METHODOLOGY FOR THE DEVELOPMENT AND EVALUATION OF ACTIVE SAFETY SYSTEMS USING REFERENCE SCENARIOS: APPLICATION TO PREVENTIVE PEDESTRIAN SAFETY

Dipl.-Ing. Adrian Ebner, BMW AG;
Randa Radwan Samaha, M.Sc., Paul Scullion, B.Sc., George Washington University;
Dipl.-Ing. Thomas Helmer, BMW AG

ABSTRACT

In the course of continuous enhancement of passive safety, the development of active safety systems becomes more important to further improve vehicle safety. To develop and evaluate active safety systems, reference scenarios need to be identified and analyzed. In this research, a methodology for the deduction of reference scenarios and a new simulation approach to evaluate the effectiveness of those systems is presented. Using the example of preventive pedestrian safety, accident data of the United States (US) and Germany are analyzed to identify scenarios for pedestrian protection representing the US and German traffic system. The objective was to identify the pre-crash situations and conditions where a system should work and which also function as representative test scenarios for evaluating the system efficacy. German accidents were analyzed using the German-In-Depth-Accident-Study. The National Automotive Sampling System General Estimates System and the Fatality Analysis Reporting System, as well as the Pedestrian Crash Data Study, were used for the US. Different methodologies were applied to define and develop as well as to identify the most important scenarios. The most important accident scenario involving pedestrians in both countries was: the vehicle is going straight, the pedestrian is crossing the street and the event happens on an urban / low speed street. To understand the reference scenarios in detail, several parameters which describe the situation, the environment, the vehicle, the driver, the pedestrian, and the consequences of the accident were analyzed. Some examples of detailed analyses of the most important scenario are: the most frequent value of the roadway alignment is a straight road, there is only one pedestrian involved who is visible without any obstruction, it is daytime with no precipitation and the road surface is dry.

KEYWORDS: ACCIDENT ANALYSIS, ACTIVE SAFETY, AUTOMOBILES, COST BENEFIT ANALYSIS, PEDESTRIANS

RESEARCH QUESTION

In 2001, about 12 percent of all highway fatalities involving motor vehicles in the US were pedestrians (Shankar, 2003). There have been many improvements to increase pedestrian safety due to measures of passive safety in the past (Kühn, 2005). But those measures have only limited abilities to protect the pedestrian. Systems which avoid or reduce the collision speed of an accident promise to have significantly higher benefits (Wisselmann, 2009). To identify and analyze reference scenarios is one important part of developing and evaluating active safety systems.

There are many different approaches to classify traffic and accident scenarios. For example, Fastenmeier (Fastenmeier, 1995) and Benda (Benda, 1983) classify driving situations. Because accident and critical scenarios are not the focus of their work there is no consideration of the opponent which is necessary and introduced in the methodology of this research. There are some examples of classifying accident scenarios. Often the methodology of analyzing the data is similar but the focus is on specific research questions and the results are rarely compared with other databases and countries. Schofer, for example, focuses on child pedestrian accidents (Schofer, 1995). The Swedish Traffic Accident Data Acquisition (STRADA) was analyzed by Huang (Huang, 2008). The defined scenarios are similar and therefore the results can be compared with the findings of this paper to get an overall view.

This paper defines the term reference scenario, shows the purposes of the different types of reference scenarios, and displays an approach to evaluate new systems. Using the example of pedestrian safety systems, reference scenarios for the assessment of safety benefits are developed by using accident data from the US and Germany. The methodology that is presented in this paper can be applied to all types of scenarios and leads to results that are comparable. Possible differences were analyzed and the results are displayed. The focus of this work is to get a combined set of scenarios in order to develop a preventive pedestrian safety system with the highest efficacy in both the US and German market. The objective is to identify the situations and conditions where a system should work and which also function as representative test scenarios for evaluating the system efficacy. The results from all analyzed databases, as well as the use of different weighting methodologies, were compared and are presented.

DEFINITION AND DESCRIPTION OF REFERENCE SCENARIOS

In this study, three types of reference scenarios were defined to assist with the development and evaluation of active safety systems: uncritical scenarios, critical scenarios, and accident scenarios (Figure 1, left side). Since the purpose of active safety systems is to improve vehicle safety, it is necessary to identify typical accident scenarios to evaluate the objective effectiveness. Drivers experience accidents infrequently because those are rare events. However, drivers experience critical situations and “close calls” more often. For example, many drivers overlook a vehicle in the blind spot while changing lanes. Although this critical situation rarely leads to an accident, accident risk is apparent to the driver and he or she would generally appreciate a warning or the knowledge that an active safety response is available. In this context, the driver forms a mental image of critical situations in which an active safety system could be effective. Information about typical critical situations is thus useful to help in estimating subjective effectiveness in order to provide products that reduce those unpleasant situations. The relative frequency of a typical critical situation generally exceeds the frequency of that situation leading to an accident.

Almost every active safety system produces false alarms. During the development of a new system the optimum between a high efficacy and a low false alarm rate has to be found. Frequent uncritical situations have to be identified to assess and analyze false alarms. A low false alarm rate is important to reach a high customer acceptance of the system.

