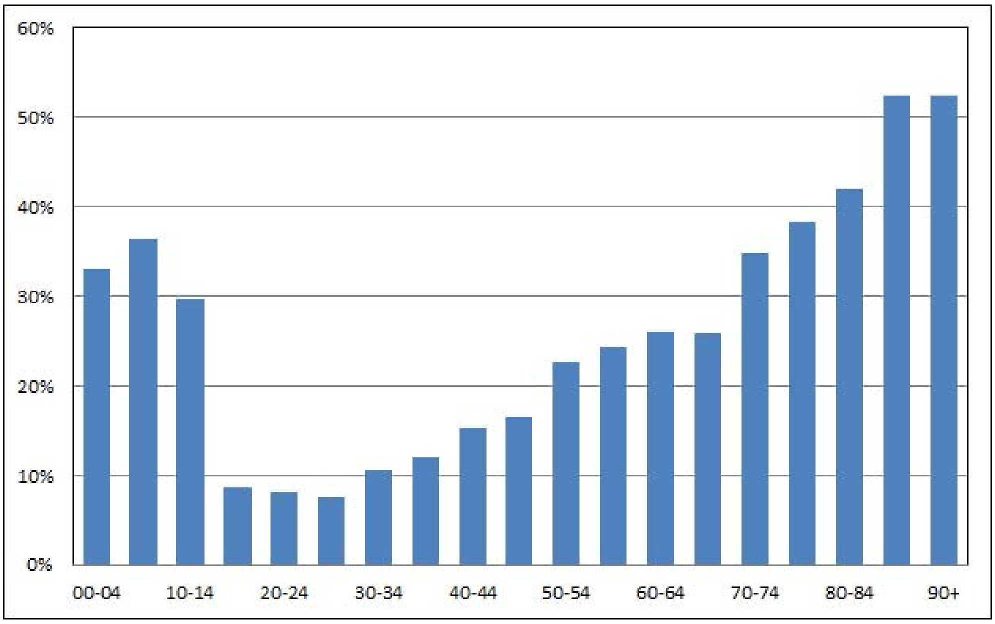

Figure 14 Pedestrian fatalities as a percentage of all fatalities by age group, EU-24, 2010 [23]

Figure 14 shows that a high number of the children fatalities were pedestrians, whereas Figure 13 shows that they only represent about 4% of the total pedestrian fatalities, while the elderly group represents about 54% of the total pedestrian fatalities in the EU-24, with 44% in Austria and 46% in Germany, see Figure 15.

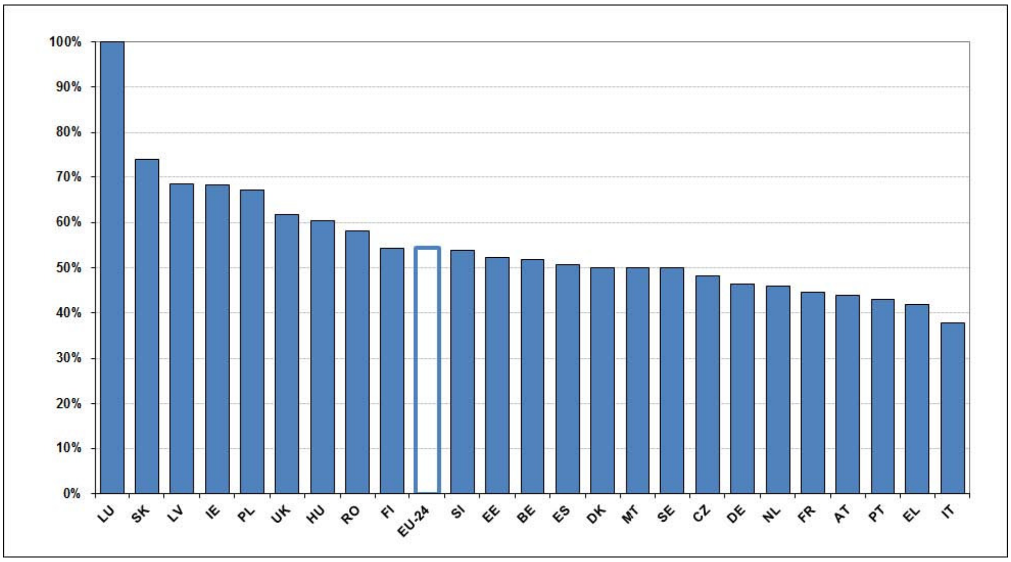

Figure 15 Elderly pedestrian fatalities (age >64) as a percentage of all pedestrian fatalities, EU-24, 2010 [23]

While 24% of all road accident fatalities are female in the EU-24, the number for pedestrian fatalities is higher, with 36% female.

In 2010, 51% of all pedestrian fatalities occurred in darkness in the EU-24 excluding Italy, Malta and Slovenia due to a high proportion of fatalities with unknown light conditions.

2.2.2 Rear end collisions

Statistics about rear end collisions are hardly found in macroscopic databases, due to their low level of detail. The data of the following chapter is taken from the ASSESS project [24], in which in-depth databases were researched for rear end collision scenarios, mainly the GIDAS (German In-Depth Accident Study) and the British OTS (On The Spot accident research). However the decision was made to use only the data from the GIDAS in this work since the difference to the OTS data is very low.

For the GIDAS query a data sample from 2001-2007 was used. This query led to 11685 cases in total resulting through further screening in 1306 accidents, which could be assigned to a rear end collision scenario. From this number of rear end collisions 4 were fatal, 122 seriously injured, 1940 slightly injured and 2916 uninjured. The results from ASSESS are stated below in Table 2. They represent the mean driving and impact speed values, as well as the statistical distributions of the other parameters.

Results

Table 2 Rear end collision results from ASSESS [24]

Parameter	Description		Distribution/mean value	Standard deviation
driving speed	ego car	ego speed	70 km/h	29 km/h
driving speed target	target car	target speed	29 km/h	22 km/h
impact speed	at $TTC = 0$	-	50 km/h	26 km/h
type of vehicle	passenger car	-	85 %	-
weather	surface	dry	53 %	-
		wet	18 %	-
		unknown	29 %	-
	visibility	fine	41 %	-
		cloudy	37 %	-
		rainy	18 %	-
		snowy	4 %	-
light	-	darkness	21 %	-
		light	79 %	-

2.3 Advanced Driver Assistance Systems

Advanced driver assistance systems are nowadays widely spread in modern cars. Their main objective is to support the driver in certain situations. Their field of application goes from non critical situations in traffic, e.g. park assistance systems, to systems which provide a safety benefit by supporting the driver in critical situations, either by indicating the driver to critical situations or even by taking control of vehicle systems autonomously, e.g. lane keeping assistant, emergency brake assistant, etc.

According to Donges, the driving task can be divided into three layers. The layer of **navigation**, which contains the choice of an appropriate route and the estimation of time needed to reach the goal. The lead layer contains the **actual driving** of the vehicle according to the given traffic situation and road layout. In the **stabilisation** layer the driver performs correcting measures to his intended driving as reaction to external influences, which cannot be foreseen [25].

The assistance system itself is made up of different subsystems which are communicating with each other. The assistance system gets information of the vehicle and of the driver. This information is provided by different sensor systems or the Human Machine Interface (HMI). On the one side there are sensors observing the environment, e.g. camera systems, radar systems etc. On the other side there are systems monitoring the car itself and its driving dynamics. The two loops of the driver assistance and the vehicle dynamics can be seen in Figure 16. The main difference between these loops is that in the vehicle dynamic loop there is no interaction between the driver and the car, whereas in the driver assistance loop the driver is involved over the HMI. There is also a point for a car2x communication system, which means that the car is possible to communicate with its surrounding, getting information on traffic and road surface for example. However these systems are still just a theory due to the problems of data transport and data safety. All this information plus the input from the HMI is gathered by the driving assistance system which handles it and then "decides", based on implemented algorithms, the further procedure. The two main possibilities are a signal via the HMI to warn the driver of an upcoming critical situation, or the direct access to the stabilisation layer to perform correcting measures autonomously through certain actuators.

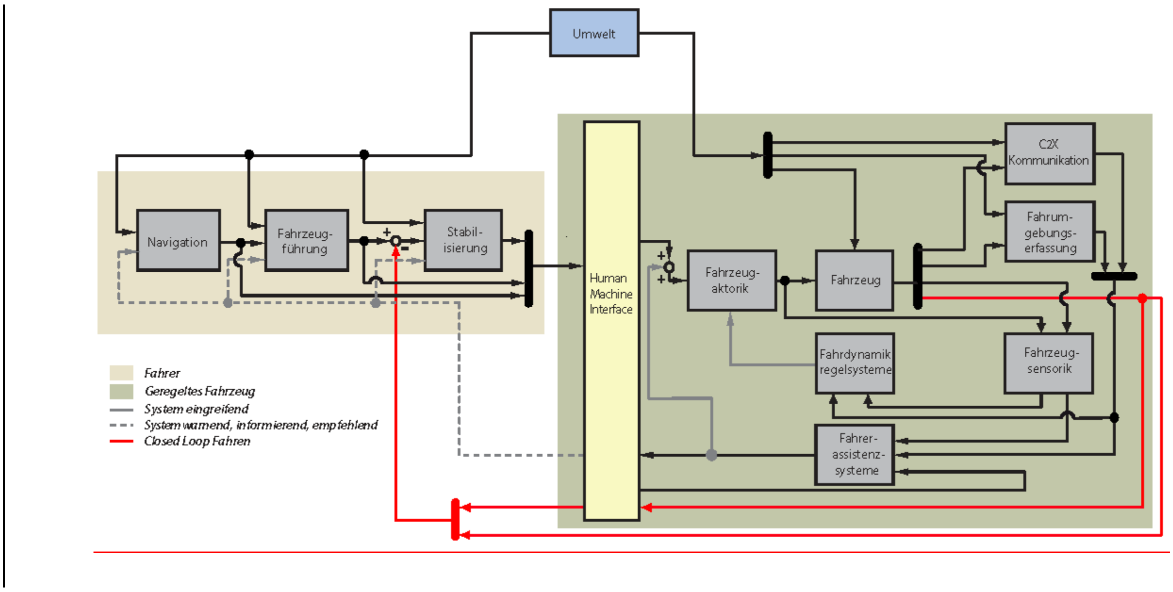

Figure 16 Driver assistance system control loop [26]

2.3.1 Components

This paragraph deals with the different components of driver assistance systems and is based on information from [25], where also more detailed reviews of the systems are stated. The focus here lies on the commonly used sensors and actuators in modern cars.

Sensors

The sensors monitoring the environment can be divided into four basic groups, ultrasonic systems, radar systems, LIDAR systems and camera systems. Figure 17 shows these sensors with their basic work range and placement in the car.

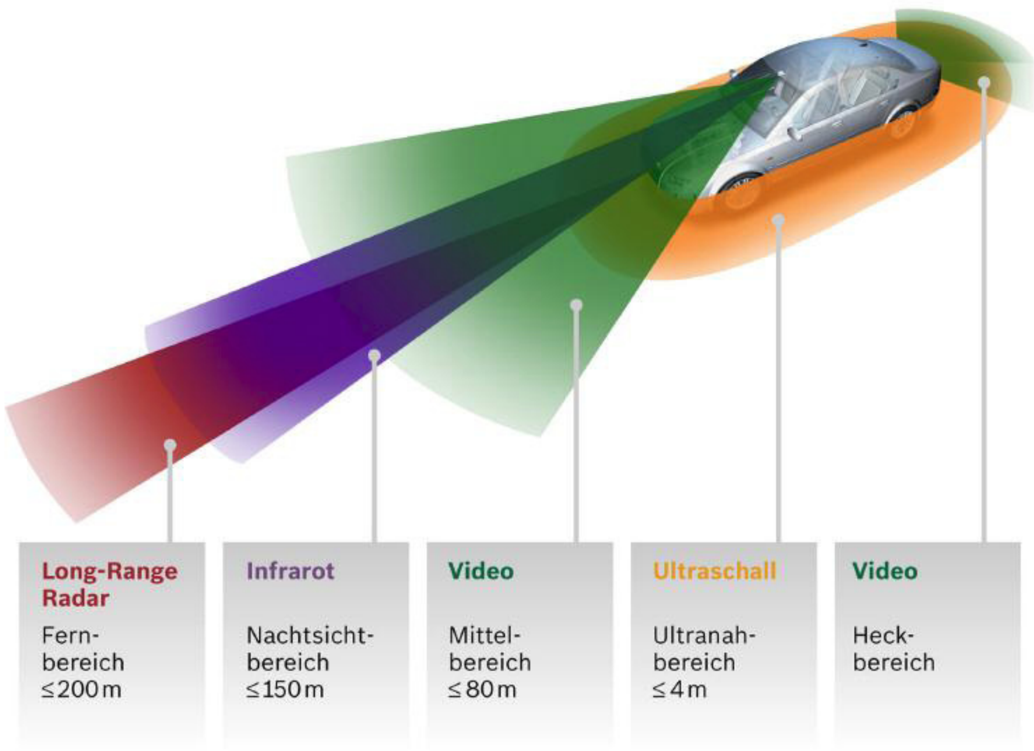

Figure 17 Sensors and their range [27]

Ultrasonic sensor

The first ultrasonic sensors in cars have been introduced in park assistance systems to measure small distances between the car and other obstacles [25]. Their work range is between 50 mm and 5 m [27]. The systems are made up of three main components, the acoustic converter element, the electronic and the casing.

The distance measurement between to objects is based on a runtime measurement. The distance is calculated by the time passed between the sending and receiving of an impulse by the sensor.

The accuracy of the measurements depends on some factors. On the one hand the physical dependencies of the speed of sound and the air, with air temperature as the most important factor. On the other hand there is the problem of the geometrical inaccuracies in the measurement of the vehicle, which are mainly specified by the position, extent, geometry and orientation of the obstacle to be detected relative to the sensor. These mistakes can be up to 20 cm and more. To reduce this, more sensors over the vehicle width are used (4 or 6) and the principle of trilateration is applied. Trilateration is a process in which one point with known distances to three other points can determine its own position in terms of the positions of those three points [28]. This means that each sensor does not only receive its own signal but also the signals of the bordering sensors. By this method it is possible to determine the position of the next obstacle in the sensor layer and calculate the actual distance to the vehicle as projection on the bumper.

Radar sensor

Radar (Radio Detection and Ranging) systems have their origins in the military. The first use of radar systems in traffic was for speed measurement by the police. In 1998 the first car equipped with a radar system was available on the market. The radar sensors were part of an Adaptive Cruise Control (ACC) installed in this car. Currently there are four frequency bands used for automotive radar systems, 24.0-24.25 GHz, 76-77 GHz, 77-81 GHz and 21.65-26.65 GHz.

The radar beam itself is not enough to measure a distance between two objects. An “information” has to be applied to the beam at the start of a measurement. This information has to be “read” when it comes back from the deflecting target. This procedure is known as modulation and demodulation. As “information” three parameters of the beam can be used:

- Amplitude A
- Frequency f_0
- Phase φ

In automotive applications the most common parameters used are a modulation of either the amplitude A or the frequency f_0. For the measurement of speed the principle of the Doppler-effect are used.

Radar waves of automotive sensors do not spread in a spherical manner but in a concentrated beam. One of the most important attributes for automotive radar systems is the maximum range. This depends on the one side on the directive antenna gain G_D which reads as

$$G_D = \frac{P(\Phi,\vartheta)_{max}}{\frac{P_{total}}{4\pi}}, \qquad (2\text{-}1)$$

with the intensity $P(\phi,\vartheta)_{max}$ in a solid angle with the maximum emission and the value $P_{total}/4\pi$ of a homogenous spherical emitter with equal total power. On the other side there is the Radar Cross Ratio (RCS) σ. Its unit is an area, which represents the concentric area πa^2 of a spherical emitter with the radius a. Typical values for automotive radar systems are between $\sigma = 1...10000$ m². This value depends on the geometry and orientation of the target. For example crash barrier pillars have often a U-profile which reflects rather much of the radar beam back and results in big RCS. This can lead to misinterpretations by the detecting system of the vehicles accounting them targets to be avoided. Also the high value range of RCS makes it nearly impossible to correctly classify the detected objects. Another problem appears in rainy conditions where “phantom” objects can appear caused by surging water on the road. Rain causes also a higher damping of the radar waves and higher signal noise which leads to decreased range of the radar.

LIDAR sensor

LIDAR (Light Detection And Ranging) is an optical procedure for distance measurement. The basic working principle is similar to the radar system, but instead of emitting radar waves, light waves are emitted. Mainly ultraviolet, infrared or waves of a visible wavelength are emitted.

The most common principle of distance measurement is the so called “Time of Flight Measurement”. This means that the runtime between the emission of the signal and the receiving after it has been reflected by an object is measured. This time is proportional to the distance. The utilization of the Doppler-effect for speed measurement is basically possible, but due to the higher requirements on measuring the Doppler-frequency in the light spectrum, a different approach is chosen. Two or more consecutive distance measurements are differentiated which results in the relative speed between the two cars.

These sensors also have the possibility to track objects. This is realized by one of the two following methods.

- Multibeam stiff
  The sensor captures the complete range. With the trajectory of the car, possible targets can be identified by excluding targets which do not lie in the trajectory. The advantage of this method is that all objects get captured. The disadvantage is the higher calculation and memory space requirement.
- Multibeam SWEEP
  The sensor only captures the relevant range lying in the trajectory of the car. The advantage of this method is the reduced calculation and memory space requirement. The disadvantage is that the capturing of the objects is dependent on the quality of the identification of the target.

As mentioned the performance of a tracking sensor depends mainly on the quality of the target identification but also on the exactness of the trajectory determination. The maximum range of LIDAR sensors is mainly influenced by the intensity of the light pulse and the sensitivity of the receiver but also by the physical properties of the air. Thus the power of the pulse is limited by security requirements referring to eye protection of people.

Camera based system

The detection of pedestrians in road traffic is one of the most important but also one of the most difficult tasks for ADAS today. The problems in this result mainly from changing weather and light situations or complex road layouts. Further the clothing of the pedestrian and possible obstruction can complicate a clean detection as well as different shapes and rapid movement. Basically two sensor types are in usage.

- Video-picture based procedure at daytime
- Infrared-camera based procedure at night

The principles of both are very similar as they differ mainly in the light spectrum absorbed.

For the detection of the pedestrian three basic principles are defined in the literature:

- “Sliding-Window” approach
  In this approach a window of a predefined size is moved over the input picture. Every section is rated by a classifier in regards to containing a pedestrian or not. To assure the independency of the pedestrian to the size of the classifying window, the input picture is rescaled and tested until its dimension is smaller than the dimension of the detection window.
- Attribute point and part of body based approach
  The basic idea in this approach is to detect and identify individual body parts. The advantage of this approach is that it works quite well with obstructed objects.
- System orientated approach
  This approach bases on prior knowledge of the correct application in the automotive environment to construct a system. One example would be the assumption of an even area on which the car and the pedestrian are moving.

The maximum range of camera based systems is nowadays ranged to about 25 m. The main reason for this relatively short range is the decreasing detection quality of the pedestrian at low resolutions, which have to be increased.

Actuators

In the following passage a short overview of the actuators of a car with an EBA system will be given, thus the focus here was laid on the different braking actuators.

Hydraulic brake system

The main task of hydraulic systems is to decelerate the car respective to the driver will in a safe manner. Therefore a separation of the braking forces between the front and rear as well as the left and right side is needed. These systems also increase the force applied by the driver on the pedal to the needed amount at the wheel. With the invention of sensor supported and electronically controlled brake force modulators it has become possible to adjust the braking momentums for each wheel separately. The modulation occurs between the brake booster and the brake force generator.

The function of the brake system can be described as followed. The driver applies a force to the braking pedal. This force is boosted by a system and converted into hydraulic energy. The result from this is brake pressure and a volume flow which is separated into two main braking circuits.

Electro-mechanical brake system

The electro-mechanical brake system is a true brake-by-wire system which means that the driver's request is transferred completely by electric signals. One of the main advantages of this is that ADAS like the EBA system can completely take control of the brake system. Other advantages are for example smaller packaging, optimized control and no vibration in ABS mode.

The brake pedal signal is transferred by electric signals to the electro-mechanical brake system on the wheels. The brake force is generated directly at the wheels with an electric motor. This force is further transferred over a mechanical transmission to the brake linings. Due to safety reasons the electric system has to be redundant.

Hybrid system

The hybrid system is a combination of the hydraulic and the electro-mechanical brake system. The front axle contains a hydraulic system while the rear axle contains an electro-mechanical system. The main cause for this system is to bridge the time until the redundant system of the electro-mechanical system is completely developed.

2.4 Overview of the different testing methods

In this paragraph different projects for testing ADAS, especially EBA systems, will be analysed. Each institution has their own methods mostly based on researches in certain databases. The goal of this chapter is to give an overview of the methods used for gathering the accident data and of the different test scenarios derived from this.

2.4.1 ADAC

The German motoring club ADAC published in 2011 results from a test series that investigated Advanced Emergency Braking Systems (AEBS). The capability to reduce the driving speed as well as the effectiveness of the warning of an imminent collision was tested. Their conclusions are that a timely warning of the driver is better than an autonomous braking with unforeseeable consequences.

Also the systems reliability was tested. According to ADAC the user will not accept false alarms which may lead to a deactivation of the system by the user [29]. The following passage is based on [30].

Data

The ADAC accident research and analysis is based upon their own databank, especially accidents including assistance of the ADAC air rescue helicopter. About 95% of these accidents cause serious or fatal injuries.

In a study performed by ADAC it is shown that these kinds of accidents are very representative of crashes causing at least serious injuries. Rear impact injury scenarios, with at least one passenger car, were analysed to identify typical causes for those.

Test procedure

Effectiveness tests

The ADAC test consists of four basic scenarios of car to car crashes with some parameter variations each.

- Approaching a slow-moving object

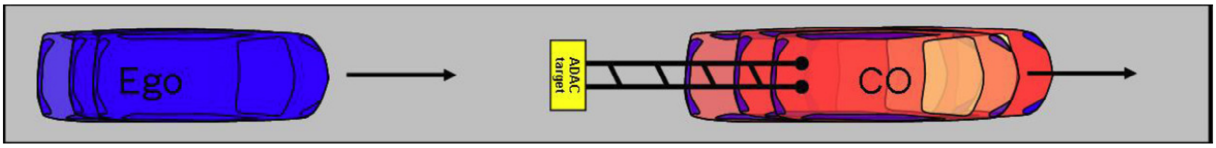

Figure 18 Approaching a slow-moving object [30]

Table 3 Approaching a slow-moving object parameters [30]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
B1_1	50	20	-	-	200
B1_2	100	60	-	-	200

- Approaching an object decelerating constantly

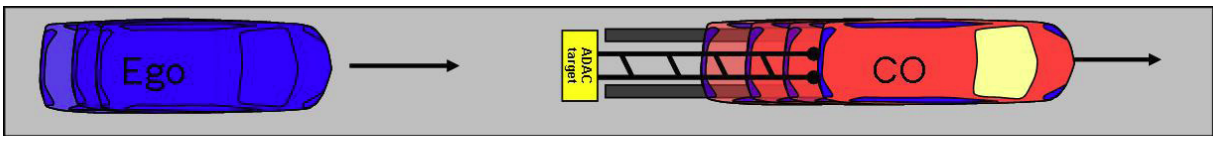

Figure 19 Approaching an object decelerating constantly [30]

Table 4 Approaching an object decelerating constantly[30]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
B2_1	60	60	-	-3	40

- Approaching an object which has come to a halt

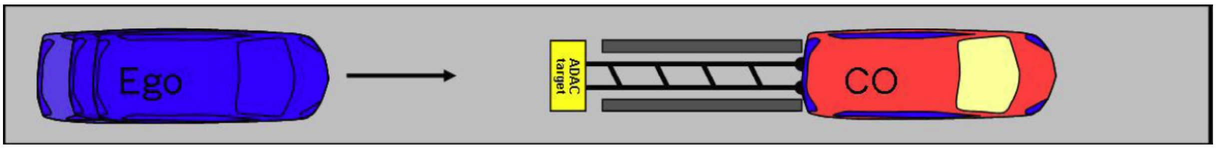

Figure 20 Approaching an object which has come to a halt[30]

Table 5 Approaching an object which has come to a halt [30]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
B3_1	50	40	-	-3	120

- Approaching a stationary object

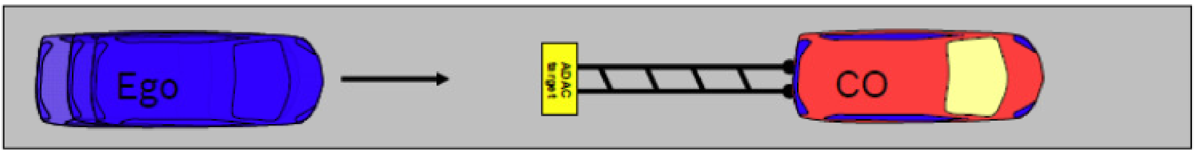

Figure 21 Approaching a stationary object [30]

Table 6 Approaching a stationary object [30]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
B4_1	20	0	-	-	250
B4_2	30	0	-	-	250
B4_3	40	0	-	-	250
B4_4	70	0	-	-	250

Misuse and reliability

False alarm may not only irritate the driver but may also lead to deactivation of the system by the driver if happening to often. The ADAC test procedure contains four misuse and reliability scenarios.

- Cornering

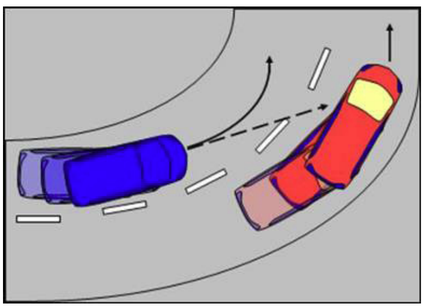

Figure 22 Fail operation test A1 – cornering [30]

Table 7 Cornering [30]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Curve radius [m]	Lane width [m]
A1	60 ± 3	30 ± 3	100 ± 10%	3.5

- Overtaking of moving traffic

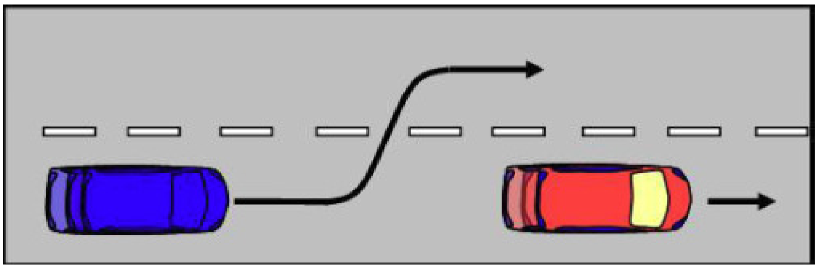

Figure 23 Fail operation test A2 – overtaking of moving traffic [30]

Table 8 Overtaking of moving traffic [30]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Initial distance [m]
A2	130 ± 3	90 ± 3	50 ± 10% behind the target vehicle, ego vehicle changes lane within 1 sec. Before changing lane, indicator light must be activated.

- Implausible braking

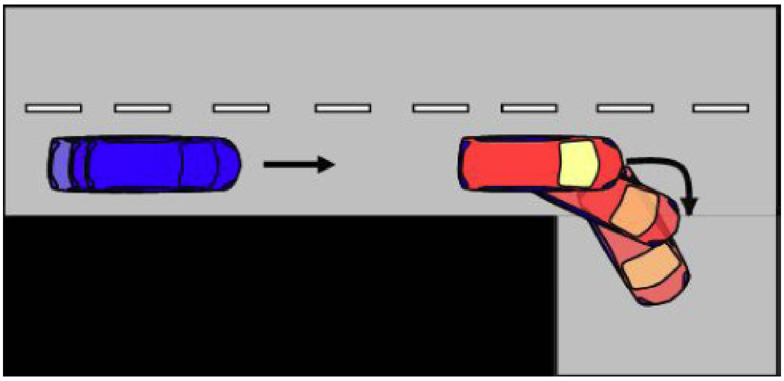

Figure 24 Fail operation test A3 – implausible braking [30]

Table 9 Implausible braking [30]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Initial distance [m]
A3	50 ± 3	50 ± 3	30 ± 10%

The target vehicle brakes from 50 km/h to 30 km/h in about 2 seconds (approximately -3 m/s²) before making a 90° turn. The indicator of the target vehicle must be turned on.

- Approaching a stationary object

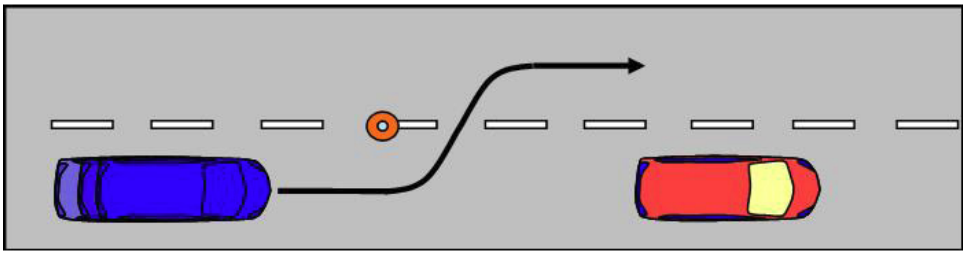

Figure 25 Fail operation test A4 – approaching a stationary object [30]

Table 10 Approaching a stationary object [30]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Initial distance [m]
A4	50 ± 3	0	30 ± 10% behind the target vehicle, ego vehicle changes lane within 1 sec. Before changing lane, indicator light must be activated.

Assessment

The assessment is carried out the following way [31]:

Effectiveness tests (80%)

- Speed reduction
- Time of first warning

Warning cascade

- Perceptibility
- Warning steps

Bonus/malus criteria

- Active break assist
- Safe distance warning
- False warnings/brake activation

2.4.2 RCAR (AEB group)

According to the AEB group their test procedures are based on real crash scenarios taking into account frequency and severity. They use data sources that include national statistics, in-depth investigation as well as insurance statistics [29].

Data

The data for the AEB group tests is based on two databases, the national accident database STATS 19 (2008) and the in-depth database OTS (2000-2009). The method used for moving from the accident data to formulation of accident scenarios is a cluster analysis, which is described in detail in [32].

Test scenarios

The AEB group test consists of 3 main scenarios, city, urban and pedestrian which are further divided into sub-scenarios [33].

City

- Approaching a stopped vehicle at test speeds from 10 to 60km/h

Figure 26 Approaching a stopped vehicle at test speeds from 10 to 60km/h [33]

Table 11 Approaching a stopped vehicle at test speeds from 10 to 60km/h [33]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
CCR1	10-60	0	-	-	-

In the CCR1 test the speed is increased in 10km/h increments if the system avoids a collision with the target car. The speed is increased in 5km/h increments if collision occurs.

- Approaching at 10km/h a car stationary at a junction

Figure 27 Approaching at 10km/h a car stationary at a junction [33]

Table 12 Approaching at 10km/h a car stationary at a junction [33]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
CCR2	10	0	-	-	-

The target car is positioned in a range of angels between 0-45 degrees.

Urban

- Approaching a moving target at 20km/h

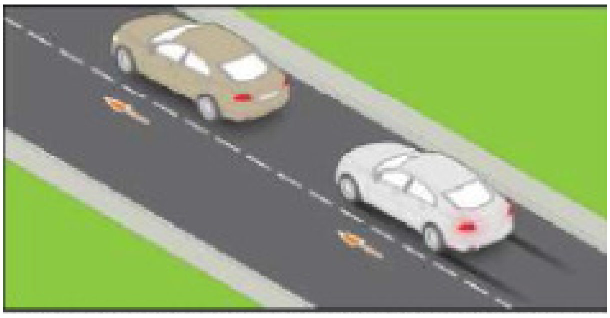

Figure 28 Approaching a moving target at 20km/h [33]

Table 13 Approaching a moving target at 20km/h [33]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
CCR3	30-...	20	-	-	-

Speed differential is starting at 10km/h and increased in 10km/h increments if the system avoids a collision with the target car. The speed is increased in 5km/h increments if a collision occurs.

- Approaching a decelerating target, both initially moving at 50km/h

Figure 29 Approaching a decelerating target, both initially moving at 50km/h [33]

Table 14 Approaching a decelerating target, both initially moving at 50km/h [33]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
CCR4	50	50	-	-2	12
CCR4	50	50	-	-6	12
CCR4	50	50	-	-2	40
CCR4	50	50	-	-6	40

Pedestrian

- Unobscured pedestrian walks out from nearside

Figure 30 Unobscured pedestrian walks out from nearside [33]

Table 15 Unobscured pedestrian walks out from nearside [33]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
CP1	10-60	-	-	-	-

For this test there are two versions, a pedestrian at centre and quarter width of the vehicle front. The speed is increased in 10km/h increments if the system avoids collision. Speed increased in 5km/h increments if a collision occurs.

- Obscured pedestrian walks out from nearside

Figure 31 Obscured pedestrian walks out from nearside [33]

Table 16 Obscured pedestrian walks out from nearside [33]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
CP2	30	-	-	-	-
CP2	50	-	-	-	-

- Unobscured pedestrian runs out in front of car from far side

Figure 32 Unobscured pedestrian runs out in front of car from far side [33]

Table 17 Unobscured pedestrian runs out in front of car from far side [33]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
CP3	40	-	-	-	-
CP3	60	-	-	-	-

- Pedestrian walking along the road at night

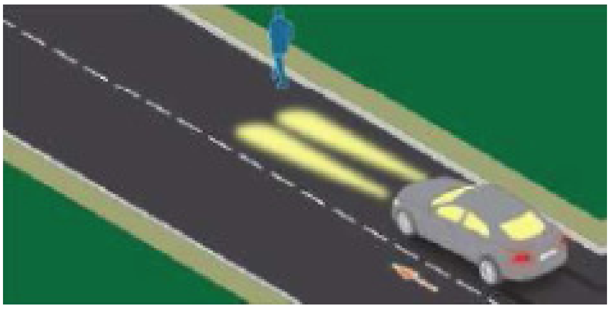

Figure 33 Pedestrian walking along the road at night [33]

Table 18 Pedestrian walking along the road at night [33]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
CP4	50	-	-	-	-
CP4	70	-	-	-	-

- Car turns at junction and pedestrian walks out

Figure 34 Car turns at junction and pedestrian walks out [33]

Table 19 Car turns at junction and pedestrian walks out [33]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
CP5	15	-	-	-	-
CP5	25	-	-	-	-

2.4.3 ASPECSS

The focus of ASPECSS lies on the protection of vulnerable road users, especially pedestrians. The main goal is the development of harmonised test and assessment procedures for the assessment of integrated pedestrian safety systems [34].

Data

The approach of ASPECSS is based on European car-to-pedestrian accident data analyses and consists of three parts. The first part is a review of accident and test scenarios and weighting factors developed by previous projects. The second part is analysis of accident data and the third part is an extrapolation and development of weighting factors for the EU-27.The data used for the second part of ASPECSS is based on analyses of high level national data and in-depth data from Germany, Great Britain and France.

From the review of former EU projects, namely APROSYS, the AEB test group and the vFSS group, initial base line scenarios were proposed. For development of definite scenarios and weighting factors further analyses of in-depth and national statistics of Germany, Great Britain and France were performed. After this, the national accident data was used for extrapolation to the EU-27 countries [35].

Test scenarios

From the data collected three base test scenarios have been developed [36].

- Child crosses from near-side behind an obstruction

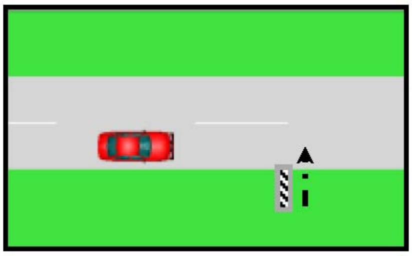

Figure 35 Child crosses from near-side behind an obstruction [37]

Table 20 Child crosses from near-side behind an obstruction [36]

Test version	Speed ego vehicle [km/h]	Speed pedestrian [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
TS1	10-60	5	-	-	-
TS1	10-60	8	-	-	-

Obstruction by a parking car as defined in the AEB group tests. The impact point on the vehicle front is varied on 25%, 50% and 75%.

- Elderly crosses from far side

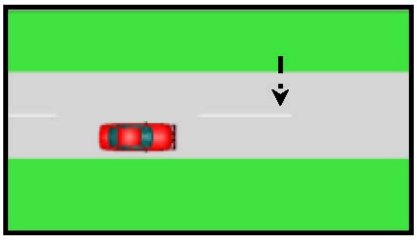

Figure 36 Elderly crosses from far side [37]

Table 21 Elderly crosses from far side [36]

Test version	Speed ego vehicle [km/h]	Speed pedestrian [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
TS2a	10-60	3	-	-	-

Obstruction by a parking car as defined in the AEB group tests. The impact point on the vehicle front is varied on 25%, 50% and 75%.

- Adult crosses from far-side

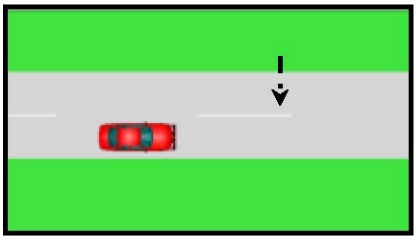

Figure 37 Adult crosses from far-side [37]

Table 22 Adult crosses from far-side [36]

Test version	Speed ego vehicle [km/h]	Speed pedestrian [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
TS3a	10-60	5	-	-	-
TS3a	10-60	8	-	-	-

Obstruction by a parking car as defined in the AEB group tests. The impact point on the vehicle front is varied on 25%, 50% and 75%.

2.4.4 ASSESS

The goal of the ASSESS project is to develop a set of test and assessment methods for a wide range of integrated vehicle systems in the longitudinal domain. More precisely pre-crash sensing performance and crash performance under conditions influenced by the driver are researched [29].

Data

The first step of the ASSESS project was an analysis of previous projects, namely APROSYS, AEBS project, PReVENT, PreVAL, TRACE, eIMPACT, CHAMELEON, SAFETY TECHNOPRO and eVALUE. The result of this was that the most promising assessment method for ASSESS is close to the approach defined in APROSYS, but the problem was that most of these previous projects did not perform relevant accident analyses, except TRACE and eIMPACT. So ASSESS benefited from the work of those two and used their data for an overview on the event of the accident on EU level. In the end the accident analysis of eIMPACT, the scenarios of CHAMELEON and the assessment flow chart from APROSYS were used in combination with results of ASSESS WP1 as a basis for the later ASSESS WPs. Further, results from Naturalistic Driving Studies (NDS) and Field Operational Tests (FOT) were used for ASSESS purposes. These were a 100 car NDS, the Integrated Vehicle-Based Safety Systems FOT (IVBSS), the Sweden Michigan FOT (SeMiFOT) and the large-scale European FOT (euroFOT).

The accident data analysis was performed by using national accident data from Germany and Sweden and also in-depth data from Germany and UK to get the required level of detail. There was also the aim of using the European accident database CARE for comparison, but due to the low level of detail in CARE this was not practical [38].

Test scenarios

The focus for ASSESS internal testing lies on the test scenario A with its sub-scenarios. Scenarios B, C and D are not tested within ASSESS as the systems in cars are not ready yet [39, 40]. Since this work focuses on rear end and pedestrian collisions, they are not reviewed here.

- Manoeuvre A1: Slower lead vehicle:

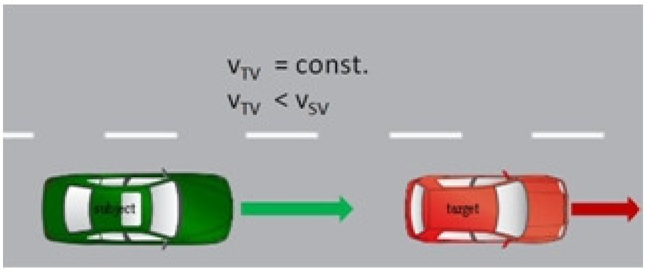

Figure 38 Slower lead vehicle [41]

Table 23 Slower lead vehicle [40]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [TTC]
A1A	50	10	-	-	TTC>>3s
A1B	50	10	-	-	TTC>>3s
A1C	100	20	-	-	TTC>>3s

- Manoeuvre A2: Decelerating lead vehicle (until stopped)

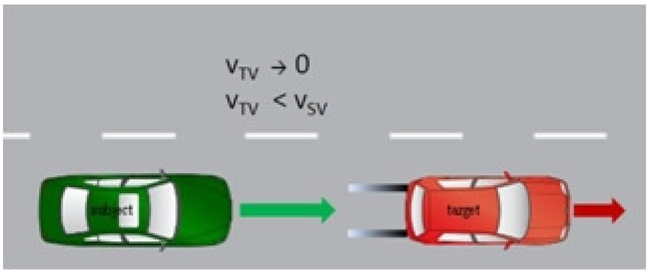

Figure 39 Decelerating lead vehicle (until stopped) [41]

Table 24 Decelerating lead vehicle (until stopped) [40]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
A2A	50	50	-	-4	14
A2B	50	50	-	-7	14
A2C	80	80	-	-4	45
A2D	80	80	-	-7	45

This scenario is performed with no lateral offset. Each test is performed with no driver reaction, with slow driver reaction and with fast driver reaction.

- Manoeuvre A3: Stopped lead vehicle

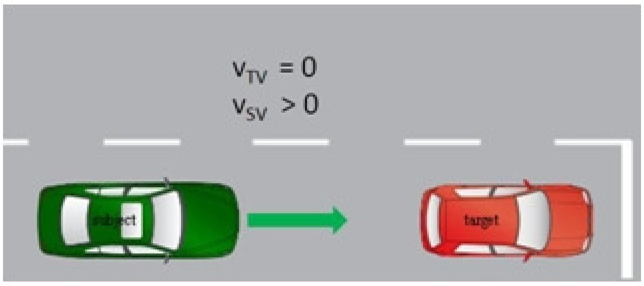

Figure 40 Stopped lead vehicle [41]

Table 25 Stopped lead vehicle [40]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [TTC]
A3A	50	0	-	-	TTC>>3s
A3B	50	0	-	-	TTC>>3s
A3C	80	0	-	-	TTC>>3s

A3A and A3C are performed with no lateral offset while A3B has 50% lateral offset. Each test is performed with no driver reaction, with slow driver reaction and with fast driver reaction.

2.4.5 NCAP

Data

For the Euro NCAP there is very little information on the methods used for creating the different accident scenarios. However the scenarios are already fixed and designated to start with the tests in 2014.

Test scenarios

There are two main scenarios, AEB City and AEB Inter Urban which will be tested. The AEB Inter Urban scenario is further divided into three sub-scenarios [42].

AEB City

- Approach to stationary target

Figure 41 Approach to stationary target [42]

Table 26 Approach to stationary target [42]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Point for Accident Avoidance (P_{AA})	Acceleration target vehicle [m/s²]	Initial distance [m]
-	10	0	1	-	-
-	15	0	2	-	-
-	20	0	2	-	-
-	25	0	2	-	-
-	30	0	2	-	-
-	35	0	2	-	-
-	40	0	1	-	-
-	45	0	1	-	-
-	50	0	1	-	-

Prequisites for scoring in AEB City:

- Minimum 1.5 points (out of 2) from the whiplash assessment of front seats
- Up to 20 km/h accidents must be completely avoided

For the speed of the ego vehicle being higher than 20 km/h, accident mitigation is rewarded. The score is calculated from the remaining impact velocity v_I.

$$P_{AA} \cdot (\frac{v_{ego} - v_I}{v_{ego}})$$

Example: At v_{ego}= 30 km/h the target is impacted at a velocity of v_I= 10 km/h:

$$2 \cdot \left(\frac{30 - 10}{30}\right) = 1.333\ Points$$

The raw score of maximum 14 points is scaled down to a maximum of 3 points and is part of the Adult Occupant assessment.

AEB Inter Urban

- Approach to stationary target

Figure 42 Approach to stationary target [42]

Table 27 Approach to stationary target [42]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Points for Collision Warning	Acceleration target vehicle [m/s²]	Initial distance [m]
-	30	0	2	-	-
-	35	0	2	-	-
-	40	0	2	-	-
-	45	0	2	-	-
-	50	0	3	-	-
-	55	0	2	-	-
-	60	0	1	-	-
-	65	0	1	-	-
-	70	0	1	-	-
-	75	0	1	-	-
-	80	0	1	-	-

- Approach to slower target

Figure 43 Approach to slower target [42]

Table 28 Approach to slower target [42]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Points for Collision Warning	Point for Accident Avoidance (P_{AA})	Acceleration target vehicle [m/s²]	Initial distance [m]
-	30	20	1	1	-	-
-	35	20	1	1	-	-
-	40	20	1	1	-	-
-	45	20	1	1	-	-
-	50	20	1	1	-	-
-	55	20	1	1	-	-
-	60	20	1	1	-	-
-	65	20	2	2	-	-
-	70	20	2	2	-	-
-	75	20	2	-	-	-
-	80	20	2	-	-	-

- Approach to braking target

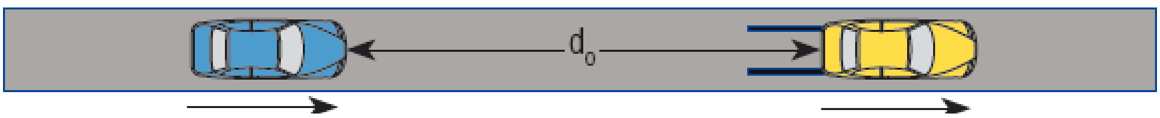

Figure 44 Approach to braking target [42]

Table 29 Approach to braking target [42]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Points for Collision Warning	Point for Accident Avoidance (P_{AA})	Acceleration target vehicle [m/s²]	Initial distance [m]
-	50	50	1	1	-2	12
-	50	50	1	1	-2	40
-	50	50	1	1	-6	12
-	50	50	1	1	-6	40

The raw score is again scaled down to a maximum of 3 points and is part of the Safety Assist assessment. The weighting of the scenarios is to be decided.

2.4.6 CAMP

As a sub-project of the Crash Avoidance Metrics Partnership (CAMP) the Crash Imminent Braking (CIB) consortium is investigating “Objective Tests for Imminent Crash Automatic Braking Systems”. The goal of this project is to define minimum performance requirements and objective tests for crash imminent braking systems and to assess the harm reduction potential of various systems and their configurations [29].

Data

The analysis of the crash data was separated into two phases, one of them being a top-down analysis of the National Automotive Sampling System (NASS) including the Crashworthiness DATA System (CDS), General Estimates System (GES) and Fatality Analysis Reporting System (FARS). This was done to define the scope of overall crash problems and to identify the main crash scenarios for further investigation.

The different databases contain very different levels of details referring to the crash situations. For example the NASS-GES contains the highest number of cases but with very little detail, it was used to show national trends in accidents, while FARS had to be considered including the fatal crashes. NASS-CDS contains also very little cases an refers only to towed vehicles but with its relative high detail it provided initial information for phase two, bottom-up analysis.

In this phase the individual crash cases were reviewed in detail in order to get representative crash scenarios for further studies. Since the previously mentioned databases did not contain sufficient information-depth, the studies were supplemented with Electronic Data Recorder (EDR) information, German In-Depth Accident Study (GIDAS) data and Field Operational Test (FOT) data. The Pedestrian Crash Data Study (PCDS) database was added due to the fact that during the top-down analysis a rather high number of accidents including pedestrians had been noted [43].

Test scenarios

In CAMP a rear end scenario has been developed with three sub-scenarios, but there is no further information on the parameters of the tests.

Rear end

- Lead Vehicle Stopped (LVS)

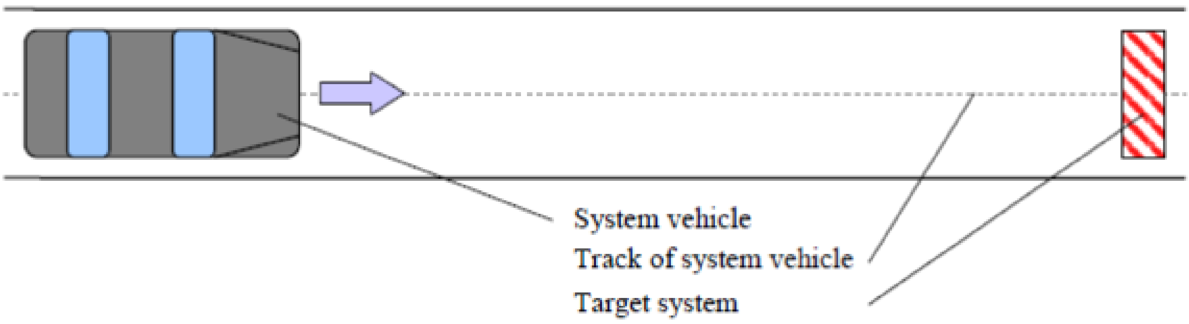

Figure 45 Lead Vehicle Stopped (LVS) [43]

- Lead Vehicle Moving (LVM)

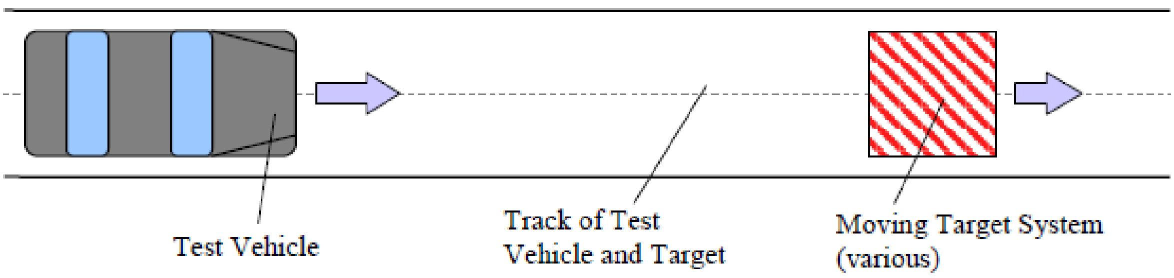

Figure 46 Lead Vehicle Moving (LVM) [43]

- Lead Vehicle Decelerating (LVD)

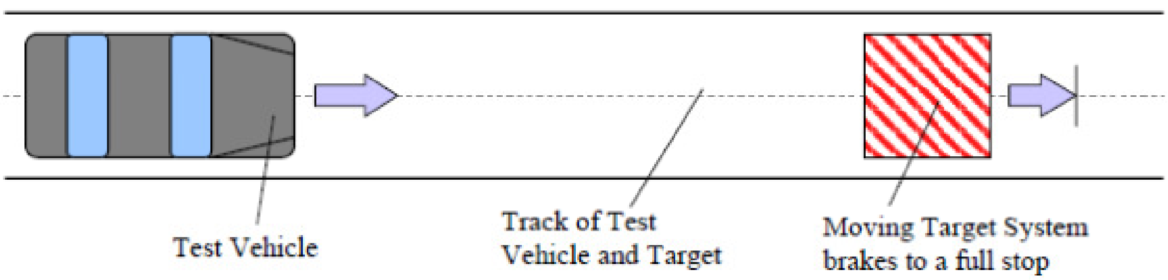

Figure 47 Lead Vehicle Decelerating (LVD) [43]

There are also some test that were not validated at the time the CAMP project finished, these can be seen in [43].

2.4.7 eValue

The eValue project developed test scenarios for different driver assistance systems. Three clusters had been defined, each of them standing for one type of safety system [44].

- Cluster 1 safety systems: longitudinal control
- Cluster 2 safety systems: lateral control
- Cluster 3 safety systems: stability control

This work will focus on the results from Cluster 1 since the emphasis is on rear end and pedestrian collisions.

Data

The data used for defining the scenarios is mainly based on accident statistics and research performed by other projects. There is only very little information on the methods used for gaining this data, therefore only the results for each scenario will be stated in the following paragraphs.

Based on accident statistics from the year 2006 or 2007 rear end collisions represent about 15% in Germany, 18% in Italy, 14% in Spain and 15% in Sweden of all accidents, while collisions with stationary objects represent 7%, 8% and 3% of total accidents in Germany Italy and Spain. In Spain 30% of the rural accidents occur in a curve, while the number in urban areas is much lower, about 5%. In Germany curves are the third most common place of accidents with 16% of all accidents.

Frontal-lateral collisions represent a number of 36% and 27% of all accidents in Italy and Spain. In Germany, Italy, Spain and Sweden collisions with pedestrians represent 9%, 8%, 11% and 9% of the total accidents [44].

Test scenarios

Two basic test scenarios were defined in eValue for longitudinal safety systems, a rear end collision scenario and a scenario with a transversally moving target. Each of the tests is performed with three different driver settings:

- Passive driver: no reaction at all
- Driver brakes mildly: after 1.5 seconds a force of 350 N is applied within 0.4 seconds to the braking pedal
- Driver brakes strongly: after 1 second a force of 700 N is applied within 0.2 seconds to the braking pedal

The information on the rear end collision and transversally moving target scenarios was taken from [45].