In this research, reference scenarios are defined as a limited number of scientifically derived traffic situations that represent a major part of the real traffic system. All three described types of scenarios have four different aspects that need to be analyzed (Figure 1, right side). Initially, the typical configurations of the situation have to be identified. That includes the movement of the subject vehicle (e.g. turning right, lane change) and the type (e.g. vehicle, pedestrian) and movement of the opponent. Then it is important to know the roadway and environmental conditions under which the scenario occurs. This information can be used to derive specifications for the sensors used in the active safety system (e.g. if the scenario addressed by the system occurs more frequently during nighttime, a camera sensor may not be effective). To separate critical from uncritical scenarios, limit values have to be defined (e.g. distances between vehicles, time to collision). Information about the cause of critical situations and accidents is important to analyze the potential benefit of systems designed to improve vehicle safety. The final aspect of describing each of the reference scenarios is the driver response. In uncritical situations, the interaction of the driver and the roadway environment helps define the thresholds when a system should or should not warn the driver. For example, if the driver does not react in the common and uncritical situation of a pedestrian crossing the street with a time to collision of 3 seconds, a system should not warn the driver. Information about the behavior of the driver (e.g. reaction time, maximum deceleration) in critical situations is necessary to identify potential benefit for and implementation of the system (e.g. if the reaction time of the driver is disproportional long, the system could reduce this time by a warning).

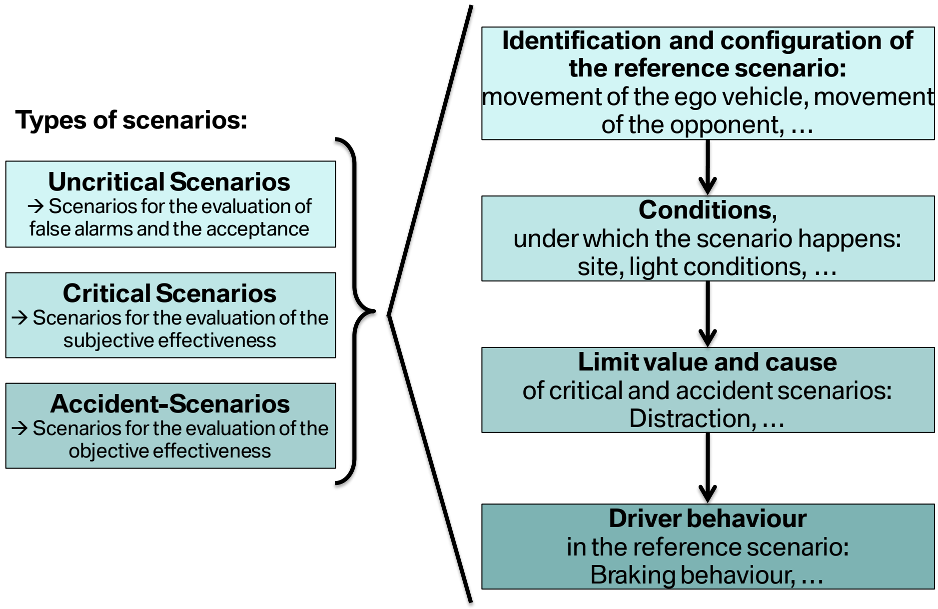

Figure 1 – Types and aspects of scenarios

DATA SOURCES TO ANALYZE THE ASPECTS OF REFERENCE SCENARIOS

Table 1 shows the data sources for the four different aspects of the three types of scenarios described above.

Data of the configuration and conditions of typical uncritical scenarios can be collected by field operational tests (FOT) or naturalistic driving studies (NDS). In these studies, vehicles are equipped with data acquisition systems to collect data while driving, e.g. videos of the driver and the environment. In naturalistic driving studies, vehicles are given to regular drivers who drive in their normal environment and with their normal behavior. The analysis of this huge amount of data can be expedited by algorithms that automatically detect critical and accident situations. For situations that cannot be detected automatically (e.g. pedestrian situations) special experiments in driving simulators or in the real world can be run to study driver behavior.

The "100-Car Naturalistic Study" (Neale, 2005) is a widely known study in which both FOTs and NDSs are used to analyze critical situations. In such studies, the causes and conditions of crashes and near-crashes can be analyzed with the use of specific limit values for critical situations. Driver related causes (e.g. distraction and fatigue) can be detected through review of in-vehicle video footage. Analysis of such huge amount of data is again expedited by algorithms that automatically detect critical situations. Because accidents are rare events, there are only a limited number of recorded crashes in NDSs and FOTs that can be analyzed. To supplement these studies, additional experiments can be run to study the driver behavior in specific situations.

Accident databases provide real-world crash data needed to further understand and define specific accident scenarios. To identify scenarios, it is important that the database used is representative of the accidents occurring in a given country. In the absence of census data, databases may provide weighting factors that could be applied to the sample crash data to provide national estimates. As the scope and scale of these databases differ, so too does the level of detail and quality of data. Databases that are based on fully reconstructed accidents provide detailed information like collision speed or braking distance, often have fewer cases and are therefore less representative of the overall crash population. On the other hand there are databases with high number of cases that are often based on police reports, subsequently providing less information. Although these large-scale databases typically provide limited engineering data, they do provide measures of exposure that are likely more representative of the crash population. It is therefore necessary to analyze different databases to generate representative as well as detailed results. To design a system that is effective world-wide, it is important to study accidents of different countries and to get a combined set of scenarios. The specific causes of accidents and details about the driver behavior (e.g. reaction time) are information that is missing in available data bases (Table 1) however these can be analyzed using NDSs and FOTs and linked to accident data. Typical accident scenarios can be visualized, e.g. in a driving simulator, to study the driver behavior with and without an active safety system. The results of identifying and analyzing reference scenarios for preventive pedestrian systems are presented later in this paper.