Rear end collision

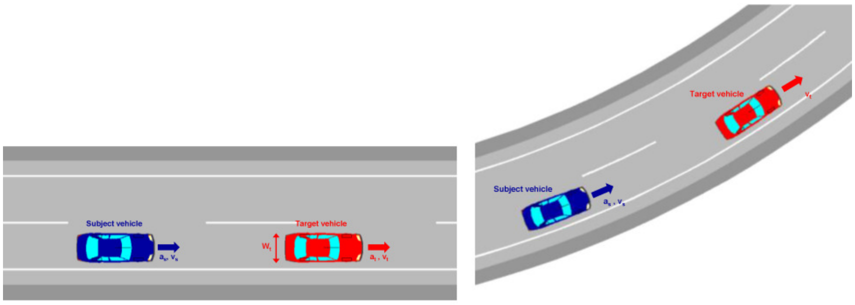

Figure 48 Rear end collision scenarios [45]

- Approach to stationary target

Table 30 Approach to stationary target [45]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Road-layout	Acceleration target vehicle [m/s²]	Initial distance [m]
1.1	50	0	Straight	-	150
1.2	70	0	Straight	-	150
1.7	50	0	Left curve	-	150
1.8	50	0	Right curve	-	150

- Approach to moving target

Table 31 Approach to moving target [45]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Road-layout	Acceleration target vehicle [m/s²]	Initial distance [m]
1.3	70	30	Straight	-	100
1.4	70	50	Straight	-	100
1.9	70	30	Left curve	-	100
1.10	70	30	Right curve	-	100

- Approach a decelerating target

Table 32 Approach a decelerating target [45]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Road-layout	Acceleration target vehicle [m/s²]	Initial distance [m]
1.5	70	70	Straight	-3	40
1.6	70	70	Straight	-5	40
1.11	70	70	Left curve	-5	40
1.12	70	70	Right curve	-5	40

Transversally moving target

- Car to car collision

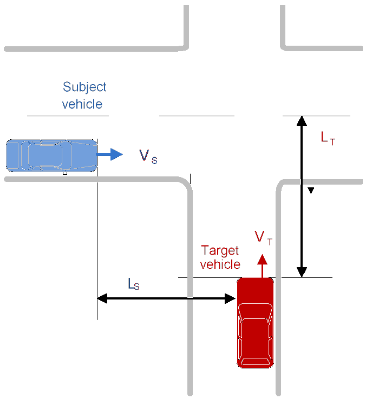

Figure 49 Transversal car to car collision [45]

Table 33 Transversal car to car collision [45]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	L_T [m]	Acceleration target vehicle [m/s²]	Initial distance [m]
1.1	30	15	15	-	30
1.2	30	30	15	-	30
1.3	50	30	30	-	50

- Car to pedestrian collision

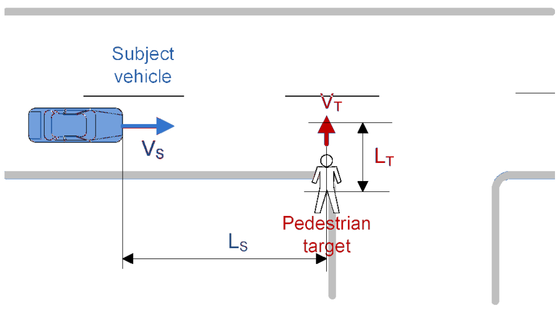

Figure 50 Car to pedestrian collision [45]

Table 34 Car to pedestrian collision [45]

Test version	Speed ego vehicle [km/h]	Speed target [km/h]	L_T [m]	Acceleration target vehicle [m/s²]	Initial distance [m]
1.4	15	5	5	-	15
1.5	30	5	5	-	30
1.6	50	5	5	-	30

2.4.8 vFSS

The aim of vFSS is the development of test procedures for driver assistance systems, especially emergency brake assistance systems. It is based on accident analyses and contains also pedestrian safety issues [29].

Data

There is very little information on the accident research performed by vFSS due to the lack of availability of deliverables. In [37] the following accident statistics research results are stated.

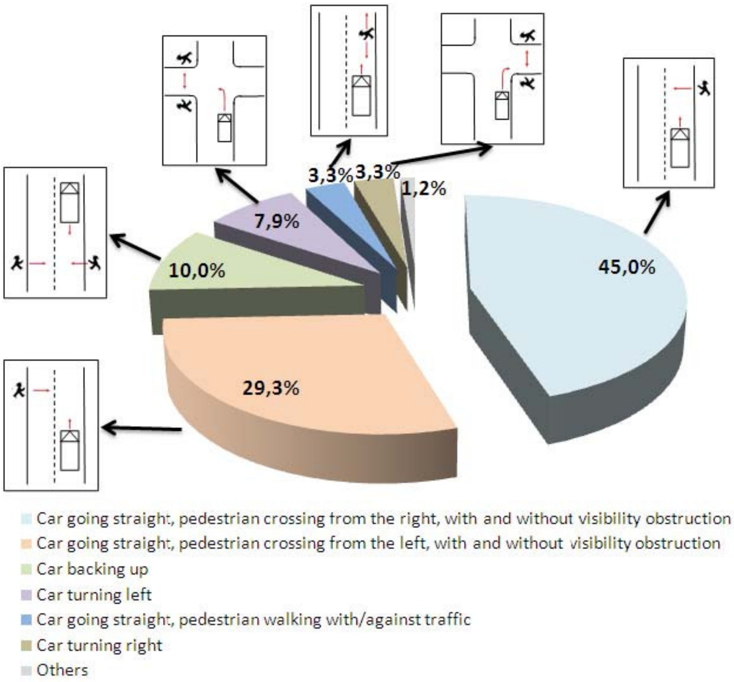

Figure 51 Distribution of scenarios [37]

Therefore the conclusion had been made by vFSS that the most relevant cases are pedestrians crossing and car going straight scenarios.

Test scenarios [37]

The two main topics handled in vFSS are pedestrian accidents and car to car accidents in longitudinal traffic.

Pedestrian

- Adult crossing from the right

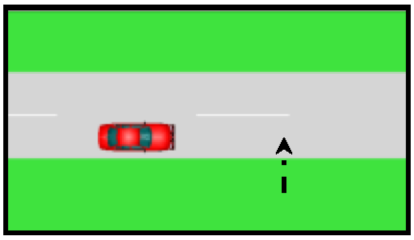

Figure 52 Adult crossing from the right [37]

Table 35 Adult crossing from the right [37]

Test version	Speed ego vehicle [km/h]	Speed pedestrian [km/h]	Acceleration ego vehicle [m/s²]	Lighting condition	Initial distance [m]
S1	45-50	5	Braking	Daylight	-

- Child crossing from the left

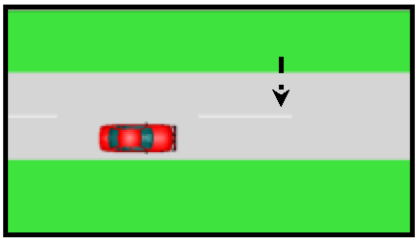

Figure 53 Child crossing from the left [37]

Table 36 Child crossing from the left [37]

Test version	Speed ego vehicle [km/h]	Speed pedestrian [km/h]	Acceleration ego vehicle [m/s²]	Lighting condition	Initial distance [m]
S2	55-60	8-10	Braking	Night	-

- Child crossing from the right.

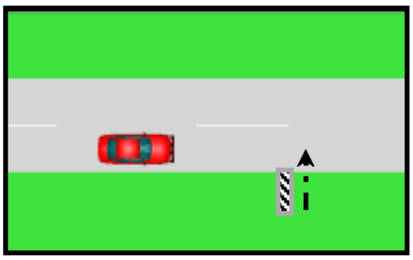

Figure 54 Child crossing from the right [37]

Table 37 Child crossing from the right [37]

Test version	Speed ego vehicle [km/h]	Speed pedestrian [km/h]	Acceleration ego vehicle [m/s²]	Lighting condition	Initial distance [m]
S5	45-50	8-10	Braking	Night	-

- Adult crossing from the right (left turn)

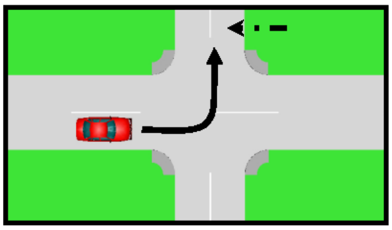

Figure 55 Adult crossing from the right (left turn) [37]

Table 38 Adult crossing from the right (left turn) [37]

Test version	Speed ego vehicle [km/h]	Speed pedestrian [km/h]	Acceleration ego vehicle [m/s²]	Lighting condition	Initial distance [m]
S3	20-25	5	Braking	-	-

- Adult crossing from the right (right turn)

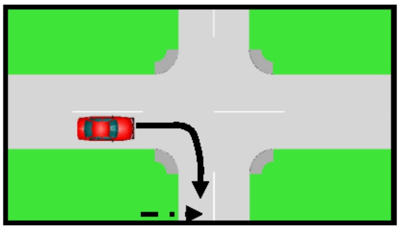

Figure 56 Adult crossing from the right (right turn) [37]

Table 39 Adult crossing from the right (right turn) [37]

Test version	Speed ego vehicle [km/h]	Speed pedestrian [km/h]	Acceleration ego vehicle [m/s²]	Lighting condition	Initial distance [m]
S4	10-15	5	Braking	-	-

Car to car

- Test procedures FCW (proposal)

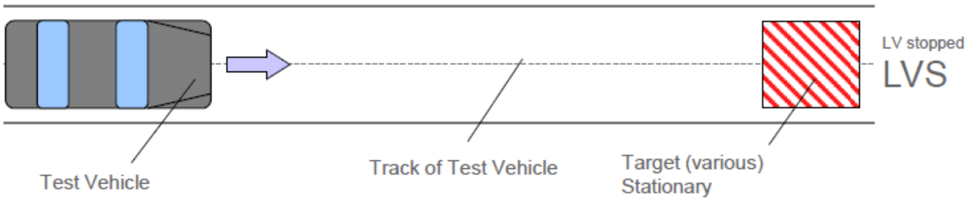

Figure 57 Test procedures FCW (proposal) LVS [37]

Table 40 Test procedures FCW (proposal) LVS [37]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
1	72	0	-	-	-

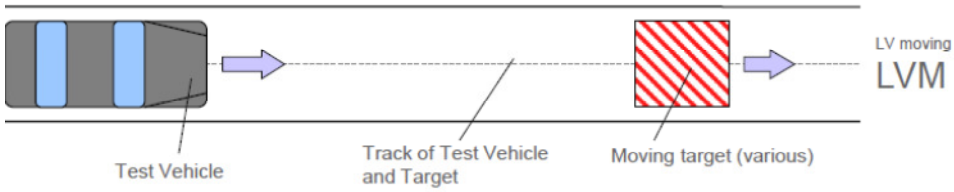

Figure 58 Test procedures FCW (proposal) LVM [37]

Table 41 Test procedures FCW (proposal) LVM [37]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
2	72	32	-	-	-

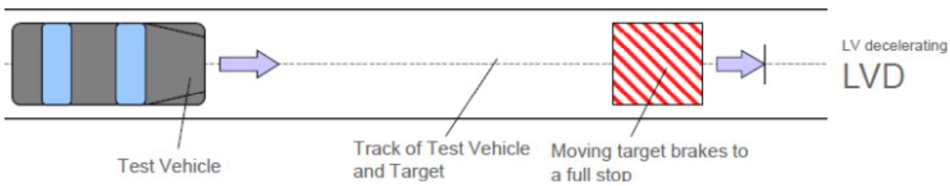

Figure 59 Test procedures FCW (proposal) LVD [37]

Table 42 Test procedures FCW (proposal) LVD [37]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
3	72	72	-	-2.9	-

- Test procedures AEB (proposal)

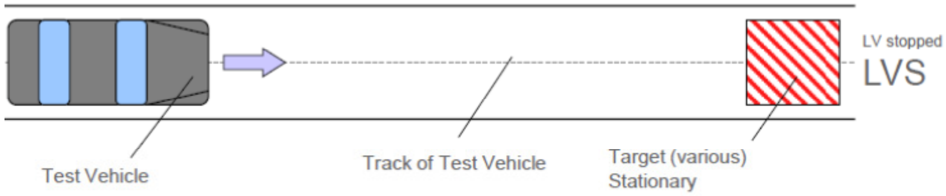

Figure 60 Test procedures AEB (proposal) LVS [37]

Table 43 Test procedures AEB (proposal) LVS [37]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
1a	25	0	-	-	-
1b	50	0	-	-	-

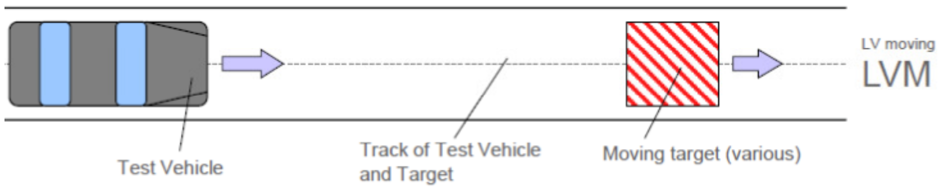

Figure 61 Test procedures AEB (proposal) LVM [37]

Table 44 Test procedures AEB (proposal) LVM [37]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
2	90	50	-	-	-

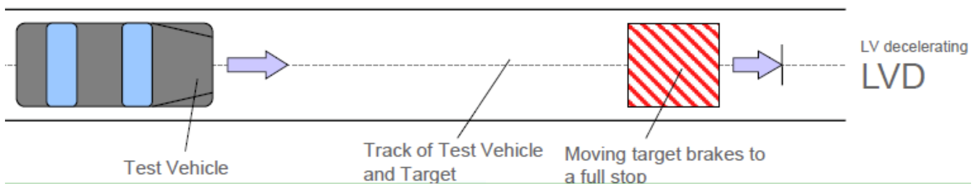

Figure 62 Test procedures AEB (proposal) LVD [37]

Table 45 Test procedures AEB (proposal) LVD [37]

Test version	Speed ego vehicle [km/h]	Speed target vehicle [km/h]	Acceleration ego vehicle [m/s²]	Acceleration target vehicle [m/s²]	Initial distance [m]
3	50	50	-	-6.2	-

In the following chapter the methodology used for creating the basic scenarios and deriving of the needed parameters is explained. Further it contains a description of how the parameters were combined to the final resulting scenarios which can be generated with the scenario generator.

3 Methodology

3.1 Development environment

As mentioned in chapter 1.4.2, the scenario generator will be implemented into the current project of the ViF. To be exact the generator will be implemented before the first phase, “Accident Scenario Definition”, of the method described in [14], as shown in Figure 63 below on a pedestrian collision example. This phase represents the pre-crash phase and ends with the first contact of the pedestrian with the car.

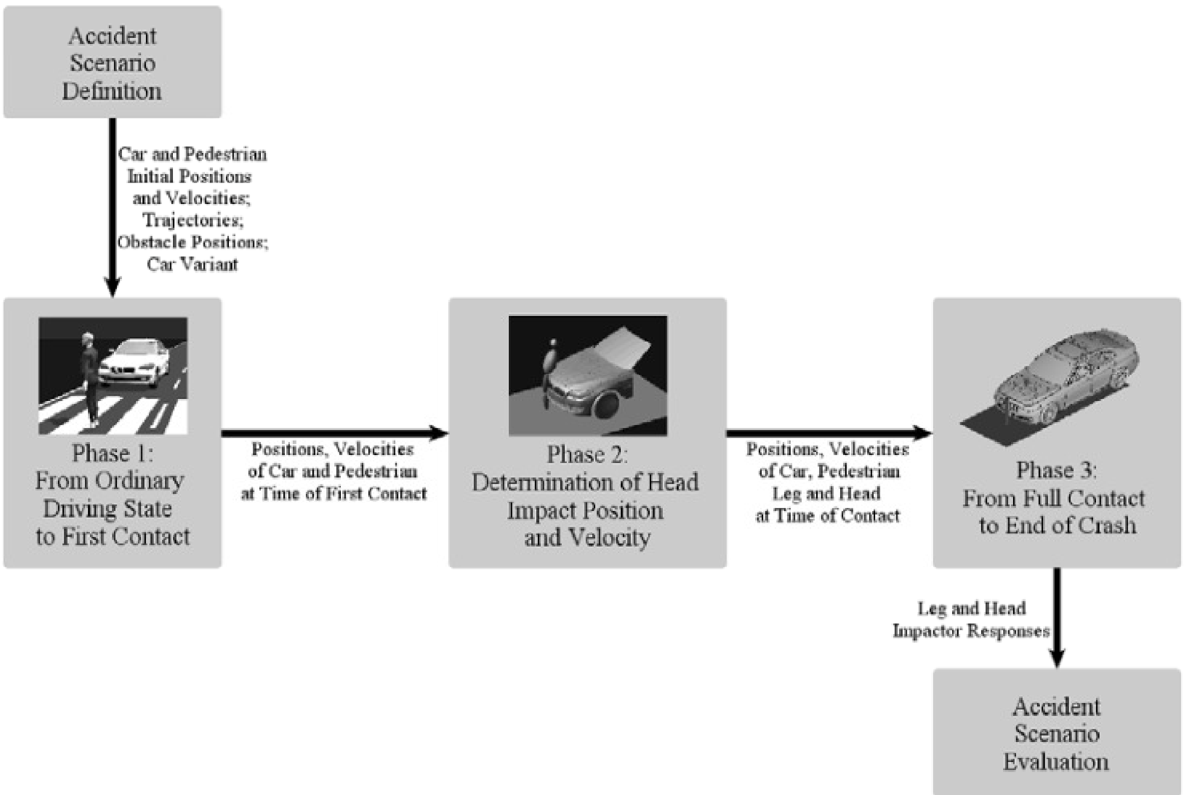

Figure 63 Simulation schedule for car to pedestrian accident scenario [14]

3.2 Generating a manoeuvre catalogue from other projects

The first step in the process of developing scenarios was a research on other projects and their methods. The projects chosen for this were the ADAC, AEB, AsPeCSS, ASSESS, Beyond NCAP, CAMP, eValue and vFSS as described in chapter 2.4 of this work. The goal of this step was to get an overview of the current testing methods and approaches for active safety systems, especially EBA systems. Also their methods for getting the parameters for the scenarios were examined. The results of this have already been stated in chapter 2.4.

The conclusion of this is that the most common scenarios in car to car rear end crashes are two cars in longitudinal motion with three sub-scenarios where,

- The ego car is moving at constant speed and the target car is moving constantly at a slower speed (c2c_tcm);
- The ego car is moving at constant speed while the target car starts with a certain driving speed and begins to decelerate constantly (c2c_tcd);
- The ego car is moving at constant speed and the target car is stopped (c2c_tcs).

There are also some scenarios at intersections in the tests but the decision was made to only concentrate on the scenarios in longitudinal motion due to the scope of this work and its focus on rear end collisions and car to pedestrian collisions.

Concerning the pedestrian collision the focus was set also on collisions in longitudinal moving of the car. This led to the main pedestrian scenario considered in this work:

- Obstructed/unobstructed pedestrian crossing from near/far side (ped_ob/un_ns/fs),
- Pedestrian walks along the road (ped_al).

The pedestrian scenarios at intersections were not considered in this work.

After getting the scenarios and their basic settings from the previous projects, more information on the different parameters was needed. Therefore initially the most important parameters used and varied in the different testing procedures had to be identified. The results from this are stated in the next paragraph.

The diagrams show the distribution of the parameters. The parameters are put into classes, meaning that one class contains all the values of the parameter between the next lower class and its own value For example in Figure 64 the class 30 km/h shows all the speed between 21 and 30 km/h, class 40 km/h shows the speed between 31 and 40 km/h and so on.

3.2.1 Car to car collision

Moving target car (c2c_tcm)

The projects with relevant data for this scenario were, ADAC, AEB, ASSESS, vFSS, eValue and NCAP.

- v_{ego}, which is the driving speed of the ego car
- v_{target}, which is the driving speed of the target car
- Distance, which is the initial distance at the start of the test
- Δv, which is the resulting speed difference calculated from the v_{ego} and the v_{target} at the start of the test

The results from this analysis are displayed in the following graphs.

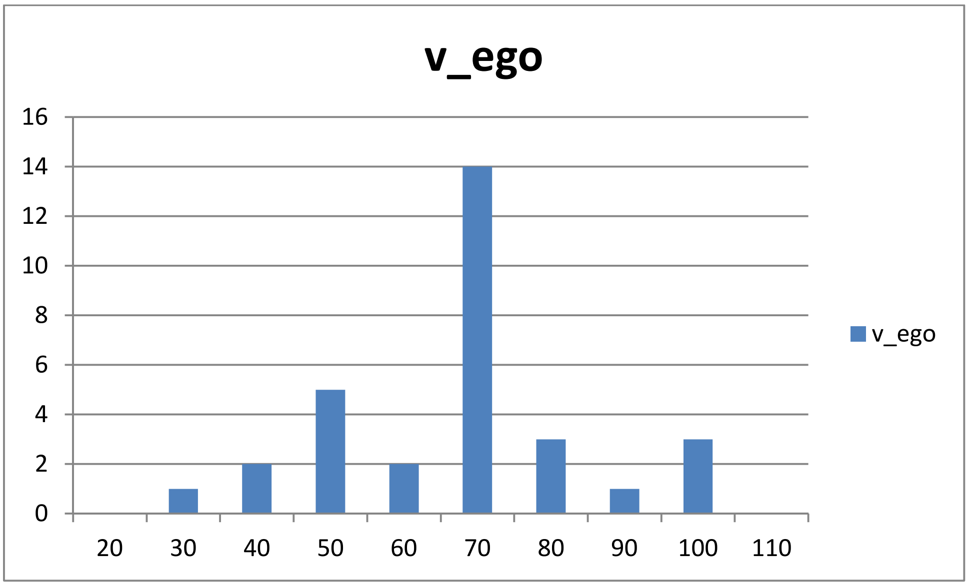

Figure 64 Moving target car (c2c_tcm) v_{ego}

As shown in Figure 64 the most common testing speed in the reviewed scenarios is between 60 and 70 km/h.

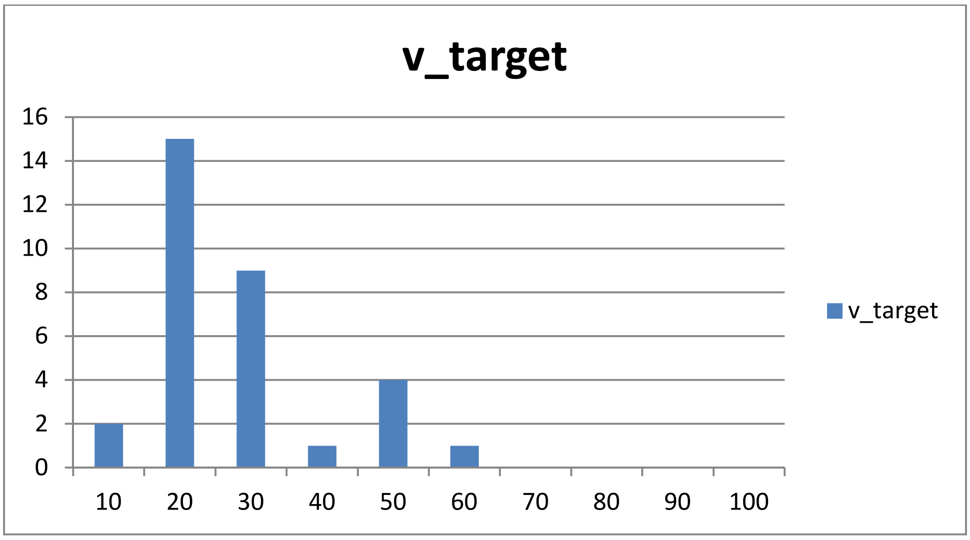

Figure 65 Moving target car (c2c_tcm) v_{target}

Concerning the target speed two classes show high significance, the class between 10 and 20 km/h and the one between 20 and 30 km/h, Figure 65.

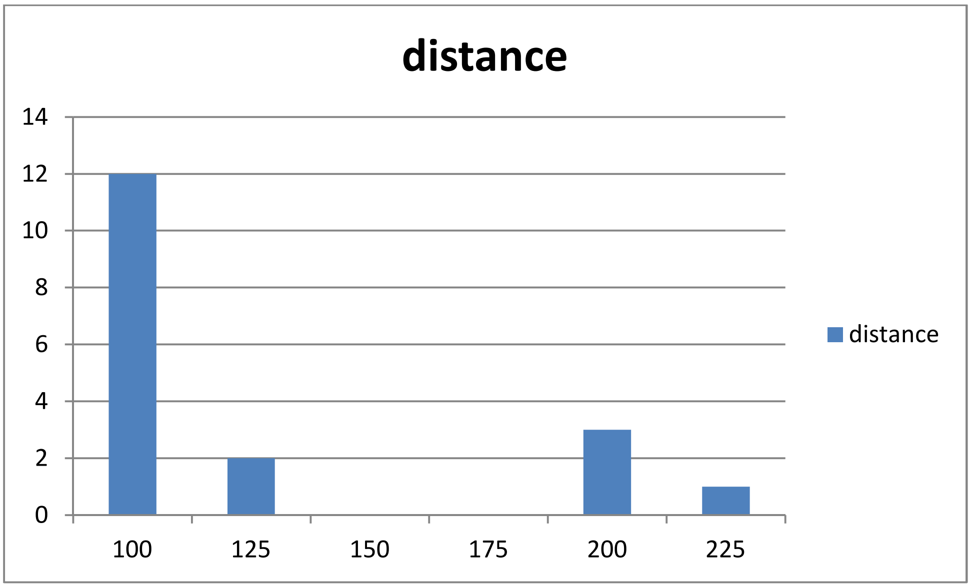

Figure 66 Moving target car (c2c_tcm) distance

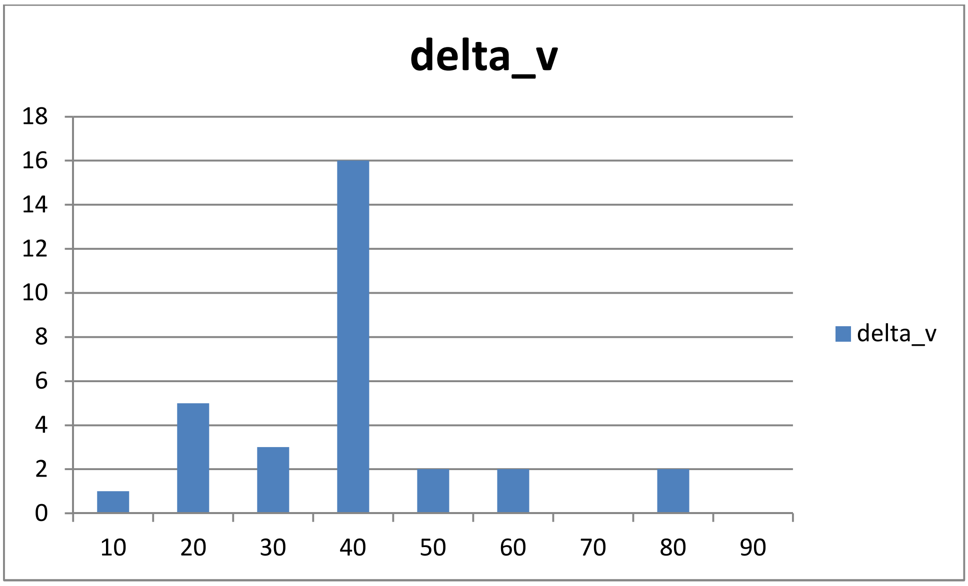

Figure 67 Moving target car (c2c_tcm) Δv

The initial distance is mainly in the class of 0 to 100 meters, and the resulting Δv is between 30 and 40 km/h, Figure 66 and Figure 67.

Decelerating target car (c2c_tcd)

The projects containing this data were ADAC, AEB, ASSESS, vFSS, eValue and NCAP.

The most relevant variables were

- deceleration target car,
- distance, which is the initial distance at the start of the test.

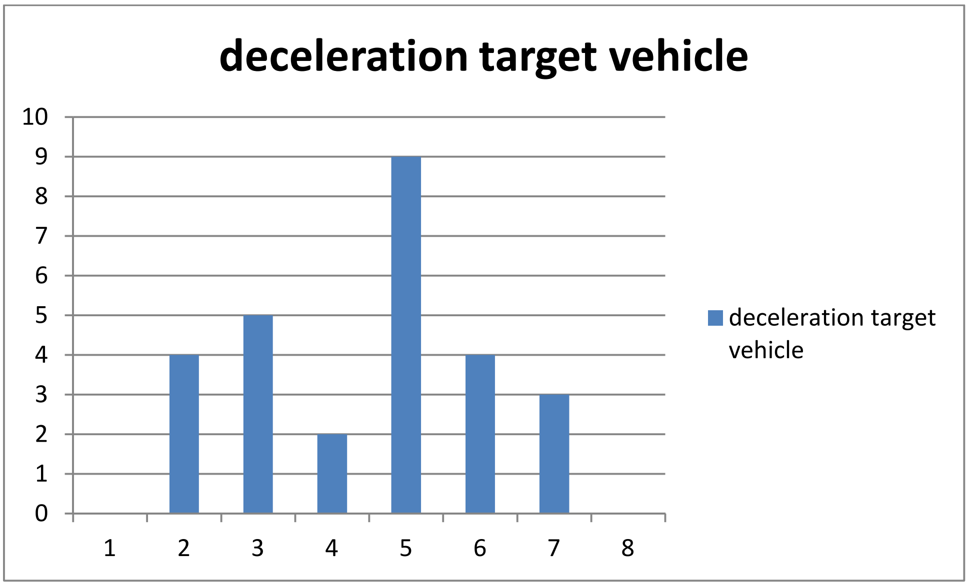

Figure 68 Decelerating target car (c2c_tcd) deceleration target car

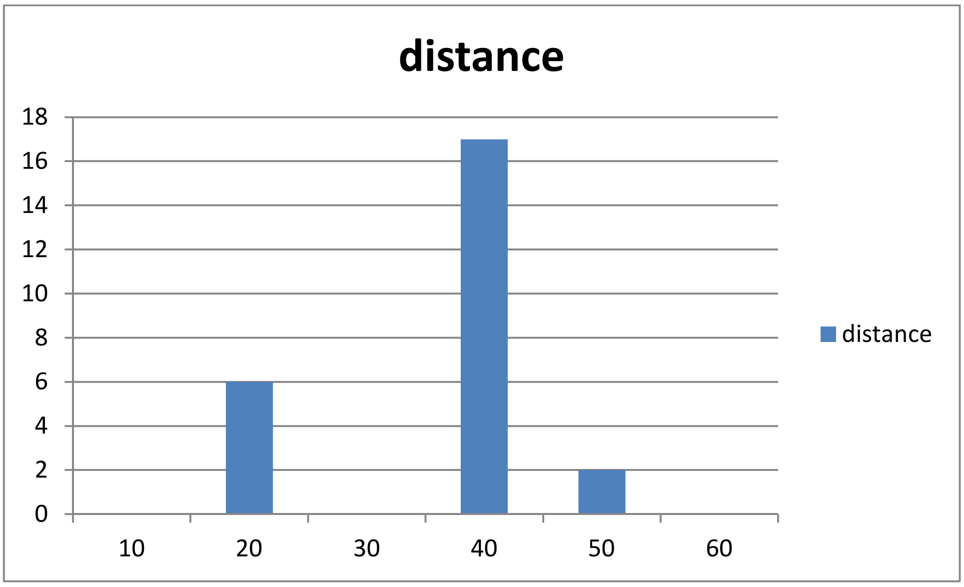

Figure 69 Decelerating target car (c2c_tcd) distance

The deceleration values go over a rather wide range from 1 to 7 m/s², as can be seen in Figure 68 while the distance for these cases concentrates between 30 and 40 meters, Figure 69.

Stopped target car (c2c_tcs)

For these scenarios the data from ADAC, AEB, ASSESS, vFSS, eValue and NCAP was used, with the following main parameters:

- v_{ego}, which is the driving speed of the ego car
- distance, which is the initial distance at the start of the test.

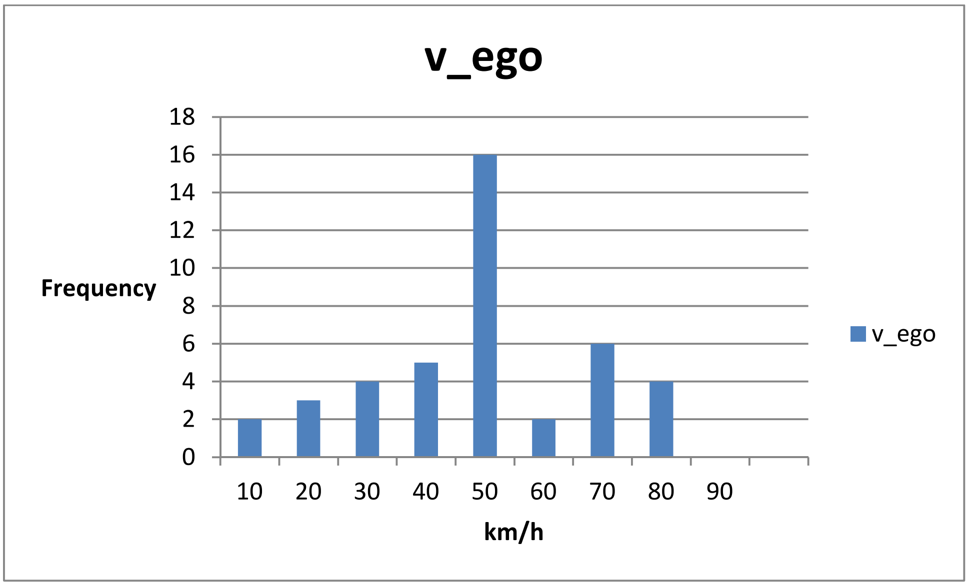

Figure 70 Stopped target car (c2c_tcs) v_{ego}

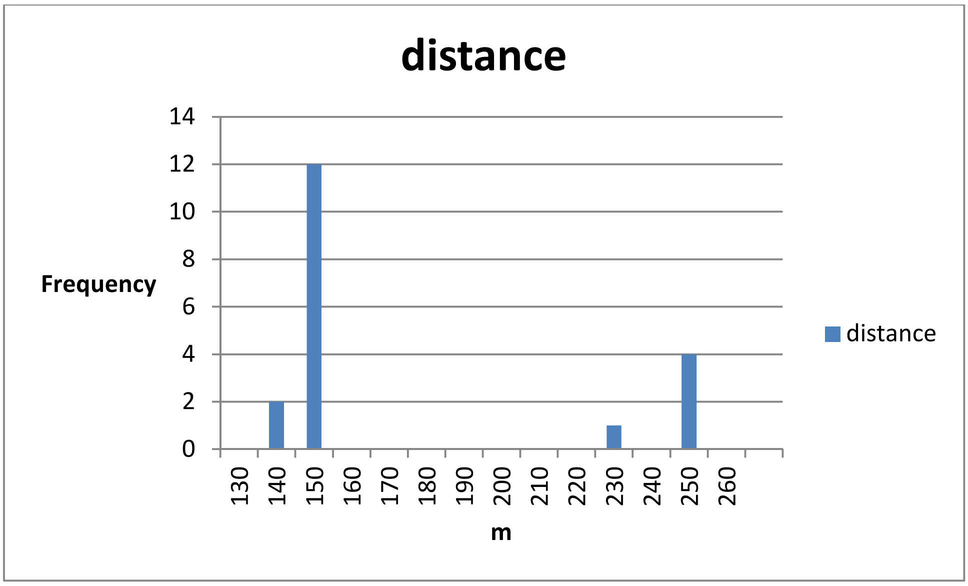

Figure 71 Stopped target car (c2c_tcs) distance

Figure 70 shows a peak in the class of 40 to 50 km/h with an initial distance of 140 to 150 meters displayed in Figure 71.

3.2.2 Car to pedestrian collision

Unobstructed pedestrian from nearside (ped_un_ns)

This data was taken from AEB, vFSS and eValue resulting in the following parameters and their distribution.

- v_{ego}, which is the driving speed of the ego car
- v_{target}, which is the speed of the pedestrian

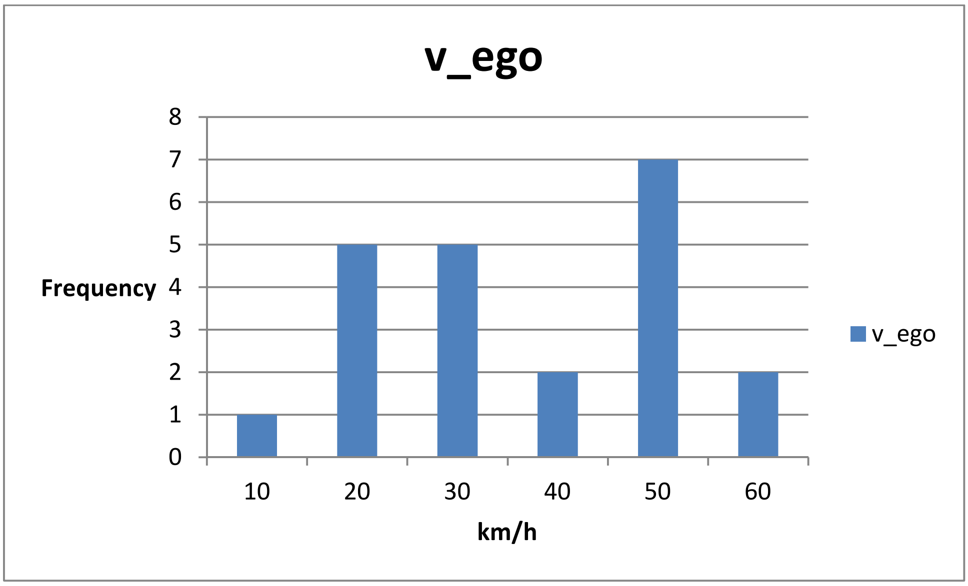

Figure 72 Unobstructed pedestrian from nearside (ped_un_ns) v_{ego}

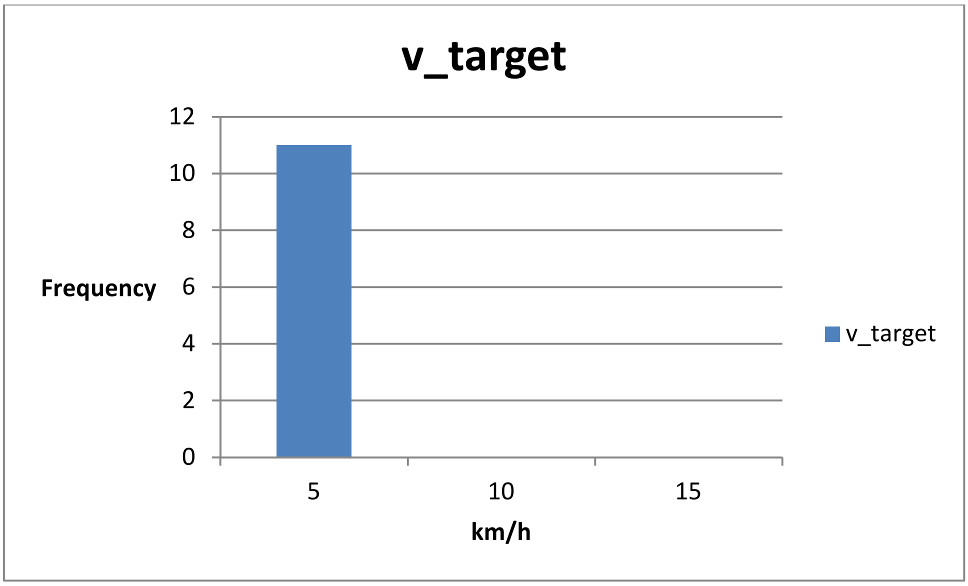

Figure 73 Unobstructed pedestrian from nearside (ped_un_ns) v_{target}

Unobstructed pedestrian from farside (ped_un_fs)

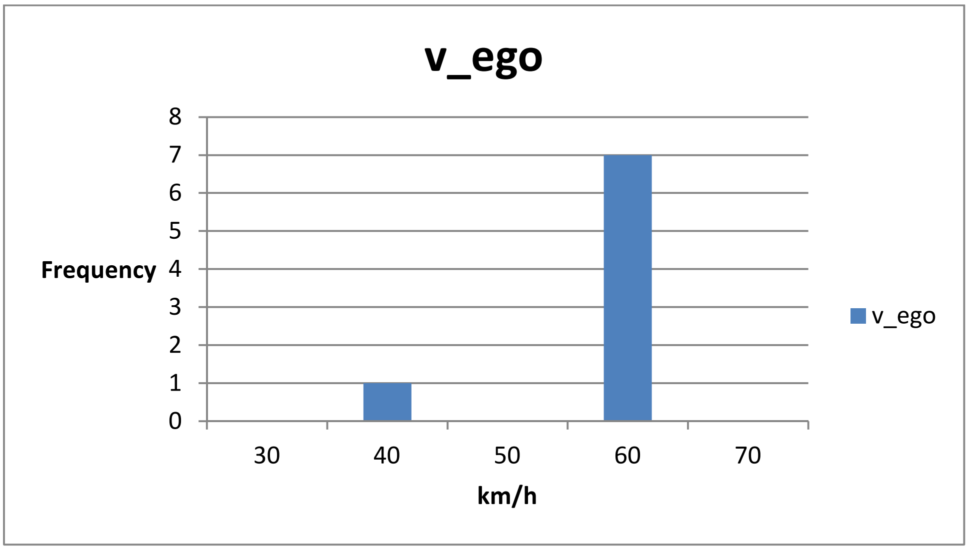

Figure 74 Unobstructed pedestrian from farside (ped_un_fs) v_{ego}

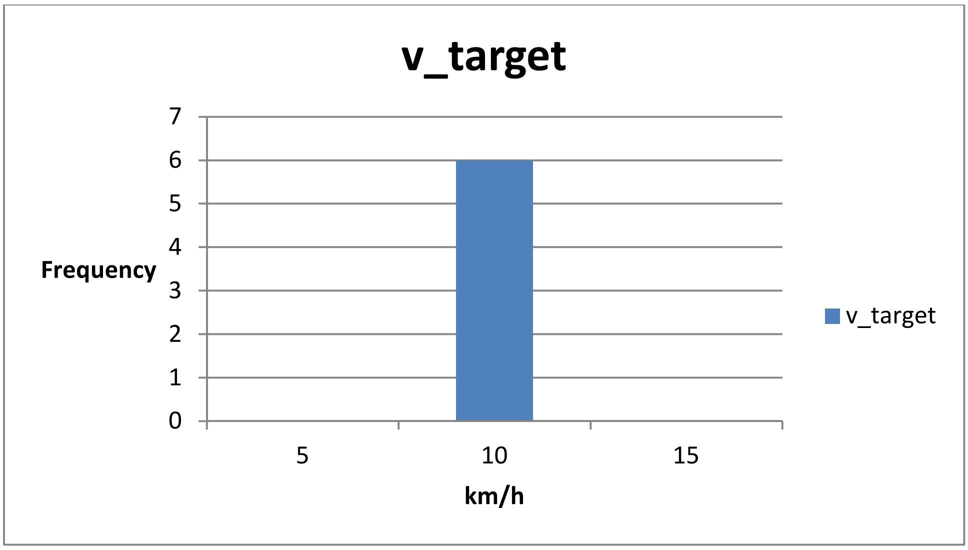

Figure 75 Unobstructed pedestrian from farside (ped_un_fs) v_{target}

Figure 72 through Figure 75 show that an unobstructed pedestrian coming from the far side usually has a higher walking speed than the one coming from near side. The ego speed on the far side accident is mainly between 50 and 60 km/h while the distribution of the ego speed in the near side case is rather even between 10 and 60 km/h.

Obstructed pedestrian from nearside (ped_ob_ns)

This was taken from AEB, vFSS and aspecss.

- v_{ego}, which is the driving speed of the ego car
- v_{target}, which is the speed of the pedestrian

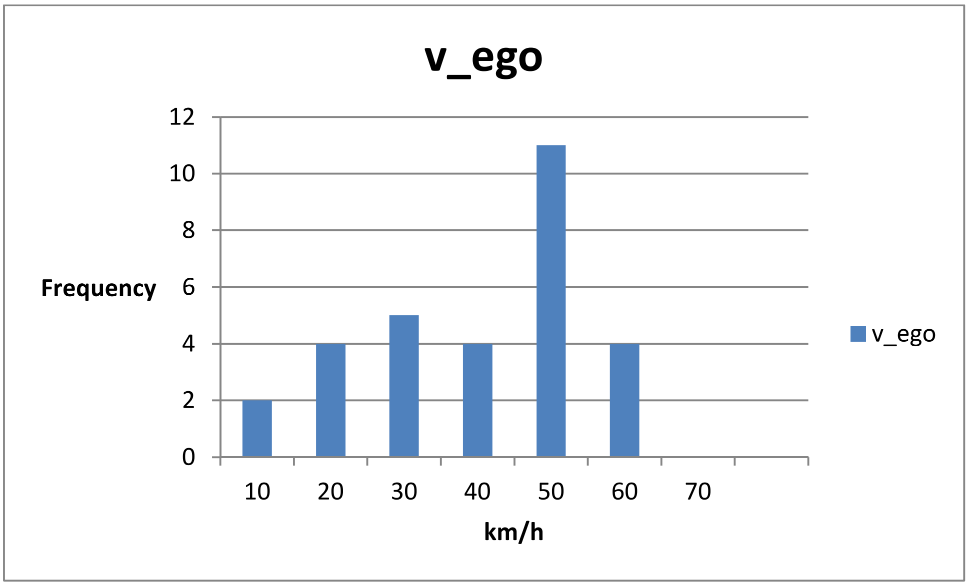

Figure 76 Obstructed pedestrian from nearside (ped_ob_ns) v_{ego}

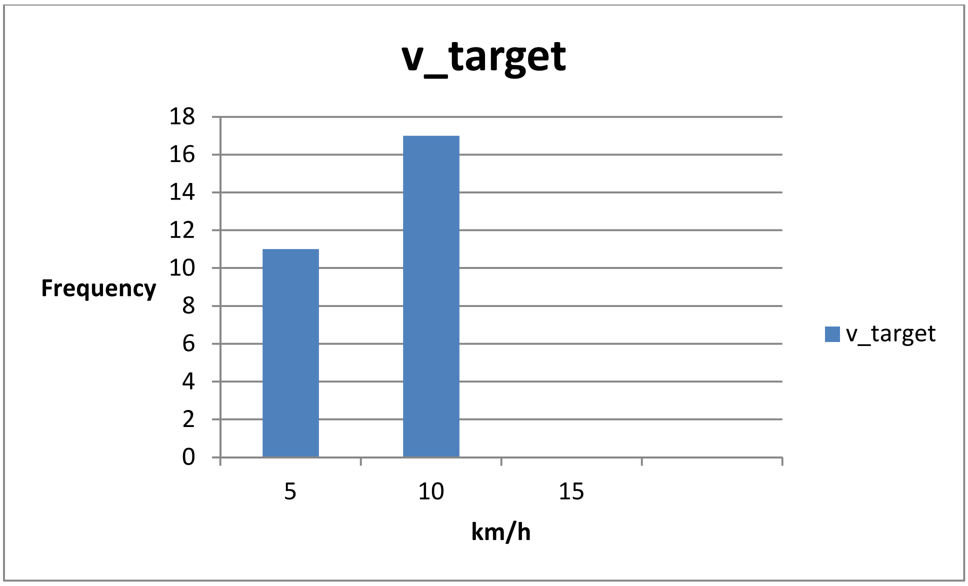

Figure 77 Obstructed pedestrian from nearside (ped_ob_ns) v_{target}

Obstructed pedestrian from farside (ped_ob_fs)

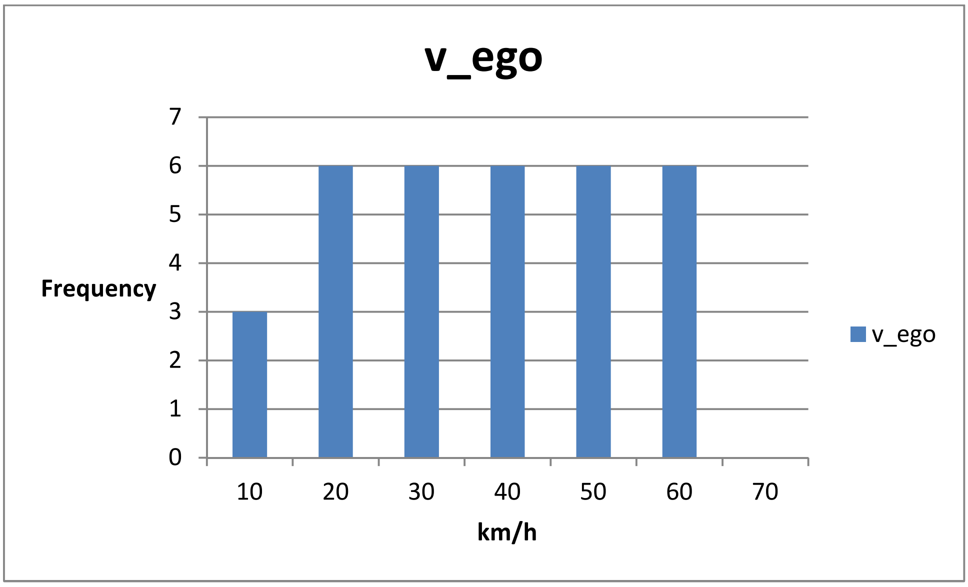

Figure 78 Obstructed pedestrian from farside (ped_ob_fs) v_{ego}

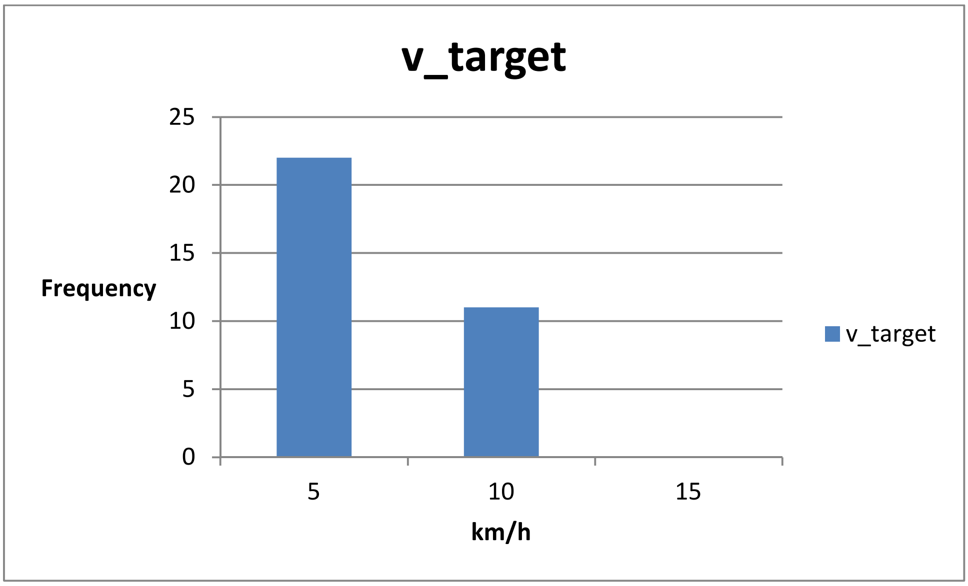

Figure 79 Obstructed pedestrian from farside (ped_ob_fs) v_{target}

The distribution of the pedestrian speed for both obstructed versions is quite similar, as can be seen in Figure 77 and Figure 79. The ego speed in the far side case is rather evenly distributed, while the distribution in the near side case peaks in the class of 40 to 50 km/h, Figure 76 and Figure 78.

The next step was to get more parameters, e.g. weather conditions, lighting conditions etc, to confirm and complete the data gained from the analysis of the previous projects. In order to achieve this, macroscopic databases and analyses of different projects referring to car accidents were researched.

3.3 Parameters derived from global statistics

The basic intention in this step was to get additional parameters needed to set up scenarios under real world circumstances from macroscopic databases. This data should be compared to the data from the previous chapter, where the different testing methods were examined. But due to the fact that macroscopic databases offer a very low level of detail and an analysis of in-depth databases was not possible at the time this work was done, the approach to this step had to be modified.

There are some projects like DaCoTA [46], which is based on data from the CARE database, that provide queries and analyses of the global data found in CARE. The DaCoTA project provides an annual statistical report and basic fact sheets with different topics. The variables used for the pedestrian scenarios and taken from the DaCoTA project [23] are:

3.3.1 Pedestrian scenarios

This data refers to all pedestrian accidents in the EU-24 in the year 2010.

- Lighting conditions
  - Dark with a share of 51% on all pedestrian accidents
  - Light with a share of 49% on all pedestrian accidents
- Road layout
  - Urban with a share of 71% on all pedestrian accidents
  - Rural with a share of 29% on all pedestrian accidents
- Pedestrian gender
  - Male with a share of 64% on all pedestrian accidents
  - Female with a share of 36% on all pedestrian accidents

3.3.2 Rear end collisions

The data for rear end collisions is hardly found in macroscopic databases due to their low level of detail. Because of that the data for this kind of accidents was mainly taken out of the ASSESS project. The main two reasons why the data was taken from ASSESS are:

- The carried out research by the ASSESS project is very detailed. As described earlier, several in-depth databases were analysed in order to get certain parameters and the rear end collision scenarios fit rather exactly with the scenarios used for this work and described in the previous paragraph.
- The methods of gathering the data and processing it to the results used in ASSESS are very exactly described in the different deliverables. Therefore the risk of misinterpreting the results is reduced.

The parameters chosen and their values can be seen in the following Table 46 and Table 47.

3.4 Choice of parameters

In a first step the parameters relevant for an accident had to be set. Based on the previous projects and data from the macroscopic databases the following tables were generated. In the column "Relevance for the manoeuvre" there are two possible marks meaning the following:

- X, which is relevant for the manoeuvre simulation
- O, which is irrelevant for the manoeuvre simulation

It was decided to mark the driver related parameters, e.g. sex, age, etc, as irrelevant because there are various driver models used which already have these parameters implemented, so there is no need to consider them in the creation of the scenarios. The decision was made to use as much data as possible from global statistics and other databases and not from the calculations performed in 3.2 in order to base the process of generating the scenarios on real field conditions. The original source of the data is listed in the last column of the tables.