Table 1. Overview of data sources to analyze reference scenarios

	Uncritical Scenario	Critical Scenario	Accident Scenario
Configuration	FOT	FOT	AD
Conditions	FOT	FOT	AD
Causes	-	FOT	(FOT)
Driver Behaviour	FOT, experiments	FOT, experiments	experiments

FOT: Data of Field Operational Tests; AD: Accident Data

EVALUATION OF ACTIVE SAFETY SYSTEMS USING REFERENCE SCENARIOS

The assessment of safety benefits of intelligent transportation systems is important for the development and acceptance of new systems. In the early phase of the development (before actual prototypes are built) it is necessary to estimate the safety benefits of different systems (e.g. forward collision warning versus lane departure warning) and different system specifications (e.g. warning versus autonomous braking). Computer simulations are an appropriate tool for assessing such estimates. The following describes the methodology for evaluating the effectiveness of active safety systems using reference scenarios to define real world traffic situations to be modeled in the computer simulations.

Figure 2 shows the fundamental overview of the methodology. The bases for the simulation are reference scenarios of uncritical and critical/accident situations containing every aspect of a scenario (described above: configuration, conditions, causes, driver behavior). These scenarios have to be implemented in the simulation program using all relevant distributions of influencing factors (e.g. distribution of driver reaction time, speed of vehicles). Using the characteristics of the vehicle and the surrounding traffic, a realistic model of the traffic system can be developed. Based on this model each scenario will be simulated several times. For each simulation run, specific values of all influencing factors are selected with variations generated to represent the 'real' traffic conditions, including normal driving situations, critical scenarios and accidents. This methodology is known as "Monte-Carlo-Simulation"). All rates and resulting distributions (e.g. collision speed) can be validated using literature or accident data bases to prove the representativeness.

The next step is to implement a system in the simulation. A model including all important system characteristics (e.g. detection distance, tolerances) has to be created including the general effect of the system on the scenario (and the whole driver-vehicle-environment-interaction). To analyze this effect experiments (e.g. in driving simulators) can be run. For example, a warning system can influence the reaction time of the driver in a critical situation. The reduction in reaction time has to be studied in experiments that analyze the reaction of a representative set of test candidates who are confronted with the system. The values which are determined will be implemented in the simulation of the system model. Another option is to analyze the effect of a system is to run FOTs where data with and without the system are collected and analyzed regarding critical situations. A requirement for running a FOT is that a real and tested system needs to be available, and can therefore only be done in a later phase of the product development.

The simulation of the system model with the selected scenarios can be run with and without the countermeasure, and different rates and values can be studied to calculate the safety benefits of the system. A macroscopic value is the number of accidents and critical situations as compared to the number of uncritical scenarios (i.e. how many accidents happen with and without the system). The presence of the system can also influence the severity of an accident. Therefore the collision speed is an important value to analyze for assessing the mitigation of an accident with the system implemented. The reduction of the collision speed can be translated to the injury severity (Rosen, 2009). The number of non-, slightly or seriously-injured persons as well as the number of fatalities, are quantifiable values for the description of the safety benefit of an active safety system.

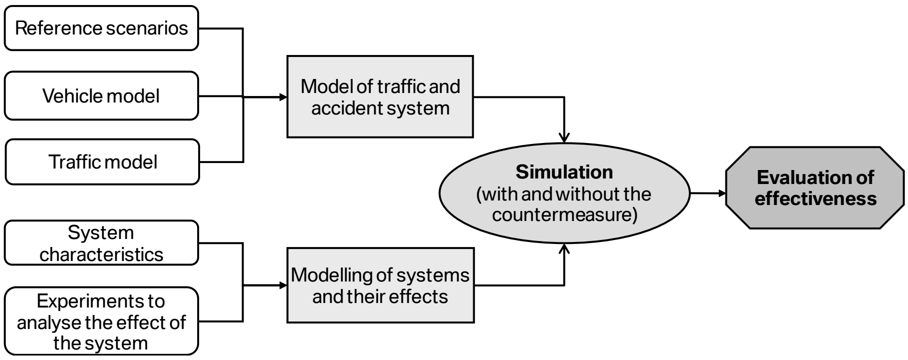

Figure 2 – Methodology to evaluate active safety systems

IDENTIFYING AND ANALYZING REFERENCE SCENARIOS USING THE EXAMPLE OF PEDESTRIAN SAFETY SYSTEMS

In the following paragraph the methodology of identifying and analyzing reference scenarios for the evaluation of effectiveness of a preventive pedestrian safety system is presented. As described above, real-world accident data is the proper source to study reference scenarios. To obtain a set of scenarios that is representative for more than one country, accident data of the US and Germany is analyzed to determine typical configurations of pedestrian accidents and conditions under which these accidents happen. These results are an important input for the design of new systems and for the implementation and validation of the computer simulation.

SOURCE OF DATA

To analyze German accidents, a dataset of the German-In-Depth-Accident-Study (GIDAS) database containing accidents recorded between 07/1999 and 12/2007 was used. The case selection criteria for this study were: the crash involves an impact to a pedestrian by a passenger car and the initial interaction was between the car and pedestrian. All data are weighted to the federal statistics in Germany using three parameters: type (e.g. accident occurs while one vehicle is turning right or left), site (urban / rural) and injury severity of the accident. 5.5% (802 cases, weighted number) of all completely reconstructed accidents in GIDAS fit the selection criteria and were used for the analysis.