3.4.1 Rear end collision

Table 46 Possible parameters rear end collision

<table>
<tr><th>Type</th><th>Description</th><th>Parameter</th><th>Relevance for the manoeuvre</th><th>Source</th></tr>
<tr><td rowspan="12">vehicle</td><td>-</td><td>driving speed</td><td>x</td><td>(ASSESS)[24]</td></tr>
<tr><td>-</td><td>driving speed target</td><td></td><td>(ASSESS)[24]</td></tr>
<tr><td>-</td><td>initial relative speed</td><td>x</td><td>-</td></tr>
<tr><td>-</td><td>impact speed</td><td>x</td><td>(ASSESS)[24]</td></tr>
<tr><td>-</td><td>distance/TTC</td><td>x</td><td>set to 5 seconds</td></tr>
<tr><td>-</td><td>angle between cars</td><td>x</td><td>-</td></tr>
<tr><td>-</td><td>collision angle</td><td>x</td><td>-</td></tr>
<tr><td>-</td><td>initial lateral offset</td><td>x</td><td>-</td></tr>
<tr><td>of target vehicle</td><td>deceleration</td><td>x</td><td>calculated from various projects as described in paragraph 3.2.1[1]</td></tr>
<tr><td></td><td>lateral offset at collision</td><td>x</td><td>(ASSESS)[24]</td></tr>
<tr><td></td><td>type of vehicle</td><td>x</td><td>(ASSESS)[24]</td></tr>
<tr><td>of ego vehicle</td><td>braking</td><td>x</td><td>(ASSESS)[24]</td></tr>
<tr><td rowspan="4">driver behaviour</td><td rowspan="4">-</td><td>age</td><td>o</td><td>-</td></tr>
<tr><td>driving experience</td><td>o</td><td>-</td></tr>
<tr><td>attention/distraction</td><td>o</td><td>-</td></tr>
<tr><td>sex</td><td>o</td><td>-</td></tr>
<tr><td rowspan="4">environmental conditions</td><td>road condition (dry, wet, icy)</td><td rowspan="2">weather</td><td>x</td><td>(ASSESS)[24]</td></tr>
<tr><td>visibility (clear, foggy,…)</td><td>x</td><td>(ASSESS)[24]</td></tr>
<tr><td>junctions, straight, curved</td><td>road layout</td><td>x</td><td>(ASSESS)[24]</td></tr>
<tr><td>light, dark, twilight</td><td>light</td><td>x</td><td>(ASSESS)[24]</td></tr>
</table>

The position parameters *collision angle* and *offset* were removed since this work focuses on pre-crash situations. Also the initial relative speed was removed as it results from the ego and target driving

[1] This calculation will be modified later on

speed. The remaining variables were analysed again and their values have been put together in a final table. The results from this are shown in Table 47 and represent the actual parameters and their values used in the scenario generating process, except for the driving speeds of the ego and the target car and the deceleration of the target car. The reason for this will be described later on in paragraph 3.6.1.

Some parameters in the table have values set “empty”. The reason for this is that at the time this work was done they were considered not relevant for the scenario generating process. However they are implemented in the scenario generator if later needed.

The initial distance is set to 5 seconds before the collision point. This guarantees a distance long enough between the two cars to not affect the driver assistance system at the starting point of the simulation immediately.

The target deceleration is also set to a certain value. This value is a result from all the tests performed by the researched programmes. In assumption of a normal distribution the mean value and standard deviation was calculated. However this deceleration was calculated from the values of all test scenarios containing a decelerating target vehicle. With this result the scenario generator would have created every scenario with a deceleration of the target car. In order to test scenarios with no deceleration this was not practical. Therefore the deceleration was calculated again including the test scenarios without target deceleration. For this scenarios the deceleration value was set to 0. The result of this was a lower mean value of the deceleration with a higher standard deviation shown in Table 47.

Table 47 Final car to car collision parameters

Parameter	Description		Distribution/mean value	Standard deviation
driving speed	ego car	ego speed	70 km/h	29 km/h
driving speed target	target car	target speed	29 km/h	22 km/h
distance/TTC	-	-	set to 5 seconds	-
angle between cars	initial	-	-	-
lateral offset	initial	-	-	-
deceleration	-	target acc	1.17 m/s²	2.13 m/s²
sex	general fatalities	male	76 %	-
		female	24 %	-
weather	surface	dry	53 %	-
		wet	18 %	-
		unknown	29 %	-
	visibility	fine	41 %	-
		cloudy	37 %	-
		rainy	18 %	-
		snowy	4 %	-
road layout	-	straight	59 %	-
		curve	41 %	-
light	-	darkness	21 %	-
		light	79 %	-

3.4.2 Pedestrian collision

The table for the pedestrian collision is based on the one from the rear end collision with some added fields describing the pedestrian attributes.

Table 48 Possible parameters pedestrian collision

Type	Description	Pedestrian collision	Relevance for the manoeuvre	Source
vehicle	-	driving speed	x	(ASPECSS)[35]
	-	initial relative speed	x	
	-	impact speed	x	(ASPECSS)[35]
	-	distance/TTC	x	set to 5 seconds
	-	angle between cars	x	
	-	collision angle	x	
	-	initial lateral offset	x	
	of target vehicle	deceleration	x	calculated from various projects as described in paragraph 3.2.1
	-	lateral offset at collision	x	
	-	type of vehicle	x	
	of ego vehicle	braking	x	
driver behaviour	-	age	o	x
		driving experience	o	o
		attention/distraction	o	(Basic Fact Sheet Pedestrians)[23]
		sex	o	x
environmental conditions	road condition (dry, wet, icy)	weather	x	x
	visibility (clear, foggy,…)		x	(ASPECSS)[35]
	junctions, straight, curved	road layout	x	(Annual Report 2012)[6]

	light, dark, twilight	light	x	(Basic Fact Sheet Pedestrians)[23]
pedestrian	-	age	x	x
		sex	x	(Basic Fact Sheet Pedestrians)[23]
		speed	x	(ASPECSS)[35]

In the case of a pedestrian collision the final parameters are listed in Table 49. Again the driving speed is not the final value used in the generation of the scenarios.

Table 49 Final pedestrian collision parameters

Parameter	Description		Distribution/mean value	Standard deviation
driving speed	-	ego speed	44 km/h	11 km/h
target speed	pedestrian	target speed	5.29 km/h	-
sex	pedestrian	male	64 %	-
		female	36 %	-
weather	visibility	fine	82 %	-
		not fine	14 %	-
road layout	-	inside urban	71 %	-
		outside urban	29 %	-
light	-	darkness	51 %	-
		light	49 %	-
initial distance	-	-	set to 5 seconds	-
age	pedestrian	-	-	-

Table 47 and Table 49 define together with the scenario definitions from chapter 3.2 the scenarios for the simulations performed in IPG Carmaker. The next step was to check if there are any dependencies between the parameters, which may affect the outcome.

3.5 Classification into dependent and independent parameters

In order to generate scenarios the dependencies between the parameters have to be known. To get to this information at first a separation into a group of independent and a group of dependent parameters was done. For the case of a car to car collision the results are displayed in Table 50, where the orange fields represent the dependent parameters.

3.5.1 Car to car collision

Table 50 Independent (white)/Dependent (orange) parameters car to car collision

Parameter	Description		Distribution/mean value	Standard deviation
driving speed	ego car	ego speed	70 km/h	29 km/h
driving speed target	target car	target speed	29 km/h	22 km/h
distance/TTC	-	-	set to 5 seconds	-
angle between cars	initial	-	-	-
lateral offset	initial	-	-	-
deceleration	-	target acc	1.17 m/s²	2.13 m/s²
sex	general fatalities	male	76 %	-
		female	24 %	-
weather	surface	dry	53 %	-
		wet	18 %	-
		unknown	29 %	-
	visibility	fine	41 %	-
		cloudy	37 %	-
		rainy	18 %	-
		snowy	4 %	-
road layout	-	straight	59 %	-
		curve	41 %	-
light	-	darkness	21 %	-
		light	79 %	-

Only four parameters were identified to be dependent from others.

- Deceleration: Possible deceleration values depend on the road surface
- Surface: The street surface depends mainly on the weather conditions.
- Driving speed ego/target car: The driving speed depends on many different parameters, which results in several problems, described in paragraph 3.6.1.

3.5.2 Pedestrian collision

The results for the pedestrian collision are shown in Table 51 again with the orange fields representing the dependent parameters.

Table 51 Independent (white)/Dependent (orange) parameters pedestrian collision

Parameter	Description		Distribution/mean value	Standard deviation
driving speed	-	ego speed	44 km/h	11 km/h
target speed	-	target speed	5.29 km/h	-
sex	pedestrian	male	64 %	-
		female	36 %	-
weather	visibility	fine	82 %	-
		not fine	14 %	-
road layout	-	inside urban	71 %	-
		outside urban	29 %	-
light	-	darkness	51 %	-
		light	49 %	-
initial distance	-	-	set to 5 seconds	-
age	pedestrian	-	-	-

In the case for the pedestrian collision only the driving speed of the ego car was identified to be dependent from other variables. Its calculation is described in the following passage as already mentioned above.

The pedestrian speed was set to a constant value independent from any other parameters.

3.6 Dependencies

In order to get accurate results the dependencies of the above highlighted variables had to be checked and described.

3.6.1 Driving speeds (v_{ego} and v_{target})

Since the driving speed is a parameter which is dependent on various other variables the speed distribution from Table 47 and Table 49 could not be used. The reason for this is that different conditions caused by the other parameters lead to different driving speed distributions. The mean value of the driving speed on a snowy road surface in the winter is definitely lower than the one on a dry surface in summer. This difference could not be distinguished from a single distribution that covers all accidents of a certain type, which means all possible combinations of parameters. Therefore a speed distribution for every possible scenario had to be defined in order to get appropriate results.

Speed parameter combinations

For reasons of simplicity the assumption was made that the driving speeds depend only on a few parameters that mainly affect the speed. With this a number of possible parameter combinations was calculated. Each combination stands for a certain scenario and for each scenario, a certain speed distribution had to be set. These speed distributions resulted from a research in the in-depth databases ZEDATU [2]and GIDAS[3]. The driving speed of the target vehicle was not directly queried from the databases but calculated. Thus the impact speed was queried which is included in those two in-depth databases due to the reconstruction of the accident. However at the time this work was finished the research of the databases was not completed. Therefore the speed distributions were set in a generic approach to certain levels randomly which can be seen in Table 52 and Table 53.

Car to car collision

Assuming that v_{ego} and v_{impact} in car to car collision scenarios mainly depend on the following parameters:

- Light conditions;
  - Dark
  - light
- Visibility;
  - Fine
  - Cloudy
  - Rainy
  - Snowy
- Sex;
  - Male
  - Female
- Road surface;
  - Dry
  - Wet
- Road layout.
  - Straight
  - Curve

From this five main parameter groups with their sub-levels a total number of 65 possible scenarios resulted. After removing those combinations that are not possible, e.g. *visibility* = rainy and *road surface* = dry, the number was reduced to 48 possible scenarios. As it can be seen easily each parameter group additionally added raises the number of possible combinations dramatically.

[2] See chapter 2.1
[3] See chapter 2.1

Table 52 Generic data car to car collision

Light condition	Sight condition	Sex	Road surface	Road layout	v_{ego} (μ)	(σ)	v_{impact} (μ)	(σ)	# of cases	Share on total cases
dark	fine	male	dry	straight	78	32	65	25	26	0,0300578
dark	cloudy	male	dry	straight	76	31	61	24	23	0,0265896
dark	rainy	female	dry	straight	67	25	50	21	25	0,02890173
dark	cloudy	female	dry	straight	65	24	48	20	22	0,02543353
dark	fine	male	wet	straight	75	26	63	21	29	0,03352601
dark	cloudy	male	wet	straight	70	24	56	20	26	0,0300578
dark	rainy	male	wet	straight	68	22	64	26	27	0,03121387
dark	snowy	male	wet	straight	65	21	52	20	21	0,02427746
dark	fine	female	wet	straight	72	25	58	22	25	0,02890173
dark	cloudy	female	wet	straight	68	23	53	21	21	0,02427746
dark	rainy	female	wet	straight	65	20	47	19	18	0,02080925
dark	snowy	female	wet	straight	60	22	47	18	11	0,01271676
dark	fine	male	dry	curve	75	28	56	21	15	0,01734104
dark	cloudy	male	dry	curve	75	27	63	24	11	0,01271676
dark	fine	female	dry	curve	72	21	62	25	6	0,00693642
dark	cloudy	female	dry	curve	72	26	60	23	3	0,00346821
dark	fine	male	wet	curve	73	24	59	2	8	0,00924855
dark	cloudy	male	wet	curve	68	20	55	22	9	0,01040462
dark	rainy	male	wet	curve	65	21	53	22	10	0,01156069
dark	snowy	male	wet	curve	62	25	50	21	4	0,00462428
dark	fine	female	wet	curve	70	35	54	19	7	0,00809249
dark	cloudy	female	wet	curve	65	22	48	26	8	0,00924855
dark	rainy	female	wet	curve	63	21	49	17	7	0,00809249
dark	snowy	female	wet	curve	58	19	42	18	5	0,00578035
light	fine	male	dry	straight	81	36	68	26	31	0,03583815
light	cloudy	male	dry	straight	80	31	64	22	28	0,03236994
light	fine	female	dry	straight	71	25	53	15	29	0,03352601
light	cloudy	female	dry	straight	70	27	51	16	25	0,02890173
light	fine	male	wet	straight	80	35	65	23	38	0,04393064
light	cloudy	male	wet	straight	76	31	59	21	35	0,04046243
light	rainy	male	wet	straight	74	26	67	25	34	0,03930636
light	snowy	male	wet	straight	70	25	53	22	27	0,03121387
light	fine	female	wet	straight	76	27	61	24	32	0,03699422
light	cloudy	female	wet	straight	72	25	55	20	29	0,03352601
light	rainy	female	wet	straight	69	22	49	18	24	0,02774566
light	snowy	female	wet	straight	66	20	50	17	17	0,01965318
light	fine	male	dry	curve	79	26	59	25	17	0,01965318
light	cloudy	male	dry	curve	78	28	65	23	13	0,0150289
light	fine	female	dry	curve	67	18	60	24	12	0,01387283
light	cloudy	female	dry	curve	66	17	60	26	9	0,01040462
light	fine	male	wet	curve	78	25	64	23	17	0,01965318
light	cloudy	male	wet	curve	74	27	59	22	15	0,01734104
light	rainy	male	wet	curve	73	26	55	20	16	0,01849711
light	snowy	male	wet	curve	69	25	53	21	8	0,00924855
light	fine	female	wet	curve	74	23	57	19	14	0,01618497
light	cloudy	female	wet	curve	70	24	55	21	12	0,01387283
light	rainy	female	wet	curve	68	22	54	22	9	0,01040462
light	snowy	female	wet	curve	66	19	46	14	7	0,00809249

	70,7	24,9	56,2	20,9	865	1

Pedestrian collision

The parameters chosen in the pedestrian collision scenario in order to determine v_{ego} are almost the same as in the car to car collision scenario, except that the road layout is not divided into straight and curve but

- Road layout.
  - Urban
  - Rural

Therefore the number of possible scenarios is the same as above, 48 in the end.

Table 53 Generic data pedestrian collision

Light condition	Sight condition	Sex	Road surface	Road layout	v_{ego} (μ)	(σ)	# of cases	Share on total cases
dark	fine	male	dry	urban	48	21	26	0,0300578
dark	cloudy	male	dry	urban	46	20	23	0,0265896
dark	fine	female	dry	urban	37	14	25	0,02890173
dark	cloudy	female	dry	urban	35	13	22	0,02543353
dark	fine	male	wet	urban	45	15	29	0,03352601
dark	cloudy	male	wet	urban	40	13	26	0,0300578
dark	rainy	male	wet	urban	38	11	27	0,03121387
dark	snowy	male	wet	urban	35	10	21	0,02427746
dark	fine	female	wet	urban	42	14	25	0,02890173
dark	cloudy	female	wet	urban	38	12	21	0,02427746
dark	rainy	female	wet	urban	35	8	18	0,02080925
dark	snowy	female	wet	urban	30	10	11	0,01271676
dark	fine	male	dry	rural	45	15	15	0,01734104
dark	cloudy	male	dry	rural	45	16	11	0,01271676
dark	fine	female	dry	rural	41	11	6	0,00693642
dark	cloudy	female	dry	rural	42	12	3	0,00346821
dark	fine	male	wet	rural	43	13	8	0,00924855
dark	cloudy	male	wet	rural	38	8	9	0,01040462
dark	rainy	male	wet	rural	36	8	10	0,01156069
dark	snowy	male	wet	rural	32	16	4	0,00462428
dark	fine	female	wet	rural	36	24	7	0,00809249
dark	cloudy	female	wet	rural	31	12	8	0,00924855
dark	rainy	female	wet	rural	35	10	7	0,00809249
dark	snowy	female	wet	rural	24	10	5	0,00578035
light	fine	male	dry	urban	50	24	31	0,03583815
light	cloudy	male	dry	urban	51	18	28	0,03236994
light	fine	female	dry	urban	40	16	29	0,03352601
light	cloudy	female	dry	urban	38	15	25	0,02890173
light	fine	male	wet	urban	55	22	38	0,04393064
light	cloudy	male	wet	urban	44	20	35	0,04046243
light	rainy	male	wet	urban	42	16	34	0,03930636
light	snowy	male	wet	urban	44	15	27	0,03121387
light	fine	female	wet	urban	43	16	32	0,03699422
light	cloudy	female	wet	urban	41	14	29	0,03352601
light	rainy	female	wet	urban	39	10	24	0,02774566
light	snowy	female	wet	urban	35	8	17	0,01965318
light	fine	male	dry	rural	48	13	17	0,01965318
light	cloudy	male	dry	rural	46	19	13	0,0150289
light	fine	female	dry	rural	35	9	12	0,01387283
light	cloudy	female	dry	rural	36	6	9	0,01040462
light	fine	male	wet	rural	45	13	17	0,01965318
light	cloudy	male	wet	rural	45	15	15	0,01734104
light	rainy	male	wet	rural	42	14	16	0,01849711
light	snowy	male	wet	rural	39	13	8	0,00924855
light	fine	female	wet	rural	44	12	14	0,01618497
light	cloudy	female	wet	rural	42	13	12	0,01387283
light	rainy	female	wet	rural	39	11	9	0,01040462
light	snowy	female	wet	rural	38	10	7	0,00809249
					40,4	13,7	865	1

Ego car speed

The ego car driving speeds result directly from the research done in the in-depth databases. As already mentioned the queries were not finished and a generic approach had to be done. This generic data has to be replaced when the results from the in-depth databases are available.

Target car speed

The speed of the target car is calculated from the speed of the ego car, the impact speed between the two cars at the time of the collision ($TTC = 0$) and the deceleration of the target vehicle before the collision.

$$v_{target} = (v_{ego} - v_{impact}) + (a_{target} * t) \tag{3-1}$$

The variable t was set to 3 seconds due to the fact that most EBA systems start to work under a distance of 3 seconds to the target.

The impact speed v_{impact} is taken from the in-depth databases analogue to v_{ego}.

3.6.2 Deceleration

The possible deceleration of the car is on the one side mainly limited by the physical conditions of the road and on the other side by the car model and the driver. In this work the deceleration of the target vehicle was put as a parameter to the scenario by the user. Therefore no dependencies were researched and considered.

3.6.3 Surface

The classification of the surface condition contains only the parameters “wet” and “dry”. Actually there is also the case of “unknown” due to the statistical distribution taken over from the ASSESS project. Other factors like damages of the surface or its material were not considered in this work due to little information on this. The road surface depends therefore only on the weather conditions which are stated in the “visibility condition” row of Table 47 and Table 49.

3.7 Checking the speed distributions

For the purpose of checking the distributions of the driving speeds generated, two approaches were defined:

- Comparing the mean values of the speed distributions resulting from the scenario generator to the mean values from Table 47 and Table 49 which result from the ASSESS research;
- Comparing the mean values of the speed distributions resulting from the scenario generator to the mean values resulting from a mixed distribution approach using the speed distributions from 3.6.1.

The comparison of the driving speed means is shown in Table 54 and Table 55 of chapter 4.1 along with the comparison of the other variables.

3.7.1 Testing under the assumption of normal distribution

This section describes shortly two of the most common methods for testing of hypotheses on distribution functions and it is based on [47]. The basic idea is to set a null hypothesis which is then tested, based on the observation of a random sample, to be correct or rejected.

The arithmetic mean reads as,

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i. \qquad (3\text{-}2)$$

Gauß-test

1. **Requirements:**
   $X_1,\ldots,X_n$ independent, $N(\mu, \sigma_0^2)$ distributed with unknown μ and known σ_0^2
2. **Test statistic:**

$$Z = \frac{\bar{X} - \mu_0}{\frac{\sigma_0}{\sqrt{n}}} \qquad N(0,1) - \text{distributed, if } \mu = \mu_0, \qquad (3\text{-}3)$$

$$p = 2(1 - \Phi(|z|)) \qquad \text{P-value for two-sided hypothesis } H_0 : \mu = \mu_0. \qquad (3\text{-}4)$$

3. **Hypotheses and decision rules:**

H_0 / H_1	$\mu = \mu_0$ / $\mu \neq \mu_0$	$\mu \leq \mu_0$ / $\mu > \mu_0$	$\mu \geq \mu_0$ / $\mu < \mu_0$
H_0 discard if	$\lvert z \rvert \geq u_{1-\frac{\alpha}{2}}$	$z \geq u_{1-\alpha}$	$z \leq u_{\alpha}$
or			
H_0 discard if	$p \leq \alpha$	$z \geq 0$ and $\frac{p}{2} \leq \alpha$	$z \leq 0$ and $\frac{p}{2} \leq \alpha$

t-test

1. **Requirements:**
   $X_1,\ldots,X_n$ independent, $N(\mu, \sigma^2)$ distributed with unknown μ and σ^2
2. **Test statistic:**

$$T = \frac{\bar{X} - \mu_0}{\frac{S}{\sqrt{n}}} \qquad t_{n-1} - \text{distributed, if } \mu = \mu_0, \qquad (3\text{-}5)$$

$$p = 2(1 - F_{t_{n-1}}(|t|)) \qquad \text{P-value for two-sided hypothesis } H_0 : \mu = \mu_0. \qquad (3\text{-}6)$$

3. Hypotheses and decision rules:

H_0 H_1	$\mu = \mu_0$ $\mu \neq \mu_0$	$\mu \leq \mu_0$ $\mu > \mu_0$	$\mu \geq \mu_0$ $\mu < \mu_0$
H_0 discard if	$\lvert t \rvert \geq t_{n-1;1-\frac{\alpha}{2}}$	$t \geq t_{n-1;1-\alpha}$	$t \leq t_{n-1;\alpha}$
or			
H_0 discard if	$p \leq \alpha$	$t \geq 0$ and $\frac{p}{2} \leq \alpha$	$t \leq 0$ and $\frac{p}{2} \leq \alpha$

With the empiric variance $S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})^2$. **(3-7)**

3.7.2 Design of experiments (DoE)

In this paragraph, which is based on information from [48, 49] , a short overview on the design of experiments shall be given.

The main goal of the design of experiments (DoE) is to get the correlation between an input (factor) and an output (response) parameter with the lowest possible number of experiments. The classic approach of experimenting is to vary one factor at a time, while keeping the others constant and then check the response. If the desired result is achieved, then this factor will be set constant and another factor will be varied. The biggest disadvantages in this approach are that it is rather work-intensive and that the correlation between different factors may not be sufficiently represented. The DoE offers more efficient methods to perform such experiments. These methods are called experimental design. Some examples of these are,

- Full Factorial,
- Fractional Factorial,
- Orthogonal Array,
- Hexagon.

As a description model for the response mostly linear combinations are used, as shown in formula (3-8) for three factors.

$$y = c_0 + c_1x_1 + c_2x_2 + c_3x_3 + c_{12}x_1x_2 + c_{13}x_1x_3 + c_{23}x_2x_3 + \varepsilon \quad \textbf{(3-8)}$$

With y representing the response, c_i representing the model coefficients, x representing the factors and ε representing the deviation.

For more detailed information please check the sources mentioned above.

3.7.3 Mixed distribution

This paragraph gives a short overview on the mixed distribution, in special for continuous variables, and is based on the work of [50].

The mixed distribution of continuous variables is defined as followed:

$$f(x) = p_1f_1(x) + p_2f_2(x) + \ldots + p_nf_n(x) \quad \textbf{(3-9)}$$

with
$$0 \le p_i \le 1 \quad \forall i \tag{3-10}$$

and
$$\sum_{i=1}^{n} p_i = 1. \tag{3-11}$$

With $f_1(x), \ldots, f_{n(x)}$ being density functions.

So the ego car speed and the impact speed in this work consist of 48 sub-distributions. With their share on the number of the total accidents the complete distribution was calculated. Since the data used for the calculations in this work is generic and not the data from the databases, it cannot be foreseen in which kind of distribution this mixture will actually result with the real accident data. Thus a normal distribution was assumed as result while the sub-distributions also were assumed as normally distributed. This possibly leads to an incorrectness in the result which can be reduced after getting the data from the databases and check the distributions again.

3.8 Combination of the parameters to accident scenarios

The combination of the parameters to resulting scenarios is a random selection of each parameter, based on its statistical distribution showed in Table 47 and Table 49. It is performed in a MATLAB script. First the independent parameters are selected randomly. Then the parameters with dependencies of the independent parameters are selected also randomly and in a last step the remaining parameters are set.

This leads to many different combinations of the parameters which can be assigned to the defined collision types, car to car or pedestrian collision. By creating a large enough number of scenarios it is possible to test their statistical relevance as described in 3.7.

In the next chapter the results from the scenario generator, including the check of statistical relevance and the IPG Carmaker simulations are presented.

4 Results

In this chapter the results of the scenario generator and the simulations in IPG Carmaker are presented. For this, 1000 scenarios of each type, car to car and pedestrian collision, were generated and analysed. The resulting mean values and the distributions were compared to the data from Table 47 and Table 49 to check possible divergences and summarised in Table 54 and Table 55.

Further 100 of these scenarios were exported to IPG Carmaker. The resulting simulations from this were shortly analysed. Further two scenarios were chosen, one from a car to car collision and one from a pedestrian collision. The aim was to check the difference resulting in variations of the EBA system. Therefore these two scenarios were run with different EBA settings. The results of this are presented in paragraph 4.2.

4.1 Result from the scenario generator

The scenario generator is a MATLAB script with a Graphical User Interface (GUI). The statistical data needed for creating the scenarios is implemented within the script and can be accessed via the associated MATLAB file. The only input variable for the user is the number of scenarios requested. Car to car collision and pedestrian collision is divided by separate executing buttons.

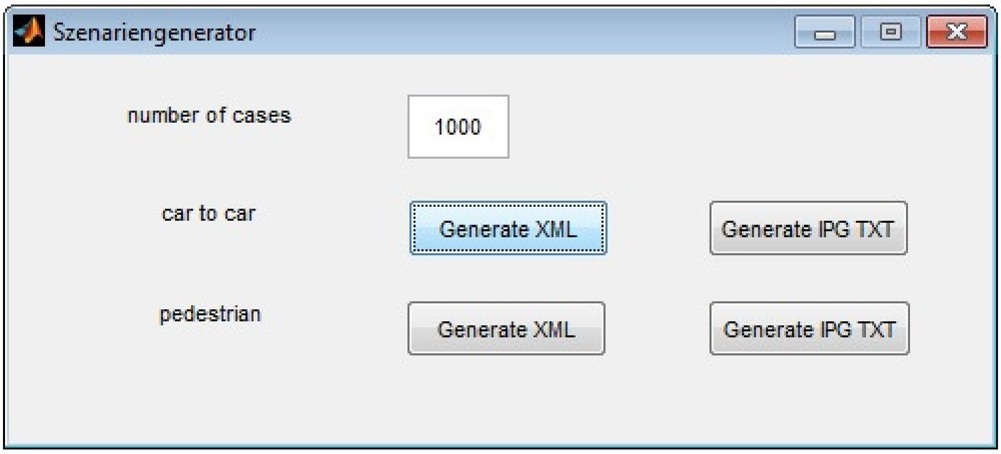

Figure 80 Scenario Generator GUI

In this version the data formats exported are XML [4]and TXT[5]. The .xml files are needed for the implementation of the results in the software package of the ViF. The .txt output is designed to be able to export the scenarios to IPG Carmaker. This .txt file can be imported into the Carmaker as an input file for the Test Manager which controls the desired number of simulations and their parameters.

For reasons of calculation all variables returning a string had to be converted into numbers with the definitions stated in the affected categories in the following.

[4] A markup language in a format which is readable by human and machine
[5] A file format containing usually text with little formatting

4.1.1 Car to car collision

Driving speeds

- v_{ego}

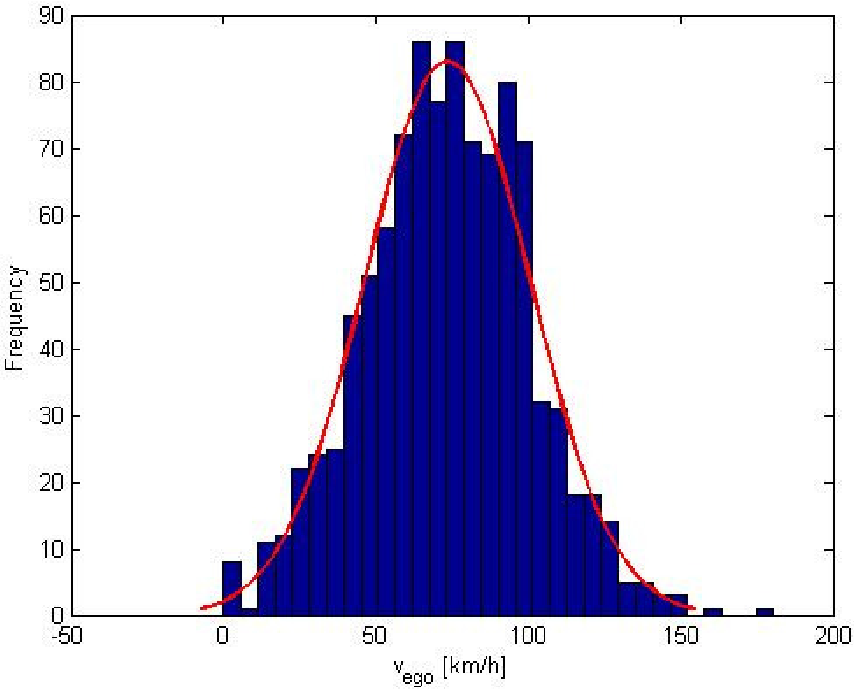

Figure 81 Ego car driving speed v_{ego}

As illustrated in Figure 81 the mean value of the driving speed of the ego car is about 74 km/h. This is rather close to the mean value of the ego car driving speed stated in the ASSESS project.

- v_{target}

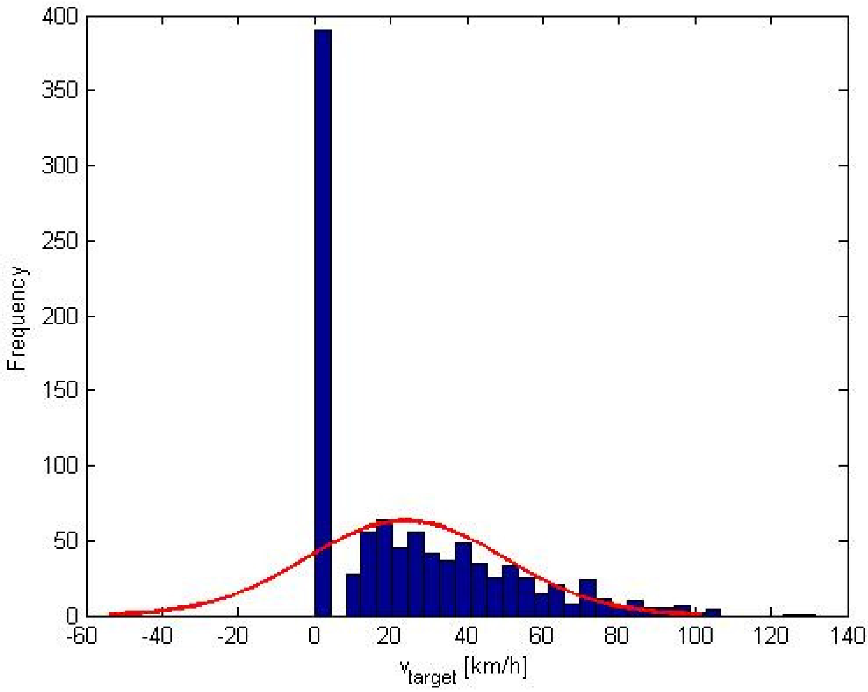

Figure 82 Target car driving speed v_{target}

The mean value of the driving speed of the target car is about 24 km/h. The high peak at 0 km/h is a result of the collision types with a stopped vehicle. These values result from the fact that due to the standard deviation there are also negative driving speed values. These negative values were set to 0 in the process of generating the scenarios. It can be seen that the frequency of the peak is somewhere beneath 400. This seems to be a rather convenient result concerning that the car to car collisions are divided into three sub scenarios, with the stopped target car scenario one of them. Furthermore all target speed below 5 km/h have been set to the value 0 and assigned to the stopped target car scenario.

Initial distance

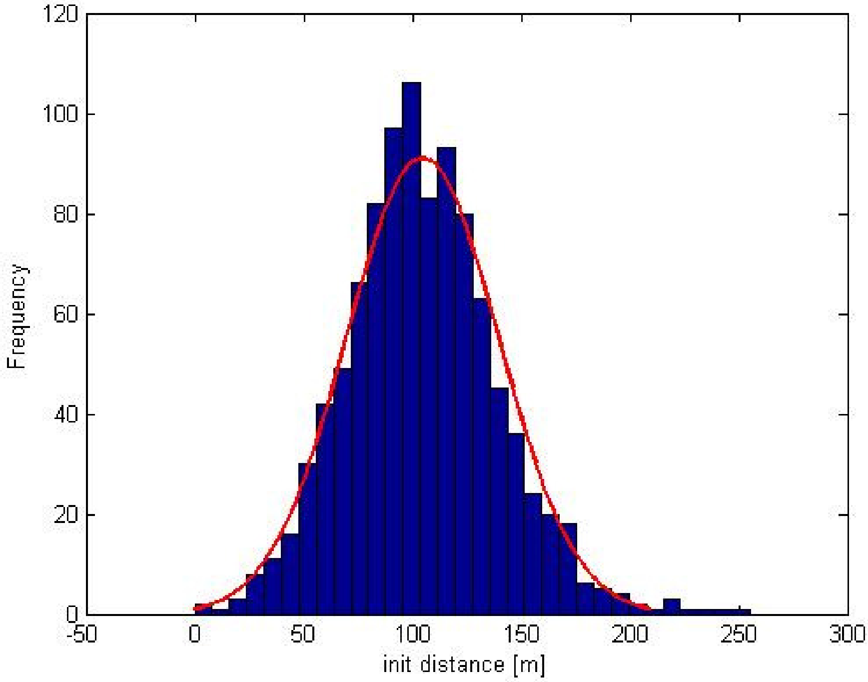

Figure 83 Initial distance

The initial distance which was set to 5 seconds in this work is about 100 m, also very close to the ASSESS data, Figure 83.

Target deceleration

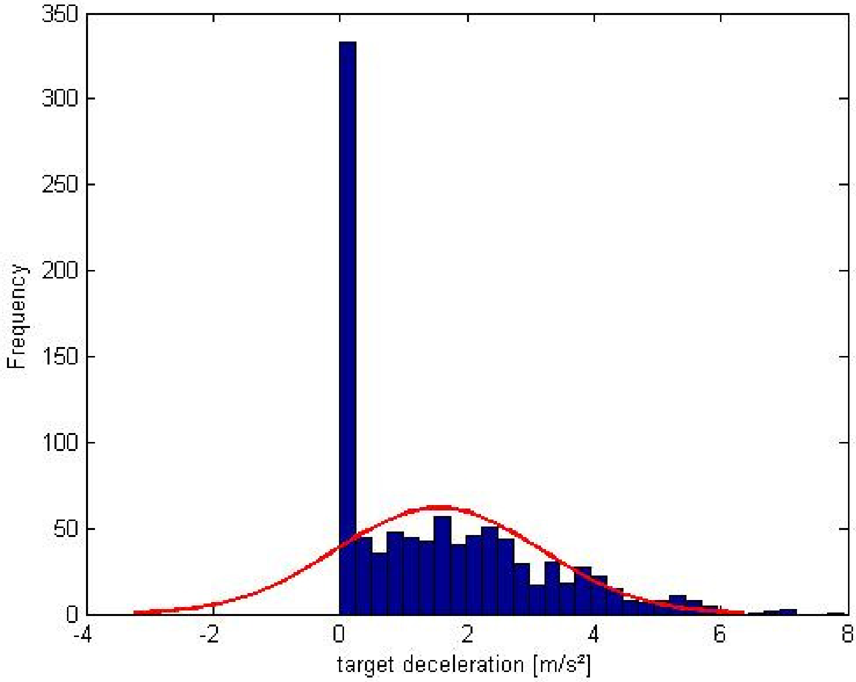

Figure 84 Target deceleration

The target deceleration varies around a mean value of 1.5 m/s², Figure 84. The peak at 0 is the result of the change in the calculation method for the target deceleration as described in paragraph 3.4.1 and the fact that all deceleration values < 0 were set to 0. Again this looks rather adequate with a share of almost one third of all the created scenarios.

Sex

- 0, which is male,
- 1, which is female.

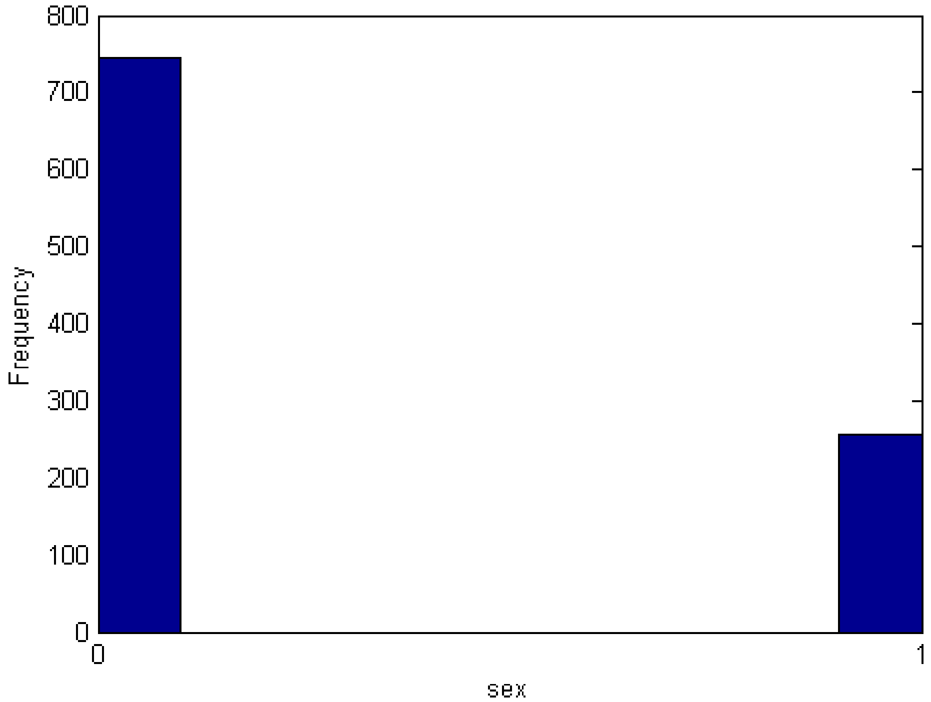

Figure 85 Sex

The gender distribution shows that in 73.3% of the created scenarios the driver was male Figure 85.

Weather conditions

- Visibility conditions
  - 0, which is fine
  - 1, which is cloudy
  - 2, which is rainy
  - 3, which is snowy

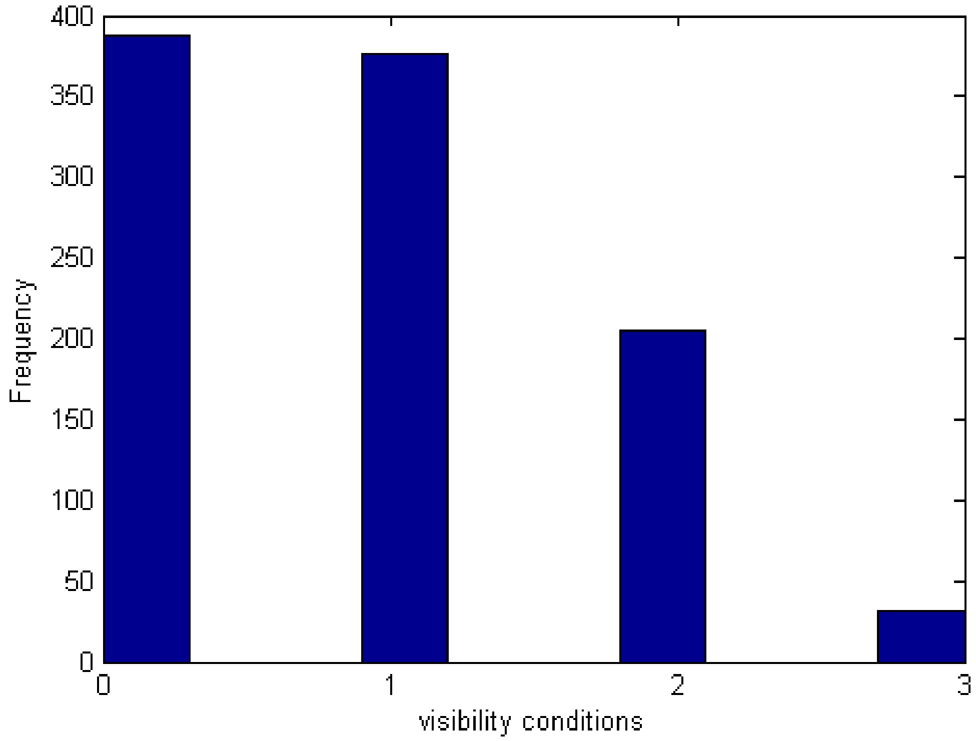

Figure 86 Visibility conditions

In 39.5% of the scenarios the weather conditions were fine while in 35% the conditions were cloudy, in 21.1% rainy and in 0.44% snowy.

- Road surface
  - 0, which is dry
  - 1, which is wet
  - 2, which is unknown

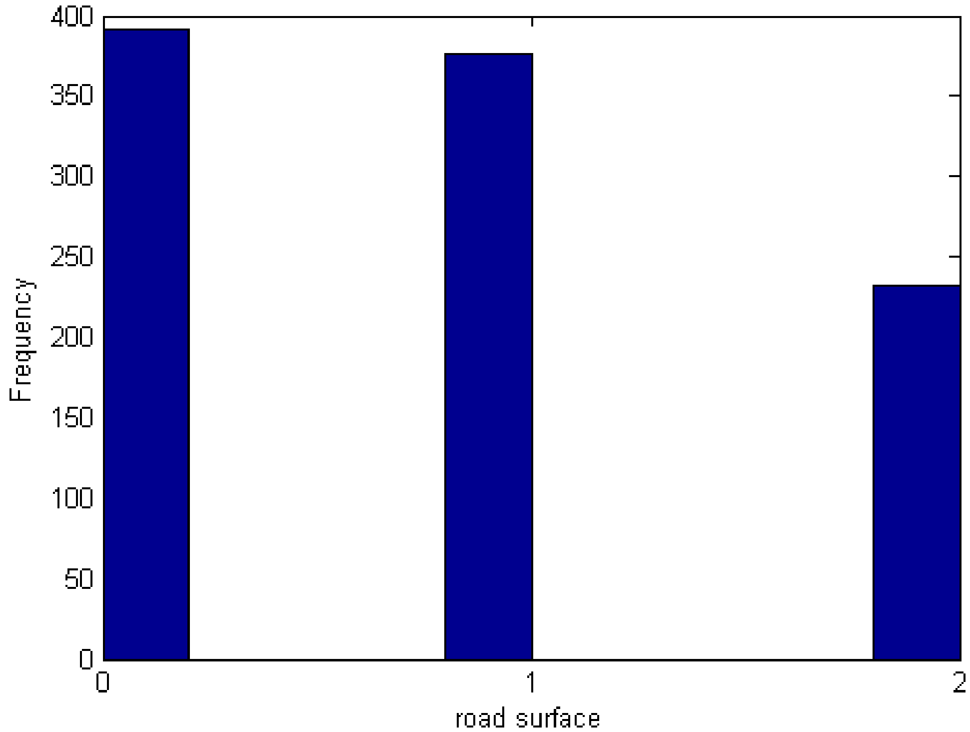

Figure 87 Road surface

The road surface was in 39.2% of the scenarios dry and in 36.8% wet, while in 24% unknown conditions were registered.

Road layout

- 0, which is straight
- 1, which is curve

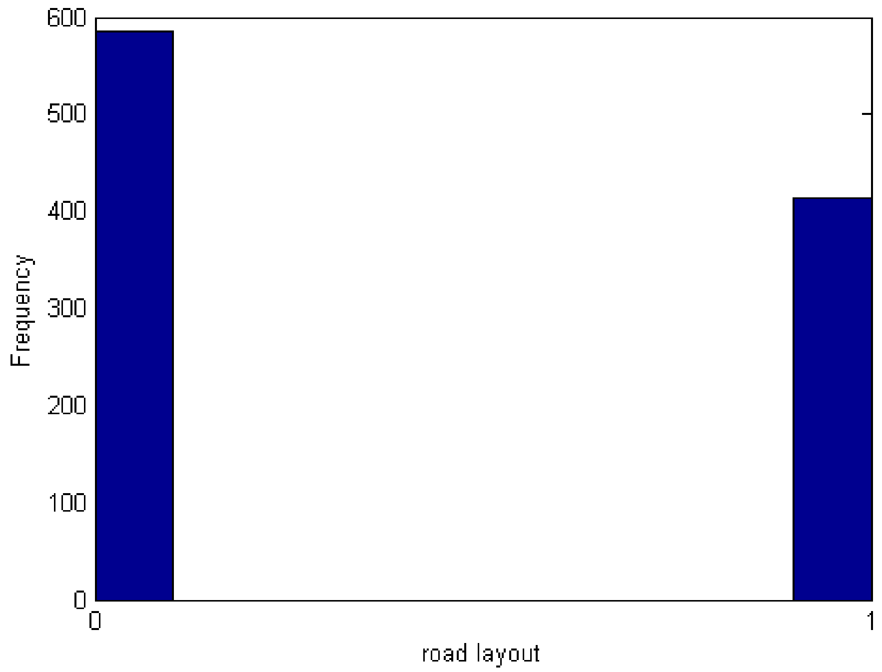

Figure 88 Road layout

The road layout was in 56.5% of the scenarios straight and in 43.5% curved, Figure 88.

Lighting conditions

- 0, which is dark
- 1, which is light

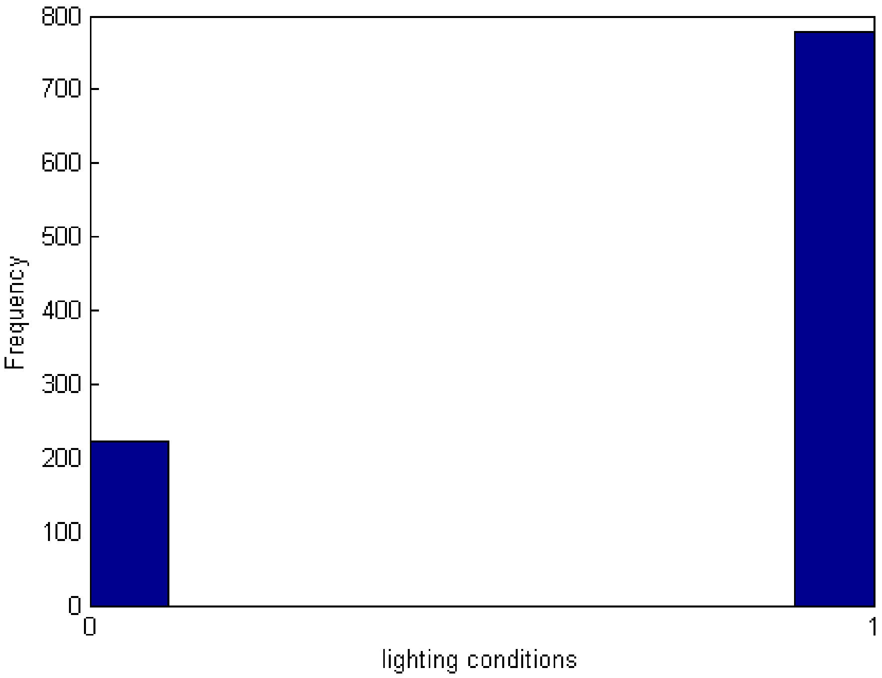

Figure 89 Lighting conditions

In 21.5% it was dark and 78.5% of the scenarios were during daytime, Figure 89.

Summary of car to car collision

Table 54 Comparison of results from statistics and the scenario generator in car to car collisions

Parameter	Description		Mean value/distribution from statistics (from mixed distribution)	Mean value/distribution from scenario generator
driving speed	ego car	ego speed	70(72) km/h	74 km/h
driving speed target	target car	target speed	29 km/h	24 km/h
distance/TTC	-	-	set to 5 seconds	100 m
angle between cars	initial	-	-	-
lateral offset	initial	-	-	-
acceleration	-	target acc	1.17 m/s²	1.5 m/s²
sex	general fatalities	male	76 %	73 %
		female	24 %	27 %
weather	surface	dry	53 %	40 %
		wet	18 %	37 %
		unknown	29 %	23 %
	visibility	fine	41 %	40 %
		cloudy	37 %	35 %
		rainy	18 %	21 %
		snowy	4 %	4 %
road layout	-	straight	59 %	56 %
		curve	41 %	44 %
light	-	darkness	21 %	22 %
		light	79 %	78 %

Table 54 shows the results of the scenario generator in comparison to the distributions from the statistics. It can be seen that the result converge rather exactly to the statistical values.

4.1.2 Pedestrian collisions

Driving speed

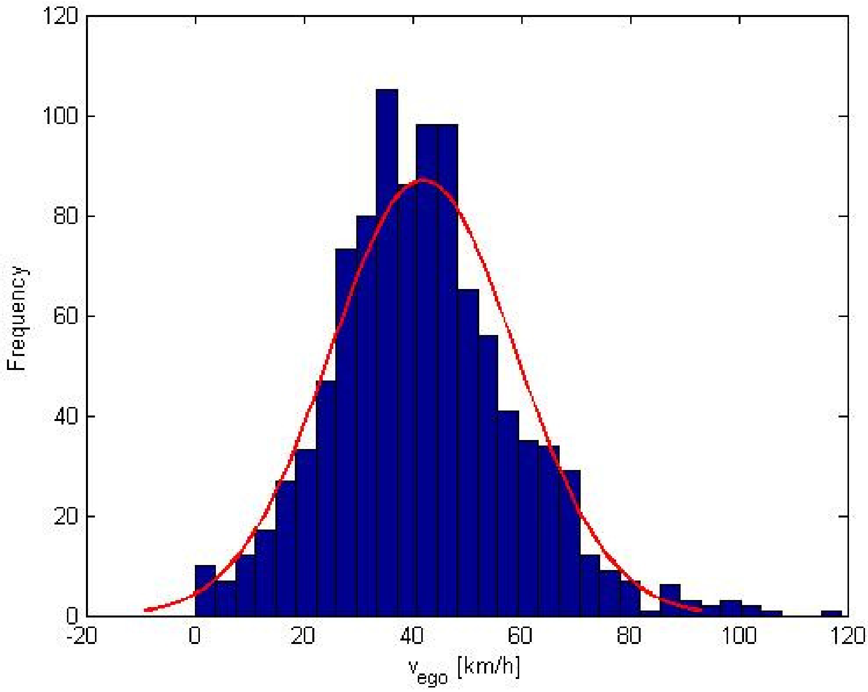

Figure 90 Ego car driving speed v_{ego}

The resulting mean value of the ego car driving speed is 42 km/h, which is very close to the results from ASSESS, Figure 90.

Pedestrian speed

The pedestrian speed was set to a constant value of 5.3 km/h based on information from [51].

Initial distance

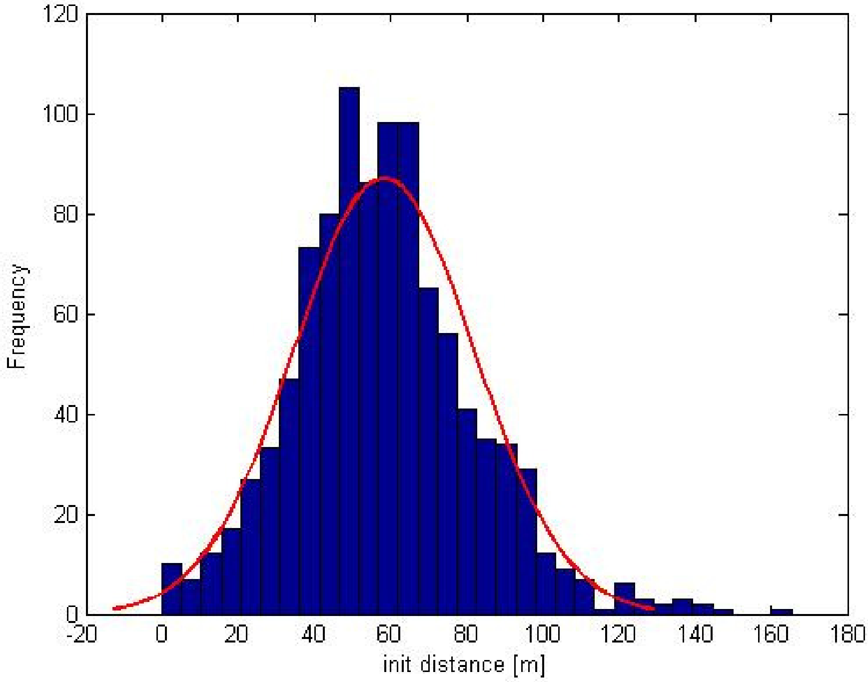

Figure 91 Initial distance

The initial distance for the pedestrian scenario is about 58 m, Figure 91. This is a result of setting the initial distance to 5 seconds, in order to ensure a gap, between the ego car and the pedestrian, big enough, to guarantee that the car detection systems does not react to the pedestrian at the simulation start.