Accident data from the National Automotive Sampling System / General Estimates System (NASS/GES) (NHTSA, 2008) and the Fatality Analysis Reporting System (FARS) (NHSTA, 2005) for the years 1997 to 2008, as well as the data of the Pedestrian Crash Data Study (PCDS) 1994 to 1998 (UMTRI, 2005), were used to identify trends within the US. The case selection criteria for this study and the US data were: no trucks, at least one pedestrian involved, maximum of two pedestrians, and a maximum of eight cars involved in each case. The populations are 874,377 cases in GES (weighted, 1.1% of all cases), 57,716 in FARS (12.8%), and 549 in PCDS (100%). The selection process for GIDAS and the US databases differ from each other because there are different parameters that describe the pre-crash movement of the car and the pedestrian.

For this study, GES is the best database in the US to get national representative estimates. FARS is used to analyze distributions for the fatal accidents and provides reliable numbers as it is a census of all fatal crashes occurring on US roadways. To analyze accidents in detail, PCDS provides the necessary in-depth information.

IDENTIFICATION OF TYPICAL CONFIGURATIONS OF SCENARIOS

Methodology

As described above the first step is to indentify typical configurations of the situation (see also Figure 1). The following three parameters were studied: the pre-crash movement of the vehicle, the pre-crash movement of the pedestrian and the site of the accident (urban or rural) (Figure 3). While GIDAS (Germany) provides a parameter that describes the site of the accident, the speed limit of the road is used for the analyses of the US databases to classify the type of the road, i.e. if the street has urban or rural character. To be able to compare the results from the US with those from Germany two groups were created and a speed limit of 45 mph was found to be an appropriate delimiter because urban roads can have a maximum speed limit of 45 mph in the US (Federal Highway Administration, 2000). The scenarios which are on an urban street (respectively have a speed limit less than 45 mph) are indicated as “low speed” in the figures. The scenarios on rural streets are named “high speed”.

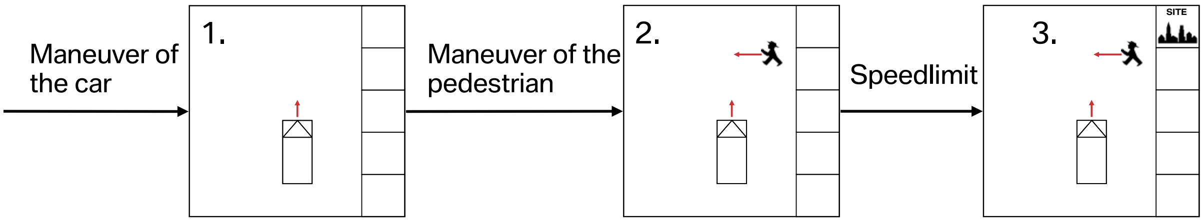

Figure 3 - Methodology for developing reference scenarios

Different methodologies were used to identify the most important scenarios, e.g. the frequency of scenarios (results are called “frequency”) or a combined factor of frequency and the severity of the accident (results are called “Harm”). The HARM metric (Gabler, 2005) is used as a measure of severity of occupant injuries. This metric provides an estimate of societal costs, such as direct medical treatment and rehabilitation costs, and the long-term reduction in productivity associated with a crash based upon the severity of occupant injuries. The HARM methodology is used to calculate benefits of safety features. In this study HARM is used to calculate the importance of typical pre-crash scenarios. For every case the societal costs are calculated and are included in the weighting factors. When applying HARM the more severe cases become more important.

The economic costs of accidents are based on the injury severity of the involved persons according to the Abbreviated Injury Scale (AIS). The Maximum Abbreviated Injury Scale (MAIS) describes the overall maximum injury severity based on AIS.

The NASS/GES does not use AIS to describe the injury severity but provides this information based on the KABCO scale (Kindelberger, 2003). To calculate economic costs in NASS/GES, the KABCO scale was mapped to the AIS scheme using the translator which was derived from 1982 – 1986 NASS data (Willke, 1999).

The economic costs from the year 2000 based on the MAIS scheme were used for this study (Blincoe, 2002). Similar calculations also exist in Germany. The economic costs of each accident calculated with the HARM metric are used as new weighting factors.

The analysis in NASS GES is done with using weighting factors which are applied to compute national estimates.

Differences between the US and Germany regarding the scenarios, as well as different priorities based on computed HARM, were identified. The various databases were also compared in order to understand the quality and representativeness of the respective data.

Table 2. Comparison of frequency / HARM calculation of importance of scenarios [%]

Valid Percent	GES Frequency	GES Harm	PCDS Frequency	PCDS Harm	GIDAS Frequency	GIDAS Harm
Veh going straight + Ped crossing (Low speed)	46	47	58	57	72	71
Veh turning left / U-turn + Ped crossing (Low speed)	12	6	16	7	8	6
Veh turning right + Ped crossing (Low speed)	6	3	6	2	3	2
Veh going straight + Ped standing in roadway (Low speed)	4	4	1	3	?	?
Veh going straight + Ped walking with/against traffic (Low speed)	4	4	3	5	2	4
Veh going straight + Ped crossing (High speed)	3	10	4	13	3	9
Veh backing up	3	2	0	0	10	No data yet
Other	22	24	12	13	2	8
Total	100	100	100	100	100	100

Most important scenario
Second-most important scenario
Third-most important scenario

Results

The GES database in the US and the GIDAS database in Germany were used to get nationally representative scenarios. The combination of the three parameters (see section Methodology) to develop reference scenarios leads to a large number of permutations of possible scenarios. Based on frequency, eight main scenarios were identified and these are listed in the left column of Table 2. The category "Other" includes all other combinations and cases in which the regarded parameters are missing or unknown. This table displays the importance of the reference scenarios based on frequency and the HARM methodology. The red colored cells indicate the most important, the orange the second-most, and the yellow the third-most important scenarios in the different databases.