Pedestrian sex

- 0, which is male
- 1, which is female

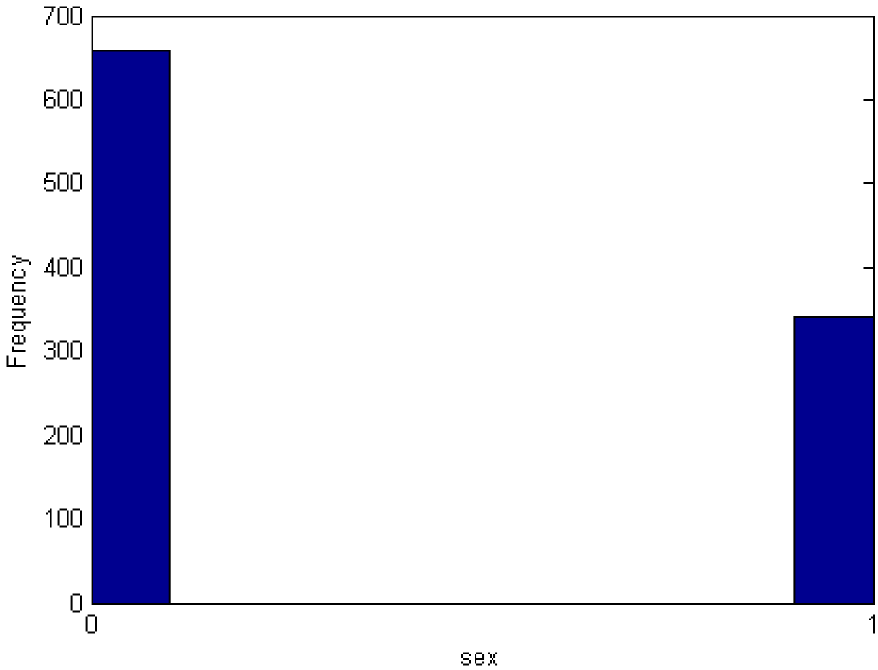

Figure 92 Sex

Of all the pedestrians in the scenarios 64% are male and 36 % female.

Weather conditions

- 0, which is fine
- 1, which is not fine

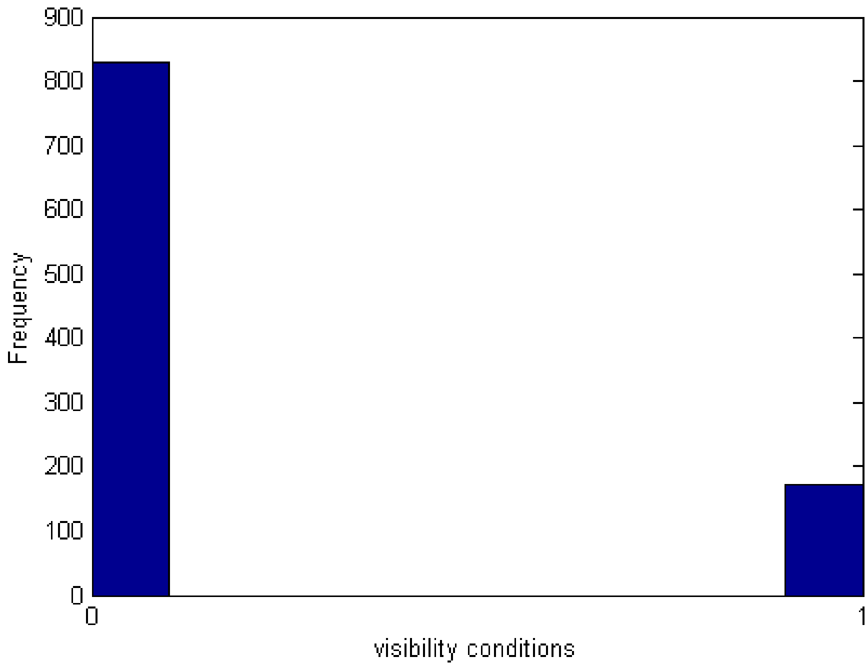

Figure 93 Visibility conditions

The weather conditions result to be in 82.9% of the scenarios fine and in 17.1% not fine, Figure 93.

Road layout

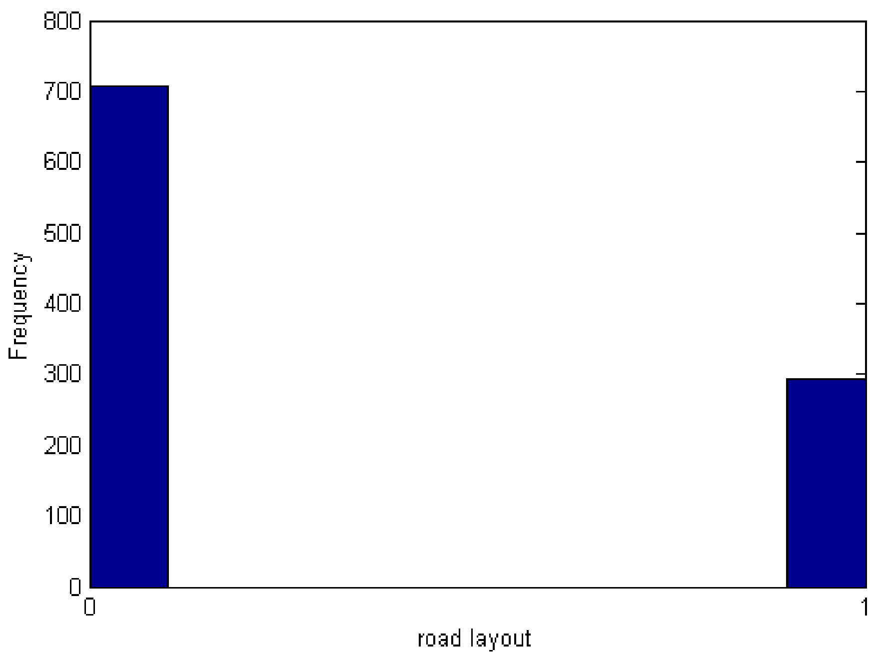

Figure 94 Road layout

Concerning the road layout, 72.2% of the scenarios occur in urban areas while 27.8% happen in rural areas, Figure 94.

Lighting conditions

- 0, which is dark
- 1, which is light

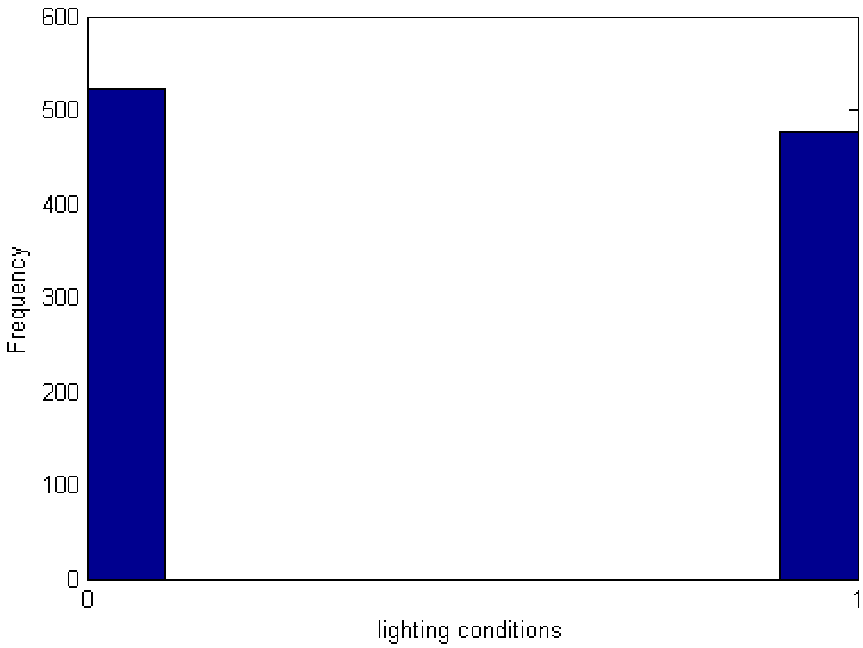

Figure 95 Lighting conditions

The distribution between darkness and light is rather even with 50.2 % scenarios in the dark and 49.8% in light, Figure 95.

Summary of pedestrian collision

Table 55 Comparison of results from statistics and the scenario generator in pedestrian collisions

Parameter	Description		Mean value/distribution from statistics (from mixed distribution)	Mean value/distribution from scenario generator
driving speed	-	ego speed	44(41) km/h	42 km/h
target speed	-	target speed	5.29 km/h	5.29 km/h
sex	pedestrian	male	64 %	64 %
		female	36 %	36 %
weather	visibility	fine	82 %	83 %
		not fine	14 %	17 %
road layout	-	inside urban	71 %	72 %
		outside urban	29 %	28 %
light	-	darkness	51 %	50 %
		light	49 %	50 %
initial distance	-	-	set to 5seconds	58 m

As Table 54 and Table 55 show the results from the scenario generator are very similar to the values from the statistics. However these results are based on a generic approach and will be discussed later on.

4.2 Results from IPG Carmaker

For the simulations in IPG Carmaker two basic approaches were carried out. First, for each of the scenarios, car to car and pedestrian collision, 100 simulations were performed. These simulations were performed with an Emergency Brake Assistant. The main goal of this test series was to check how many collisions could be possibly avoided in those scenarios with the usage of an EBA system in comparison to a driver that does not react at all. This step was called the “Possible avoidance”.

In a further step one specific case out of the 100 scenarios mentioned above was picked out and researched in more detail. For this scenario different variations in the EBA system were made to see how this affects the outcome of the collision. As main parameter for evaluating the systems efficiency and the benefit or harm the variations in the system led to, the impact speed was chosen. This step was called “EBA variation”.

The basic setting of the EBA system included following parameters:

Long range sensor

- Range: 150 m
- Opening angle: 16°
- Type of tracking: Following driving lane[6]

Time of intervention: at $TTC = 3$ s

Maximum deceleration: 2.5 m/s²

These values do not represent real EBA systems, which react with a much shorter time of intervention and higher deceleration values. However, the main goal of this chapter was to demonstrate the consequences that variations of the EBA system have and to show the possible potential that such systems bear. There was no intention of actual testing of realistic systems.

Additionally a short range sensor was added to the car. This sensor was mainly used for detecting a contact between the ego car and the target. Also the resulting impact speeds were determined by this sensor. Its properties are:

Short range sensor

- Range: 5 m
- Opening angle: 170°
- Type of tracking: Next target[7]

4.2.1 Car to car collision

The parameters for all car to car collisions imported from the scenario generator were the following:

[6] The detection of the target is done by investigating the vehicle trajectory, width of driving lane and distance to the object.
[7] The sensor identifies the closest object and calculates the distance. The object with the smallest overall distance is defined as the target.

- Ego car driving speed v_{ego}
- Target car driving speed v_{target}
- target deceleration a_{target}
- initial distance s_{init}
- coefficient of friction μ

The coefficient of friction is based on the road surface condition generated in the scenario generator. Together with information from [52] the following values were defined:

- Dry surface: $\mu = 0.8$
- Wet surface: $\mu = 0.5$
- Unknown surface condition: $\mu = 0.7$

The test scenario was set up of two cars following each other. The ego car was equipped with a radar sensor measuring the distance between itself and the target car in front. The ego car started with v_{ego} and the target car with v_{target} with the initial distance s_{init} between those two. The deceleration a_{target} of the target car was immediately applied. Since the deceleration of the target car and the driving speed of the target car may both resulted in a value of zero, stopped target car scenarios and constantly slower driving target car scenarios were included.

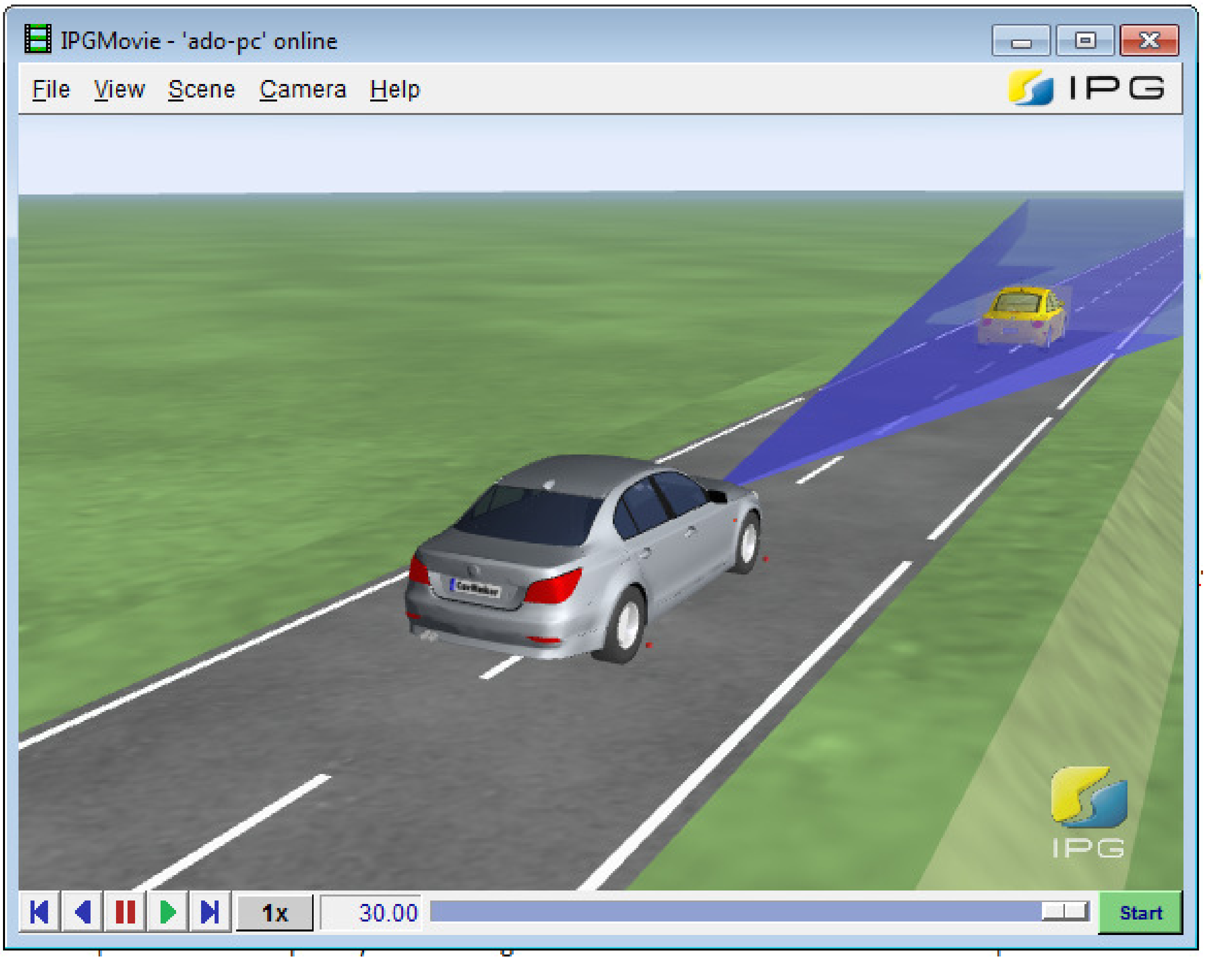

Figure 96 IPG Carmaker car to car scenario

Possible avoidance

From the 100 simulations carried out the within the Carmaker, the EBA system with its default settings avoided 84% of the collisions. This is a rather high value. However it is resulting from a comparison to a completely not reacting driver. The rate of collisions avoided compared to a real driver cannot be answered in this work, since the basic approach for all steps has always been the worst case situation with a non reacting driver. Thus with a few modifications in the calculations of the parameters as shown in chapter 3 and the implementation of a driver model, the scope of this work can be expanded for reviewing such scenarios.

EBA variation

The following scenario was chosen for the EBA variation in a car to car collision:

- v_{ego} = 92.75 km/h
- v_{target} = 0 km/h
- a_{target} = 0 m/s²
- s_{init} = 128.82 m
- μ = 0.5

These values show that it was a scenario with a stopped target vehicle and a wet road surface.

This scenario led to a crash with the standardised setting from the EBA system. In the following a variation of the maximum deceleration performed by the EBA system of the ego car was done.

With a maximum deceleration value of a = 2.5 m/s² this scenario resulted in a crash with a resulting impact speed v_{impact} of 26.8 km/h.

- Variation 1
    - For variation 1 the maximum deceleration performed by the EBA system was set to a = 3 m/s². With this variation the accident could completely be avoided.
- Variation 2
    - In variation 2 the deceleration maximum was set to a value of a = 2 m/s². This resulted in a collision with a resulting impact speed v_{impact} = 47.9 km/h.

Summary

Table 56 Summary of IPG Carmaker EBA variations c2c

Name	a [m/s²]	v_{impact} [km/h]
Standard	2.5	26.8
Variation 1	3	avoided
Variation 2	2	47.9

This shows how the variation of one parameter, in this case the maximum deceleration performed by the EBA system can change the accident outcome. While raising the maximum value by 0.5 m/s² the accident could be completely avoided, a reduction by 0.5 m/s² resulted in a collision with almost the double impact speed

4.2.2 Pedestrian collision

For the pedestrian collision the following parameters from the scenario generator were used:

- Ego car driving speed v_{ego}
- initial distance s_{init}
- coefficient of friction μ

The pedestrian speed v_{ped} was set to 5.3 km/h.

The scenario contained a pedestrian crossing the street with the velocity v_{ped}. The ego car started with the initial speed v_{ego} from the initial distance s_{init}. The pedestrian started to walk after 2.5 seconds. This is a critical time, since the initial distance calculated is based on a 5 seconds gap. This means that there were only 2.5 seconds left to react and stop the car.

For this test an additional short range radar sensor was added to the car. It has a smaller longitudinal range but covers a wider field of width with a higher opening angle as it can be seen in Figure 97.

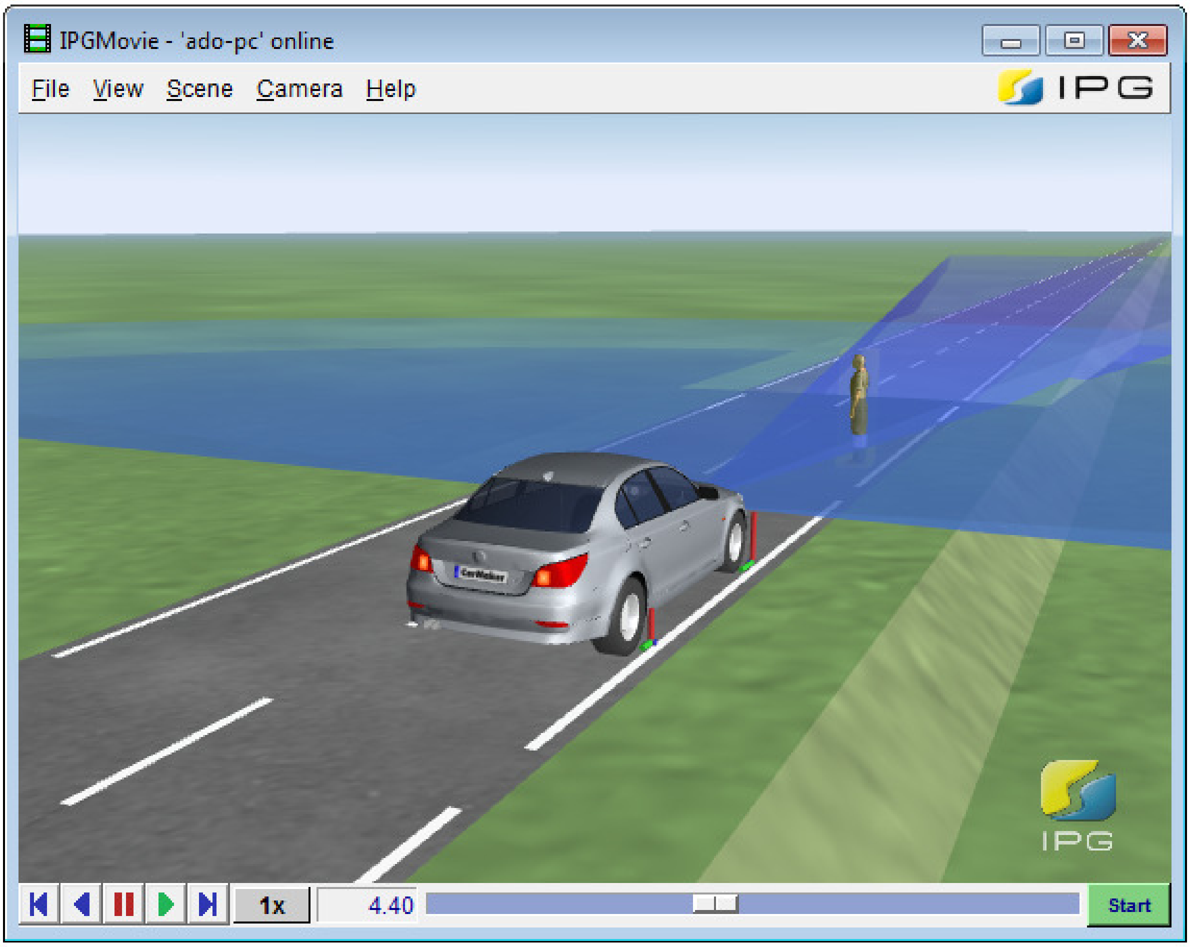

Figure 97 IPG Carmaker pedestrian scenario

Possible avoidance

In the 100 pedestrian scenarios only 4 accidents occurred, meaning an avoidance of 96% under the named parameters and conditions. Thus a change of the pedestrian's starting time to cross the road from 2.5 to 3 changed the result dramatically to 61% avoidance. This shows the importance of this parameter. It is very hard to make predictions about it since it only depends on the pedestrian.

EBA variation

For the EBA variation the following pedestrian crossing scenario was chosen:

- v_{ego} = 50.72 km/h
- s_{init} = 70.45 m
- μ = 0.8
- pedestrian starts after 3 seconds

The pedestrian started to cross the road after 3 seconds. The EBA system reacted with a delay of 0.5 seconds to the pedestrian's movement and started to brake with the maximum deceleration value of a = 2.5m/s² in the standard configuration. This resulted in a collision with a v_{impact} of 36.4 km/h.

- Variation 1
  - In this variation the maximum deceleration value a, of the EBA system, was raised to 3 m/s². With this change the collision was avoided.
- Variation 2
  - In this variation the maximum deceleration value a was set back to 2.5m/s² but the reaction time of the EBS system was also reduced to react faster (0.1 seconds delay) to the pedestrian movement on the side of the road. The result was an avoidance of the collision.

Summary

Table 57 Summary of IPG Carmaker EBA variations ped

Name	a [m/s²]	Start of braking relative to start of pedestrian movement [s]	v_{impact} [km/h]
Standard	2.5	0.5	36.4
Variation 1	3	0.5	avoided
Variation 2	2.5	0.1	avoided

The summary in Table 57 shows again that an increase of the maximum deceleration performed by the EBA system bears a certain safety benefit. In this special case the accident was avoided by this measure. Another interesting result is that a reduction of the system's reaction time by 0.4 seconds completely avoided the accident from variation 2. The variation of this parameter seems to be of special importance for the crossing pedestrian scenario. Due to the lateral movement of the pedestrian the reduction of the reaction time of the EBA system in the car was just enough to reduce the speed to such an extent that the car passed the pedestrian without contact.

In the next chapter the results from the Scenario Generator and the IPG Carmaker will be discussed shortly.

5 Discussion

This present thesis deals mainly with the testing assessment of ADAS, especially EBA systems, the results from chapter 4 shall be reviewed and discussed in this chapter.

One of the goals of this work was the generation of statistical relevant testing scenarios for EBA systems. These scenarios should not only contain the “standard” scenarios similar to the ones tested by other projects but also some rare configurations like snowy conditions and scenarios in the dark. The difference between this approach and the “standard” manoeuvres is that this enables the possibility to rate the system under conditions closer to the “Real Life” situations. This means that the system’s actual field effectiveness, and so the “Real Life Benefit”, can be assessed instead of rating the system in one certain scenario set up.

Looking at the results from the scenario generator in Table 54 and Table 55 it can be seen that the results of a large number of created configurations converge rather exactly to the results they are based on. This shows that the random selection based on the statistical distributions performed by a MATLAB script is working. However the values for the driving speed were implemented by a generic approach. This bears some insecurity in the results. It can be not foreseen how the actual speed distributions gathered from the in-depth databases will look like. Therefore the out coming distribution of the total driving speed distribution based on the mixed distribution approach cannot be foreseen. In this work the assumption was made that all speeds are distributed normally.

The statistical data is based mostly on work done by other projects and macroscopic databases. Although this data is rather convenient, this work would probably profit from an own in-depth database research. This would provide a higher variability in the parameter choice and would enable to specialize the scenario generator to the project in which it is currently implemented by choosing the needed parameters.

In paragraph 3.7 two possible approaches of checking the results of the speed distributions are stated. Thus the mixed distribution approach seems to be the more accurate way to check the speed distribution alone, since it is based on the same data as the different sub-distributions. However the results of the mixed distribution have to be compared to real world data, to see if the performed in-depth research delivered correct data. Some methods for these comparisons are stated in paragraph 3.7.1 and 3.7.2.

The mixed distribution approach in this work is based on 48 eight sub-speed distributions. This is a rather high number of divisions and so the number of available cases from the in-depth databases should not be too low. This might result in problems with smaller databases, which do not contain many accidents. However this could be avoided for example by collecting data from a greater time span and so getting more results.

For the tests in the IPG Carmaker two different approaches were chosen for each collision type. First 100 scenarios from the scenario generator were run with an EBA equipped car and the number of avoided crashes was checked. However the reference here was the worst case scenario, a completely non reacting driver. Due to that it cannot be said how high the crash avoidance number in a real life scenario would be with a reaction of the driver. This test was mainly performed to check if the scenarios generated are working and to examine the maximum possible collision avoidance number for the system with the described standard settings. Of course there are some variables which were set to certain values over the whole test series, but highly affect the outcome. For example the starting of the target vehicle deceleration and the pedestrian movement are two important factors that can be hardly foreseen.

In a second step some variations were applied to the EBA system, mainly affecting the maximum deceleration value performed or the time of intervention. It was shown that variations of these parameters highly influence the outcome, from complete collision avoidance to almost doubling the resulting impact speed. Especially in the pedestrian collision the importance of the variations was demonstrated. As the pedestrian is a lateral moving target, the reduction of the speed led in one case to complete collision avoidance, due to the fact that the car passed the constantly moving pedestrian without contact. Since the pedestrian has a rather low lateral moving speed, this effect may be bigger on targets with higher speed like cars crossing the street at intersections.