The results based on the calculation of frequency are described in the following. The most important accident scenario involving pedestrians is the vehicle is going straight, the pedestrian is crossing the street, on an urban / low speed roadway (see Table 2, "Frequency"). The second important reference scenario is when the vehicle is turning left; the third is when the vehicle is turning right.

The main crash scenarios resulting from the analysis of the PCDS data were found to be very similar to GES although PCDS is a very small sample of pedestrian accidents and there are no weighting factors to get national estimates. This implies that the distribution of PCDS cases is representative with respect to the three described parameters. There is a large number of "Other" in GES because in this database more values are missing or unknown compared to the other databases.

The comparison of US and German results showed that, overall, the scenarios are very similar. It is very surprising that the results of the analyses of all databases and both countries are so similar despite the significant differences in infrastructure (e.g. average number of lanes in the US is higher), distribution of the vehicle fleet (e.g. higher proportion of larger vehicles like SUVs), and the exposure of vehicles and pedestrians (miles driven per person is higher and miles walked is lower in the US). The reason for the similarity could be that the underlying causes and mistakes that lead to a pedestrian accident are comparable. Unfortunately however, collected accident data do not provide reliable information about the causes for an accident. Such data could be collected by other kinds of studies (e.g. naturalistic driving studies).

The number-one scenario in the US is even more important in Germany, accounting for 72%. The only difference observed between US and German pedestrian accidents was the importance of the "backing up" scenarios in Germany. The probable reason for this is that most of those cases are not documented in the US databases because they do not frequently occur on public roadways (backing up typically occurs in driveways for example) and are therefore underrepresented in the NASS databases due to the nature of the sampling scheme. PCDS focused on the forward movement of the vehicle so "backing up" cases are not included. Also the results from STRADA show that the scenario in which a vehicle is going straight and a pedestrian is crossing the street is with over 50% the most important one (Huang, 2008). STRADA is since 2002 the official information system on a national level for collecting and storing traffic accidents resulting in fatalities or injuries in Sweden.

The relative importance of the scenarios changes when the severity of an accident is considered (see Table 2, "HARM"). The scenarios in which the vehicle is going straight and which are on a high speed road become more important since they are more severe. The importance of "vehicle turning" scenarios decreases.

Regarding GES, the importance of scenarios in which the car is going straight increases by 21.5% while the importance of scenarios in which the car is turning left, right, or is backing up each decreases by around 50%. The reason for that is that the speed of the vehicle in those scenarios is much lower in comparison with vehicles going straight (see also distribution of impact speed, Figure 5). The collision speed is the most important influence factor for the severity of a pedestrian accident; the higher the collision speed, the higher the injury and accident severity (Rosen, 2009). Using HARM analysis, which is based on both the frequency and severity of the accident, the scenarios on high speed roads become more important, e.g. in GES the importance of the scenario in which the vehicle is going straight and the pedestrian is crossing a high speed road increases by 337% (see Table 2) and changes from the sixth to the second most important scenario. Again the reason is that the speed of the vehicle on streets with a higher speed limit is typically higher than on an urban street. The order of the most important scenarios is nearly the same for both weighting methods because the importance of the situations in which the vehicle is going straight increases but that of the low speed situations decreases. Analysis of both PCDS and GIDAS show comparable results regarding the frequency of situations (Table 2).

Table 3. Reference scenarios HARM compared with FARS and GES fatal [%]

<table>
<tr><th>Valid Percent</th><th>GES Harm</th><th>PCDS Harm</th><th>GIDAS Harm</th><th>FARS Frequency</th><th>GES Fatal</th></tr>
<tr><td>Veh going straight + Ped crossing (Low speed)</td><td>47</td><td>57</td><td>71</td><td>39</td><td>44</td></tr>
<tr><td>Veh turning left / U-turn + Ped crossing (Low speed)</td><td>6</td><td>7</td><td>6</td><td>2</td><td>1</td></tr>
<tr><td>Veh turning right + Ped crossing (Low speed)</td><td>3</td><td>2</td><td>2</td><td>1</td><td>1</td></tr>
<tr><td>Veh going straight + Ped standing in roadway (Low speed)</td><td>4</td><td>3</td><td>?</td><td rowspan="2">11</td><td rowspan="2">9</td></tr>
<tr><td>Veh going straight + Ped walking with/against traffic (Low speed)</td><td>4</td><td>5</td><td>4</td></tr>
<tr><td>Veh going straight + Ped crossing (High speed)</td><td>10</td><td>13</td><td>9</td><td>16</td><td>17</td></tr>
<tr><td>Veh going straight + Ped walking with/against traffic or standing in roadway (High speed)</td><td>?</td><td>?</td><td>?</td><td>9</td><td>8</td></tr>
<tr><td>Veh backing up</td><td>2</td><td>0</td><td>No data yet</td><td>2</td><td>2</td></tr>
<tr><td>Other</td><td>24</td><td>13</td><td>8</td><td>20</td><td>19</td></tr>
<tr><td>Total</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td></tr>
</table>

Table 3 compares the results from GES, PCDS and GIDAS based on the HARM methodology with the results from FARS. The same trend is observed in FARS: The scenarios in which the vehicle is going straight and which are on a high speed road become even more important. In FARS, the parameter that describes the movement of the pedestrian does not distinguish between "standing in roadway" and "walking with / against traffic". As a result, these two scenarios are combined in Table 3.

To analyze the representativeness of the GES database regarding pedestrian accidents, the results of fatal cases of GES and the census of FARS are compared in Table 3. The GES fatal cases show extremely high correlation with FARS. That means that at least this population of GES cases is representative for national distributions.

ANALYZING REFERENCE SCENARIOS IN DETAIL

Methodology

The second aspect of scenarios that could be studied by using accident data are the conditions under which the scenario happens (see Table 1). Several parameters which describe the situation, the environment, the collision, etc. were analyzed to understand the details of the pre-crash scenarios. The main parameters used to develop and analyze reference scenarios were:

- Parameters describing the situation:
    - Relation to junction, Traffic way flow, Initial speed, Alcohol involvement, …
- Parameters describing the environment:
    - Light condition, Atmospheric condition, Road surface, …
- Parameters describing the collision:
    - Number of injured persons, Collision speed, …

Results

As mentioned above, to design a preventive safety system and to estimate its benefit, it is important to understand the scenarios in detail and to study all important parameters under which those accidents happen and which could influence the performance of the safety system, the driver, or the pedestrian.

In the following some interesting examples, calculated with the “frequency” methodology, are described. Like the importance of the derived scenarios, the distributions of the most important parameters are also very similar between the US and Germany.

The light conditions are very important for the evaluation and design of a system because they could influence the performance of the sensors on which the system is based on, e.g. cameras only work properly during daytime. In both countries most of the accidents happen during daytime (around 62%), although the visibility of pedestrians is worse in the dark and extra lighting for example reduces the number of collisions at crossings (Martin, 2006). A reason for that contradiction could be the exposure of pedestrian crossings during night time. It is likely that fewer pedestrians walk in traffic and cross streets in the dark and therefore less conflicts and accidents occur during nighttime.

Besides the overall distributions of parameters, a detailed analysis of parameters in each scenario is important. The results of the evaluation of safety benefits are in general more accurate by regarding each scenario separately because detection rate and performance depends on the factors and special circumstances of each situation (e.g. movement of the car / pedestrian). Figure 4 shows the distribution of light conditions in the different scenarios (GIDAS). The Pearson Chi-square test is used to identify differences between the distributions in the scenarios. Each distribution is tested against the distribution of all other scenarios. The numbers on top of the columns display the p-value and the results show that the distributions in the scenarios 1 to 4 are significantly different (p-value <= 0,05) compared to the distribution in all other cases. This shows that it could lead to imprecision if you use the overall distribution instead of the detailed analysis of parameters for the system development. For example, the distribution of light conditions in the scenario in which the vehicle is backing up (daytime: over 80%) differs significantly from the overall distribution (daytime: around 62%). The selection of the sensor to address the performance during nighttime might be different if the overall distribution is considered instead of the actual distribution in that specific scenario in which nighttime is more or less irrelevant.

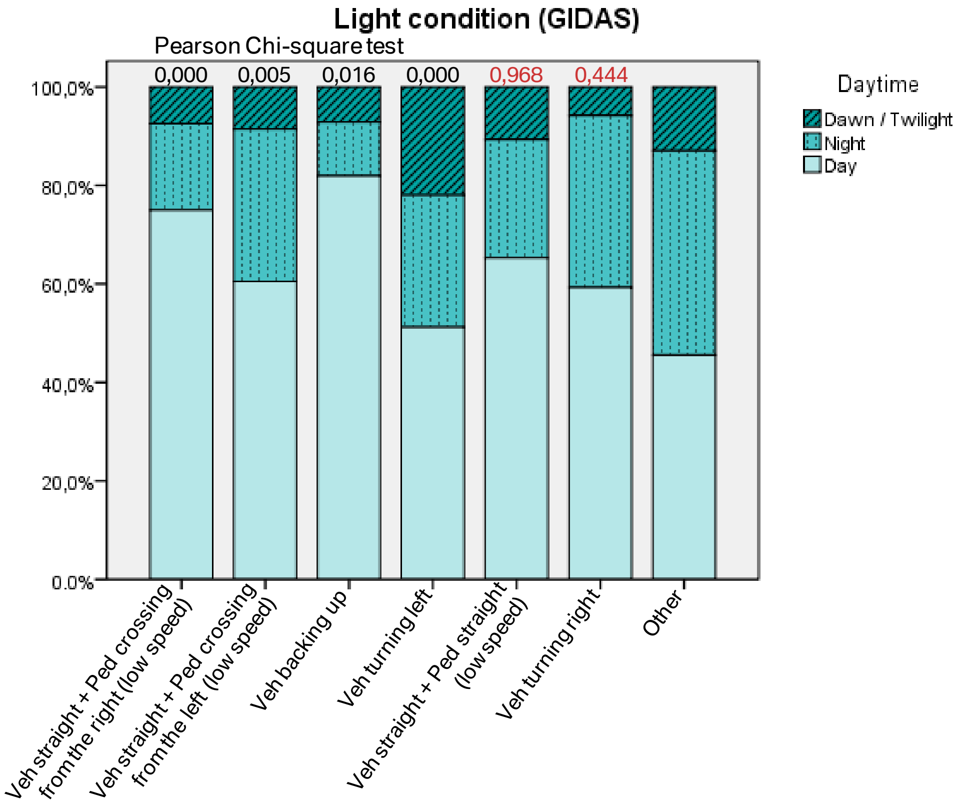

Figure 4 - Distribution of different scenarios in Germany by time of day (GIDAS)

Another important parameter for the system design is the impact speed. PCDS is used to analyze impact speed in the US. Figure 5 shows the distribution of impact speed in each of the different reference scenarios. A similar trend is observed when compared to reference scenarios by time of day, where the distribution of impact speed differs between each of the identified scenarios. Obviously the impact speeds in vehicle maneuvers like turning or backing-up are lower when compared to impacts where the car is going straight. In those scenarios, the average impact speed is around 30 km/h. These differences in the distributions highlight why situations in which the vehicle is going straight are more severe. This becomes more apparent when using the "HARM" methodology for calculating the importance of scenarios (as discussed above).