However the rating was only based on the avoidance of the collision and the reduction of the impact speed. Although these two criteria are very important factors when it comes to the injuries resulting from an accident, other accident characteristics have to be also considered. For example the position of the first contact is one important factor not reviewed in this work. It is clearly a difference if a pedestrian is hit with the middle point of the car front or if he is hit on a more left or right point. Taking the example from before, a further speed reduction caused by a more “aggressive” setting of the EBA system may result in a first contact point on the very left side of the car. The problem might be that the pedestrians head hits against the A-pillar of the car instead of the front window. This probably results in a more severe injury though the impact speed is lower than in an EBA system with regular setting. This is just one example but it shows the problems with rating ADAS like EBA systems.

6 Summary

6.1 Conclusion

In order to test and assess driver assistance systems with simulations, starting scenarios for the application of these systems are needed. This thesis focused on the Emergency Brake Assist system and its usage in rear end collisions and pedestrian collisions. Therefore a scenario generator was programmed in MATLAB based on real accident data. The results from this scenario generator were exported to IPG Carmaker and various simulations were run to check collision outcomes with the usage of an EBA system.

6.1.1 Rear end collision

As Table 54 shows the results from the 1000 generated scenarios converge rather exactly against the values from the statistics taken from ASSESS and the values calculated with the mixed distribution approach. The results in the mean ego driving speeds differ only by approximately 5% from the ASSESS results and only around 3% from the mixed distribution approach. The results in the mean driving speed of the target car also differ only around 8% from the ASSESS values. This is a rather interesting result since the calculation of the target speed contains the impact speed which was set generically, the time distance which was set to a value of $t = 3$ seconds and the target deceleration which was calculated from all available projects. All the other variables converge highly against the values from the statistics of course since the distribution is implemented in the generator. The target deceleration differs by almost 30%. This is probably due to the fact that the calculation of the deceleration was adjusted that the results contain also scenarios with non decelerating target cars. The share of the three possible scenarios looks quite convenient. As can be seen in Figure 82 and Figure 84, the share on the scenarios with non decelerating targets is almost one third as well as the share with stopped targets, leaving one third with decelerating targets.

From the 100 simulations in IPG Carmaker 16% ended with a collision of the two cars. This was checked against a completely non reacting driver, meaning that these 16% of the collisions were not avoidable with the standard settings used for the EBA system. In the variations of the EBA system the influence of a possible change in the system was demonstrated. In this case the maximum deceleration value the EBA system performed was varied. The outcome of the scenario reached from an avoidance of the collision by setting the maximum deceleration value to 3 m/s² instead of 2.5 m/s², to almost doubling the impact speed by reducing the value to 2 m/s².

6.1.2 Pedestrian collision

Looking at the results from the pedestrian collision scenarios in Table 55, it can be seen that they converge in a similar way to the statistics they are based on, likely to the rear end collision scenarios. The difference between the mean driving speed of the generated scenarios and the statistical values is only about 5%. The difference between the generated and the mixed distribution mean value of the driving speed is even lower with about 2%.

From the 100 scenarios tested in IPG Carmaker only 4% were not avoidable with the system's standard settings. In order to demonstrate the impact of the pedestrian's choice of starting to cross the road, this parameter was changed to 3 seconds after the simulation start, instead of 2.5 seconds. As a consequence the avoidance number decreased to 61%. For the EBA variation in the case of pedestrian scenario two different variables were changed. At first the maximum value of the deceleration performed by the EBA system was raised by 0.5 m/s^2 to a value of 3 m/s^2. This resulted in an avoidance of the accident which had a resulting impact speed of 36.4 km/h in the standard setting. Then this maximum deceleration value was set back to 2.5 m/s^2, but the systems time of reaction was shortened from formerly 0.5 seconds after the pedestrian started moving to 0.1 seconds. This resulted in an avoidance of the accident. The car could not be stopped either, but due to the more time for braking it just missed the pedestrian, which was constantly moving on.

With the results from the IPG carmaker simulations it can be said that already small differences in the intervention strategies may result in big differences of the accident outcome. However this cannot be taken as a request to make the setting of the EBA system more "aggressive" to avoid more collisions or at least to mitigate the consequences of an accident. Other factors have to be considered. For example a false triggering of the system may cause accidents, or the driver reaction in combination with the systems' intervention may lead to unforeseen and uncontrollable situations.

6.2 Outlook

This work will be completed in the near future with the data from the in-depth databases ZEDATU and GIDAS. From this, the data concerning the driving speeds will be finalised and implemented into the scenario generator. After this, the scenario generator will be implemented into the development environment of the Virtual Vehicle Research Center project described in paragraph 1.4.2 and 3.1. This will form the basis for a new assessment method, based on numerical simulations, with the goal the rate the actual field effectiveness of the system. It will make it possible to actually rate the real life benefit of s safety system instead of the benefit it has in a certain test set up.

List of Figures

Figure 1 Reported road fatalities, injury crashes, motorised vehicles and vehicle-kilometres [1].......... 1
Figure 2 Comparison EU-27/World - 2010 (passenger cars/1000 inhabitants) [4]................................ 2
Figure 3 Annual number of fatalities, injury accidents and injured people (EU-27), 2001-2010 [6] 3
Figure 4 The number of road accident fatalities in the EU-24, 2000-2010, compared with the trend required to reach the 2010 objective [8]... 3
Figure 5 Aspects of traffic safety and examples for safety measures [10].. 4
Figure 6 The Beyond NCAP assessment method [13]... 5
Figure 7 Trends and outlooks in passenger transport demand for the different modes of transport in EU-25 - 1990-2030 (Gpkm) [4] 12
Figure 8 Road accidents involving personal injury per thousand of population EU-27 – 2010 [4]...... 12
Figure 9 Change in road fatalities between 2001 and 2010 (%) [4]... 13
Figure 10 Evolution of road fatalities and injured in EU-27 - 2000-2010 [4]...................................... 13
Figure 11 Pedestrian fatalities per million inhabitants by country, 2010 [23] 16
Figure 12 Number of pedestrian fatalities and proportion of total fatalities in EU-19, 2001-2010 [23]17
Figure 13 The number of pedestrian fatalities by age group, EU-19, 2001 and 2010 [23]................... 17
Figure 14 Pedestrian fatalities as a percentage of all fatalities by age group, EU-24, 2010 [23].......... 18
Figure 15 Elderly pedestrian fatalities (age >64) as a percentage of all pedestrian fatalities, EU-24, 2010 [23] 18
Figure 16 Driver assistance system control loop [26].. 20
Figure 17 Sensors and their range [27]... 21
Figure 18 Approaching a slow-moving object [30]... 25
Figure 19 Approaching an object decelerating constantly [30].. 25
Figure 20 Approaching an object which has come to a halt[30]... 26
Figure 21 Approaching a stationary object [30].. 26
Figure 22 Fail operation test A1 – cornering [30]... 26
Figure 23 Fail operation test A2 – overtaking of moving traffic [30].. 27
Figure 24 Fail operation test A3 – implausible braking [30] 27
Figure 25 Fail operation test A4 – approaching a stationary object [30] 28
Figure 26 Approaching a stopped vehicle at test speeds from 10 to 60km/h [33] 29
Figure 27 Approaching at 10km/h a car stationary at a junction [33].. 29
Figure 28 Approaching a moving target at 20km/h [33]... 30
Figure 29 Approaching a decelerating target, both initially moving at 50km/h [33]............................ 30
Figure 30 Unobscured pedestrian walks out from nearside [33]... 31
Figure 31 Obscured pedestrian walks out from nearside [33]... 31
Figure 32 Unobscured pedestrian runs out in front of car from far side [33].. 32
Figure 33 Pedestrian walking along the road at night [33]... 32
Figure 34 Car turns at junction and pedestrian walks out [33].. 33
Figure 35 Child crosses from near-side behind an obstruction [37].. 34
Figure 36 Elderly crosses from far side [37] 34
Figure 37 Adult crosses from far-side [37] 35
Figure 38 Slower lead vehicle [41] 36
Figure 39 Decelerating lead vehicle (until stopped) [41] 36
Figure 40 Stopped lead vehicle [41].. 37
Figure 41 Approach to stationary target [42] 37

Figure 42 Approach to stationary target [42] 38
Figure 43 Approach to slower target [42] 39
Figure 44 Approach to braking target [42] 39
Figure 45 Lead Vehicle Stopped (LVS) [43] 41
Figure 46 Lead Vehicle Moving (LVM) [43] 41
Figure 47 Lead Vehicle Decelerating (LVD) [43] 41
Figure 48 Rear end collision scenarios [45] 43
Figure 49 Transversal car to car collision [45] 44
Figure 50 Car to pedestrian collision [45] 44
Figure 51 Distribution of scenarios [37] 45
Figure 52 Adult crossing from the right [37] 46
Figure 53 Child crossing from the left [37] 46
Figure 54 Child crossing from the right [37] 46
Figure 55 Adult crossing from the right (left turn) [37] 47
Figure 56 Adult crossing from the right (right turn) [37] 47
Figure 57 Test procedures FCW (proposal) LVS [37] 48
Figure 58 Test procedures FCW (proposal) LVM [37] 48
Figure 59 Test procedures FCW (proposal) LVD [37] 48
Figure 60 Test procedures AEB (proposal) LVS [37] 49
Figure 61 Test procedures AEB (proposal) LVM [37] 49
Figure 62 Test procedures AEB (proposal) LVD [37] 49
Figure 63 Simulation schedule for car to pedestrian accident scenario [14] 50
Figure 64 Moving target car (c2c_tcm) v_{ego} 52
Figure 65 Moving target car (c2c_tcm) v_{target} 52
Figure 66 Moving target car (c2c_tcm) distance 53
Figure 67 Moving target car (c2c_tcm) Δv 53
Figure 68 Decelerating target car (c2c_tcd) deceleration target car 54
Figure 69 Decelerating target car (c2c_tcd) distance 54
Figure 70 Stopped target car (c2c_tcs) v_{ego} 55
Figure 71 Stopped target car (c2c_tcs) distance 55
Figure 72 Unobstructed pedestrian from nearside (ped_un_ns) v_{ego} 56
Figure 73 Unobstructed pedestrian from nearside (ped_un_ns) v_{target} 56
Figure 74 Unobstructed pedestrian from farside (ped_un_fs) v_{ego} 57
Figure 75 Unobstructed pedestrian from farside (ped_un_fs) v_{target} 57
Figure 76 Obstructed pedestrian from nearside (ped_ob_ns) v_{ego} 58
Figure 77 Obstructed pedestrian from nearside (ped_ob_ns) v_{target} 58
Figure 78 Obstructed pedestrian from farside (ped_ob_fs) v_{ego} 59
Figure 79 Obstructed pedestrian from farside (ped_ob_fs) v_{target} 59
Figure 80 Scenario Generator GUI 75
Figure 81 Ego car driving speed v_{ego} 76
Figure 82 Target car driving speed v_{target} 77
Figure 83 Initial distance 78
Figure 84 Target deceleration 79
Figure 85 Sex 80
Figure 86 Visibility conditions 81
Figure 87 Road surface 82
Figure 88 Road layout 83
Figure 89 Lighting conditions 84

Figure 90 Ego car driving speed v_{ego} ... 86
Figure 91 Initial distance ... 87
Figure 92 Sex ... 88
Figure 93 Visibility conditions ... 89
Figure 94 Road layout ... 89
Figure 95 Lighting conditions ... 90
Figure 96 IPG Carmaker car to car scenario ... 93
Figure 97 IPG Carmaker pedestrian scenario ... 95

List of Tables

Table 1 Transport network (in 1000 km) [4] ... 11
Table 2 Rear end collision results from ASSESS [24] ... 19
Table 3 Approaching a slow-moving object parameters [30] ... 25
Table 4 Approaching an object decelerating constantly[30] ... 25
Table 5 Approaching an object which has come to a halt [30] ... 26
Table 6 Approaching a stationary object [30] ... 26
Table 7 Cornering [30] ... 27
Table 8 Overtaking of moving traffic [30] ... 27
Table 9 Implausible braking [30] ... 27
Table 10 Approaching a stationary object [30] ... 28
Table 11 Approaching a stopped vehicle at test speeds from 10 to 60km/h [33] ... 29
Table 12 Approaching at 10km/h a car stationary at a junction [33] ... 30
Table 13 Approaching a moving target at 20km/h [33] ... 30
Table 14 Approaching a decelerating target, both initially moving at 50km/h [33] ... 31
Table 15 Unobscured pedestrian walks out from nearside [33] ... 31
Table 16 Obscured pedestrian walks out from nearside [33] ... 32
Table 17 Unobscured pedestrian runs out in front of car from far side [33] ... 32
Table 18 Pedestrian walking along the road at night [33] ... 32
Table 19 Car turns at junction and pedestrian walks out [33] ... 33
Table 20 Child crosses from near-side behind an obstruction [36] ... 34
Table 21 Elderly crosses from far side [36] ... 34
Table 22 Adult crosses from far-side [36] ... 35
Table 23 Slower lead vehicle [40] ... 36
Table 24 Decelerating lead vehicle (until stopped) [40] ... 36
Table 25 Stopped lead vehicle [40] ... 37
Table 26 Approach to stationary target [42] ... 38
Table 27 Approach to stationary target [42] ... 39
Table 28 Approach to slower target [42] ... 39
Table 29 Approach to braking target [42] ... 40
Table 30 Approach to stationary target [45] ... 43
Table 31 Approach to moving target [45] ... 43
Table 32 Approach a decelerating target [45] ... 43
Table 33 Transversal car to car collision [45] ... 44
Table 34 Car to pedestrian collision [45] ... 44
Table 35 Adult crossing from the right [37] ... 46
Table 36 Child crossing from the left [37] ... 46
Table 37 Child crossing from the right [37] ... 47
Table 38 Adult crossing from the right (left turn) [37] ... 47
Table 39 Adult crossing from the right (right turn) [37] ... 47
Table 40 Test procedures FCW (proposal) LVS [37] ... 48
Table 41 Test procedures FCW (proposal) LVM [37] ... 48
Table 42 Test procedures FCW (proposal) LVD [37] ... 48
Table 43 Test procedures AEB (proposal) LVS [37] ... 49
Table 44 Test procedures AEB (proposal) LVM [37] ... 49

Table 45 Test procedures AEB (proposal) LVD [37] 49
Table 46 Possible parameters rear end collision 61
Table 47 Final car to car collision parameters.. 62
Table 48 Possible parameters pedestrian collision 63
Table 49 Final pedestrian collision parameters 64
Table 50 Independent (white)/Dependent (orange) parameters car to car collision............................. 65
Table 51 Independent (white)/Dependent (orange) parameters pedestrian collision 66
Table 52 Generic data car to car collision 68
Table 53 Generic data pedestrian collision 70
Table 54 Comparison of results from statistics and the scenario generator in car to car collisions...... 85
Table 55 Comparison of results from statistics and the scenario generator in pedestrian collisions 91
Table 56 Summary of IPG Carmaker EBA variations c2c.. 94
Table 57 Summary of IPG Carmaker EBA variations ped 96

Bibliography

[1] IRTAD, 2013, "IRTAD Annual Report 2013," International Transport Forum, Paris.

[2] Toroyan, T., 2013, "Global status report on road safety 2013: supporting a decade of action," World Health Organization, http://www.who.int/violence_injury_prevention/road_safety_status/2013/en/index.html.

[3] World Health Organization, 2009, "Global status report on road safety: time for action," World Health Organization, Geneva, Switzerland.

[4] Nicodème, C., Diamandouros, K., Díez, J., 2012, "European Road Statistics 2012," European Union Road Federation, Belgium.

[5] Brandstaetter, C., Evgenikos, P., Yannis, G., 2011, "Annual Statistical Report - 2011," Deliverable D3.1 of the EC FP7 project DaCoTA, http://www.dacota-project.eu/Deliverables/DaCoTA-WP3-D3.5/DaCoTA_WP3_D3_5_final-with-Annex.pdf.

[6] Brandstaetter, C., and et al., 2012, "Annual Statistical Report - 2012," DaCoTA, Deliverable D3.9 of the EC FP7 project DaCoTA, http://safetyknowsys.swov.nl/Statistics/Annual/DaCoTA-3.9-ASR-KFV-2012.pdf.

[7] Broughton, J., Knowles, J., Brandstatter, C., 2011, "Traffic Safety Basic Facts - 2011," DaCoTA, http://www.dacota-project.eu/Deliverables/DaCoTA-WP3-D3.6/BFS2011_DaCoTA-TRL-1-3-Main%20figures.docx.

[8] Broughton, J., Brandstatter, C., Yannis, G., 2012, "Traffic Safety Basic Facts 2012 - Main Figures," DaCoTA, http://www.dacota-project.eu/Deliverables/BFS%20ASR%202012/BFS2012_DaCoTA-TRL_Main%20figures.pdf.

[9] Kramer, F., 2006, "Passive Sicherheit von Kraftfahrzeugen; Biomechanik Simulation Sicherheit im Entwicklungsprozess," Friedr. Vieweg & Sohn Verlag , GWV Fachverlage GmbH, Wiesbaden; SpringerLink (Online service), Wiesbaden, .

[10] Eichberger, A., 2010, "Contributions to primary, secondary and integrated traffic safety," Vieweg, Wiesbaden, pp. XXIV, 172, LVIII S.

[11] NCAP, "ABOUT US l Euro NCAP - For safer cars crash test safety rating," NCAP, Website, http://www.euroncap.com/about.aspx.

[12] NCAP, "The rewards explained l Euro NCAP - For safer cars crash test safety rating," NCAP, Website, http://www.euroncap.com/rewards/explained.aspx.

[13] Ratingen, M.v., Williams, A., Castaing, P., "Beyond NCAP: promoting new advancements in safety," NCAP, 11-0075, http://www.euroncap.com/files/Beyond-NCAP-Promoting-New-Advancements-in-Safety---0-92d2029e-0c15-4f7c-be5e-1c6a9704c0c2.pdf.

[14] Wimmer, P., Rieser, A., and Sinz, W., 2013, "A new simulation method for virtual design and evaluation of integrated vehicle safety systems," Virtual Vehicle Research Center, Virtual Vehicle Research Center;University of Technology Graz;.

[15] Karabatsou, V., Pappas, M., Elslande, P.v., 2007, "A-priori evaluation of safety functions effectiveness - Methodologies," TRACE, Deliverable D4.1.3, http://www.trace-project.org/publication/archives/trace-wp4-d4-1-3.pdf.

[16] Yang, W., Chen, H., and Brown, D. B., 1999, "Detecting safer driving patterns by a neural network approach," Proceedings of the 1999 Artificial Neural Networks in Engineering Conference (ANNIE '99), Anonymous ASME, Fairfield, NJ, United States, **9,** pp. 839-844.

[17] Chong, M. M., Abraham, A., and Paprzycki, M., 2004, "Traffic Accident Analysis using Decision Trees and Neural Networks," CoRR, **cs.AI/0405050**.

[18] Page, Y., Riviere, C., Cuny, S., 2007, "A posteriori evaluation of Safety Functions effectiveness - Methodologies," TRACE, Deliverable D4.2.1, http://www.trace-project.org/publication/archives/trace-wp4-d4-2-1.pdf.

[19] Farmer, C. M., Lund, A. K., Trempel, R. E., 1997, "Fatal Crashes of Passenger Vehicles before and After Adding Antilock Braking Systems," Accident Analysis & Prevention, **29**(6) pp. 745-757.

[20] Evans, L., 1999, "Antilock Brake Systems and Risk of Different Types of Crashes in Traffic," Journal of Crash Prevention and Injury Control, **1**(1) pp. 5-23.

[21] Page, Y., and Cuny, S., 2006, "Is Electronic Stability Program Effective on French Roads?" Accident Analysis & Prevention, **38**(2) pp. 357-364.

[22] Tomasch, E., and Steffan, H., 2013, "Biomechanics 02 - Accident Analysis and Statistics," Vehicle Safety Institute - University of Technology Graz, Graz.

[23] Pace, J. F. et al., 2012, "Basic Fact Sheet "Pedestrians"," DaCoTA, Deliverable D3.9 of the EC FP7 project DaCoTA, http://www.dacota-project.eu/Deliverables/BFS%20ASR%202012/BFS2012_DaCoTA_INTRAS_Pedestrians.pdf.

[24] Wisch, M., Fagerlind, H., Sulzberger, L., 2010, "Specifications for scenario definitions," ASSESS, Deliverable D1.2, http://www.assess-project.eu/downloadables/Public%20Deliverables/ASSESS%20D1.2%20-%20FINAL-Detailed%20analysis%20of%20field%20data-PUBLIC-2010.12.21.pdf.

[25] Winner, H., Hakuli, S., and Wolf, G., 2012, "Handbuch Fahrerassistenzsysteme; Grundlagen, Komponenten und Systeme für aktive Sicherheit und Komfort," Vieweg+Teubner Verlag / Springer Fachmedien Wiesbaden GmbH, Wiesbaden; SpringerLink (Online service), Wiesbaden, .

[26] Eichberger, A., Bernsteiner, S., Magosi, Z.F., 2013, "Virtuelle Absicherung von Gesamtfahrzeugintegration bei Fahrerassistenzsystemen am Beispiel Abstandstempomat, Notbremsassistent und Spurhalteassistent," Verband deutscher Ingenieure (VDI), Baden-Baden.

[27] Sinz, W., Schneider, B., Klein, E., 2013, "LÜ Crashtest - Active Safety – Pedestrian Protection," Vehicle Safety Institute - University of Technology Graz, Graz.

[28] Eren, T., Goldenberg, O. K., Whiteley, W., 2004, "Rigidity, computation, and randomization in network localization," INFOCOM 2004. Twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies, Anonymous **4,** pp. 2673-2684 vol.4.

[29] ActiveTest, "Active Test > Active Testing > Initiatives," ActiveTest, Website, http://www.activetest.eu/.

[30] ADAC, 2011, "Comparative test of advanced emergency braking systems," ADAC, http://www.activetest.eu/pdf/adac_aebs_report_en.pdf.

[31] Gauss, C., and Silvestro, D., 2011, "ADAC test procedure for advanced emergency braking systems (AEBS)," ADAC, http://www.activetest.eu/pdf/workshop1/02_silvestro_adac.pdf.

[32] Lenard, J., and Danton, R., 2010, "Accident data study in support of development of Autonomous Emergency Braking (AEB) test procedures," Loughborough Enterprises Ltd.;Loughborough University., Loughborough.

[33] Avery, M., 2011, "Autonomous Emergency Braking," AEB Test Group, http://www.activetest.eu/pdf/workshop1/03_petersson_aeb.pdf.

[34] Nombela, M., 2011, "aspecss presentation," ASPECSS, ActiveTest Workshop on Collision warning and autonomous braking systems.

[35] Wisch, M., Seiniger, P., Pastor, C., 2013, "Scenarios and weighting factors for precrash assessment of integrated pedestrian safety systems," ASPECSS, Deliverable D1.1, http://www.aspecss-project.eu/userdata/file/Public%20deliverables/ASPECSS-D1.1-FINAL-Scenariosweighting-BASt-2013-02-17-PUBLIC.pdf.

[36] ASPECSS, 2013, "ASPECSS Newsletter N°3," aspecss, http://www.aspecss-project.eu/userdata/file/Newsletters%20and%20leaflets/ASPECSS-Newsletter%203%20Issue-March-2013.pdf.

[37] Schebdat, H., 2011, "Advanced Forward-Looking Safety Systems –Working group introduction and status update first Active Test Workshop," vFSS, http://www.activetest.eu/pdf/workshop1/05_schebdat_vfss.pdf.

[38] McCarthy, M., Fagerlind, H., Heinig, I., 2009, "Preliminary Test Scenarios," ASSESS, Deliverable D1.1, http://www.assess-project.eu/downloadables/Public%20Deliverables/ASSESS%20D1.1-FINAL-Preliminary_Test_Scenarios-PUBLIC-2009.11.19.pdf.

[39] Rodarius, C., 2012, "ASSESS WP4 lessons learned," ASSESS, http://www.assess-project.eu/downloadables/Final%20Workshop%2025%20Sept%202012/03-Pre-crash%20evaluation%20WP4_ASSESS%20workshop%20-%20ActiveTest-Carmen%20Rodarius.pdf.

[40] Bartels, O., Langner, T., Aparicio, A., 2010, "Action plan pre-crash evaluation ," ASSESS, Deliverable D4.1, http://www.assess-project.eu/downloadables/Public%20Deliverables/ASSESS%20D4.1b%20-%20FINAL%20-%20Action%20plan%20pre_crash%20evalution-PUBLIC-2010-03.01.pdf.

[41] ASSESS, "Work package 1 - Definition of Targets," ASSESS, Website, http://www.assess-project.eu/site/en/WP1%20-%20Definition%20of%20Targets.php.

[42] NCAP, "Euro NCAP 2013 - 2016 Newsletter," carhs, http://www.carhs.de/etc-doc/EuroNCAP_UpDate_2013-2016-Part_I-AEB.pdf.

[43] Carpenter, Michael, G., Feldmann, 2011, "Objective Tests for Imminent Crash Automatic Braking Systems Final Report Volume 1 of 2," CAMP, DOT HS 811 521, .

[44] Camuffo, I., Cicilloni, R., Fürstenberg, K., 2009, "Concepts Definition," eValue, Deliverable D1.2, http://www.evalue-project.eu/pdf/evalue-090520-d12-v20-final.pdf.

[45] Jacobson, J., Eriksson, H., Herard, J., 2011, "Final Testing Protocols," eValue, Deliveralble D3.2, http://www.evalue-project.eu/pdf/evalue-101031-d32-v20-final.pdf.

[46] DaCoTA, "DaCoTA," DaCoTA, Website, http://www.dacota-project.eu/.

[47] Müller, W., Berkes, I., and Tichy, R., 2007, "Statistik für Maschinenbauer (Teil II)," Institut für Statistik TU-Graz, Skriptum Wahrscheinlichkeitstheorie und Statistik für Maschinenbauer, Graz.

[48] Kapitza, M., 2008, "Design of experiments," Fraunhofer-Institut für Algorithmen und Wissenschaftliches Rechnen SCAI, Seminarvortrag, http://www.scai.fraunhofer.de/fileadmin/ArbeitsgruppeTrottenberg/WS0809/seminar/Kapitza.pdf.

[49] Siebertz, K., Bebber, D.v., and Hochkirchen, T., 2010, "Statistische Versuchsplanung," Springer Berlin Heidelberg, .

[50] Krottmaier, G., 2010, "Statistische Evaluierung der Genauigkeit von BLIDS Messsystemen für unterschiedliche Verkehrsszenarien," Technische Universität Graz, Diplomarbeit, Institut für Statistik der Technischen Universität Graz.

[51] Ishaque, M. M., and Noland, R. B., 2008, "Behavioural Issues in Pedestrian Speed Choice and Street Crossing Behaviour: A Review," TRANSPORT REVIEWS, **28**(1) pp. 61-85.

[52] Warner, C.Y., Germane, G.J., James, B., 1983, "Friction Applications in Accident Reconstruction," Society of Automotive Engineers, 830612, SAE Technical Paper 830612.

A. Appendix