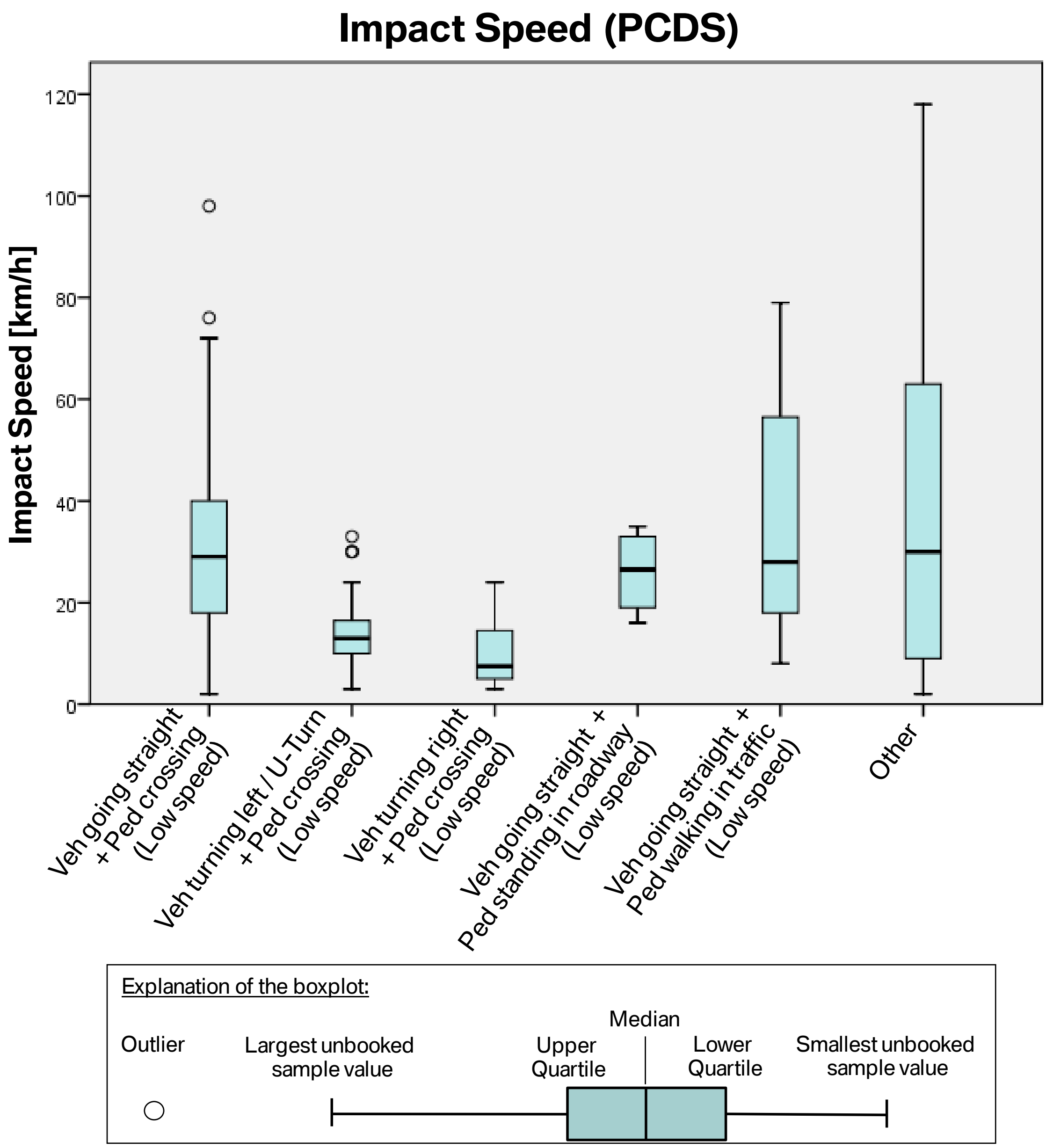

Figure 5 - Impact speed in the different scenarios in km/h (PCDS)

Table 4 summarizes the results of further detailed analyses to indentify the most important scenario. This involves a car going straight, pedestrian crossing (in Germany: crossing from the right) on a low speed road (in Germany: urban). In these circumstances, the most frequent value of the roadway alignment is a straight road and there is only one pedestrian involved who is visible without any obstruction. With regards to the environmental conditions, it is daytime with no precipitation and the road surface is dry.

When taking the most frequent values of important parameters, exact situations can be defined that could be used as test scenarios in the real world or simulator testing. Although Table 4 presents a very specific situation, the importance of this scenario is around 10% (frequency methodology) in the US and Germany and, therefore, can be used as an initial focus for system design. 10% is considered to be considerable for a situation, given so many parameters are specified. Also, if a system can manage this scenario it is expected to be effective in other situations, for example rain or wet road surface.

Table 4. Most important parameter values of reference scenario 1

Situation	Roadway alignment	Straight road with/without intersection
	Visibility obstruction	Visible without obstruction
Environment	Daytime	Day
	Precipitation	No precipitation
	Road surface	Dry
Causes	Number involved persons	One

CONCLUSIONS AND OUTLOOK

Analyses have shown that active safety systems have more potential to increase pedestrian safety than passive safety (Wisselmann, 2009). A new methodology to design and evaluate the safety benefits of preventive systems was presented using reference scenarios as the key element. There are different types of reference scenarios that are needed to develop a system and different aspects of scenarios that have to be analyzed. The identification and analyses of scenarios using accident databases from different countries are important to design a system with the highest efficacy. The results would be input for the development process and to set up a computer simulation to calculate the safety benefits.

The study of accident reference scenarios for a preventive pedestrian safety system was used as an example to display the methodology. It is encouraging that analyses of pedestrian accidents in different databases and by different weighting methodologies in the US and Germany showed similar results. The identified crash scenarios have the same importance in each database and even the calculated frequencies are very similar. As a result, it is possible to identify and define a more refined and concise set of reference scenarios that represent most of the pedestrian accidents in the US and Germany. These scenarios can be used to develop preventive pedestrian safety systems and to create objective and representative test scenarios for the evaluation of the efficacy of such systems. With the knowledge of the importance of a specific test scenario, results of computer simulations can be extrapolated to all pedestrian accidents and an overall effectiveness

For pedestrian crashes, the most important scenario in Germany and the US involves the vehicle going straight and the pedestrian is crossing an urban / low speed road. If the severity of the accidents is considered, “high speed road” and “vehicle is going straight” scenarios become more important while the importance of “vehicle turning” and “backing up” scenarios decreases.

These results will be implemented in a computer simulation to prove the safety benefits of a preventive pedestrian safety system.

In this paper, the methodology for developing reference scenarios by using pre-crash movements and analyzing relevant parameters was demonstrated to be the right approach to design test scenarios on the basis of accident data. In the future, this methodology will be adopted to other kinds of accidents such as vehicle-vehicle-crashes.

ACKNOWLEDGEMENT

Special thanks go to the German Academic Exchange Service that supported this transatlantic research by a scholarship.

REFERENCES

Benda, H.; Hoyos, C.; Schaible-Rapp, A.: Klassifikation und Gefährlichkeit von Straßenverkehrssituationen, Bundesanstalt für Straßenwesen, Aachen, 1983.

Blincoe, L.; Seay, A.; Zaloshnja, E.; Miller, T.; Romano, E.; Luchter, S.; Spicer, R.: The Economic Impact of Motor Vehicle Crashes 2000. U.S. Department of Transportation, National Highway Traffic Safety Administration, May 2002.

Fastenmeier, W.: Autofahrer und Verkehrssituation: Neue Wege zur Bewertung von Sicherheit und Zuverlässigkeit moderner Straßenverkehrssysteme. Köln / Bonn, 1995.

Federal Highway Administration: Road Function Classification. 2000.

Gabler, C.; Digges, K; Fildes, B.; Sparke, L.: Side Impact Injury Risk for Belted Far Side Passenger Vehicle Occupants. 2005.

Huang, S.; Yang, J; Eklund, F. Evaluation of remote pedestrian sensor system based on the analysis of car-pedestrian accident scenarios, Safety Science, 2008, Volume 46, Issue 9

Kindelberger, J.; Eigen, A.: Younger Drivers and Sport Utility Vehicles. DOT HS 809 636, Traffic Safety Facts, Research Note, 2003.

Kühn, M.; Fröming, R.; Schindler V.: Fußgängerschutz - Unfallgeschehen, Fahrzeuggestaltung, Testverfahren. Springer, Berlin, 2005.

Martin, A.: Factors influencing pedestrian safety: a literature overview. 2006.

Neale, V.; Dingus, T.; Klauer, S.; Sudweeks, J.; Goodman, M.: An overview of the 100-car study and findings. ESV Conference 2005, 2005.

National Highway Traffic Administration (NHTSA): Fatality Analysis Reporting System (FARS). DOT HS 809 726, 2005.

National Highway Traffic Administration (NHTSA), National Automotive Sampling System (NASS GES, NASS CDS), DOT HS 807 304, 2008.

Rosen, E.; Sander, U.: Pedestrian fatality risk as a function of car impact speed. Accident Analysis and Prevention, 2009, Number 41, pages 536-542.

Schofer, J; Christoffel, K.; Donovan, M.; Lavigne, J.; Tanz, R.; Wills, K.: Child pedestrian injury taxonomy based on visibility and action, Accident Analysis & Prevention, , 1995, Volume 27, Issue 3 Pages 317-333.

Shankar, U.: Pedestrian Roadway Fatalities. DOT HS 809456, National Center for Statistics and Analysis, 2003.

University of Michigan Transportation Research Institute (UMTRI): National Automotive Sampling System Pedestrian Crash Data Study (NASS PCDS). 2005.

Willke, D.; Summers, S.; Wang, J.; Lee, J.; Partyka, S.; Duffy, S.: Ejection Mitigation Using Advanced Glazing: Status Report II. Transportation Research Center, August 1999.

Wisselmann, D.; Gresser, K.; Hopstock, M.; Huber, W.: Präventiver statt passiver Fußgängerschutz. Gesamtzentrum für Verkehr Braunschweig e.v. (Hrsg.): AAET 2009 - Automatisierungssysteme, Assistenzsysteme und eingebettete Systeme für Transportmittel, pages 60–76, 2009.