METHOD TO ASSESS THE EFFECTIVENESS OF ACTIVE PEDESTRIAN PROTECTION SAFETY SYSTEMS

Stefan Schramm
Department of Automotive Technology, Technical University Munich
Franz Roth
Audi AG
Paper Number 09-0398

ABSTRACT

The effectiveness analysis assesses the benefit of future safety systems in terms of collision mitigation or collision avoidance based on real life accident data. The safety systems are evaluated by case-by-case analyses based on in-depth accident data (e.g. GIDAS). For this purpose an innovative simulation environment was developed that recreates the technical specification of the proposed system consisting of function algorithm, sensor, and actuators. Therefore results of component tests and complete system tests are included into the simulation. The accidents from the database are varied in the simulation by applying stochastic methods, guaranteeing the validity of the results from a statistical viewpoint. In addition to technical parameters such as a reduction in collision speed, the evaluation also includes a reduction in collision probability. Furthermore, when evaluating the functions a distinction is made between controlled and regulated actions. For each type a special simulation technique is used, which on the one hand is a purely offline analysis of previously simulated data and on the other hand an online or in-the-loop simulation. In order to be able to consider driver reactions on defined warning strategies realistically, it is essential to integrate a driver behaviour model into the simulation. To determine the driver behaviour, studies with probands are conducted using a new simulator technology. The test scenarios for these proband studies are based on accidents of the internal Audi accident research unit (AARU) database. In order to convert the technical evaluation parameters of the accident, e.g. collision speed, to injury severity, injury-risk-functions are required. To sum up, a new method of assessing the effectiveness of integrated safety systems will be presented, which incorporates new simulation techniques, driving experiments and real life accident data to assess a well-founded evaluation of integrated safety systems.

INTRODUCTION

The requirements arising from pedestrians' safety legislation and consumer ratings have intense effects on the today's vehicle development. The design of the vehicle and the technology of the front end especially depend strongly on these measurers and induce trade-offs during the vehicle development process. Further passive measures lead to an increasing vehicle weight or cars being built higher and consequently to higher emissions. Besides secondary collisions of the pedestrians e.g. with the road are not covered by passive measures. Studies based on real accident data proved that systems enhancing the driver's braking are considerably more effective in pedestrian accidents. These studies lead to the definition of phase 2 regarding pedestrian legislation in the European Community which prescribes the installation of a brake assist system in new cars since November 2009 in combination with reduced passive measures compared to the original proposal of pedestrian legislation phase 2. Consequently a first step in resolving the conflicts of aim described above has been carried out.

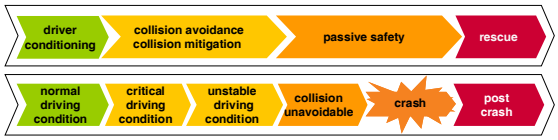

Figure 1: Chronological sequence of a normal driving condition until collision [3]

A further reduction of accidents and injuries of pedestrians can be achieved by using integrated safety systems. These systems consist of sensor systems, functional algorithms and actuating elements in addition to passive safety measures. These integrated systems are also effective during the pre-crash phase, e.g. a critical or unstable driving situation, compared to passive measures which are only effective when the collision has already happened (Figure 1). Studies of accident data have shown that a high percentage of accidents result from incorrect driving behaviour, so that integrated safety systems can help to avoid or

mitigate the collision during the pre-crash phase and account for reaching the goal of a further reduction of injuries or fatalities in road traffic accidents. To quantify the effectiveness of these integrated systems on real accident data, new methods of evaluation are necessary. In this article a method for an effectiveness analysis of integrated safety systems is presented and exemplified on the use case for pedestrian safety. [3], [8], [9], [10]

DEVELOPMENT PROCESS AND EFFECTIVENESS ANALYSIS

Development process of integrated safety systems

The development process of integrated safety systems consists of three main steps that are passed through iteratively. These three steps are function definition, testing and effectiveness analysis (Figure 2). The function definition comprehends the development of the functional algorithms, triggering strategies and the design of actuating elements. The testing includes an assessment of all system components or the total system itself in a realistic environment. Further, the effectiveness analysis contains the benefit assessment of collision avoidance and collision mitigation regarding a definite system component or the total safety

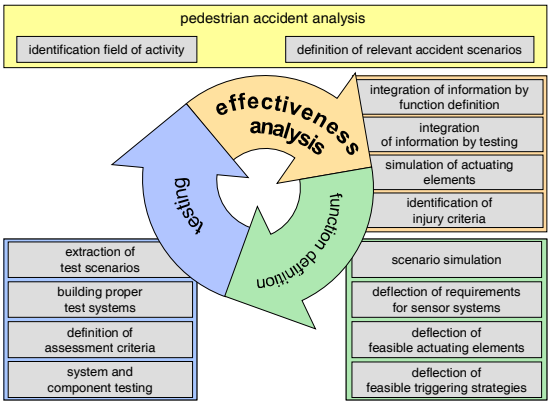

Figure 2: Function development process of integrated pedestrian safety systems [7]

system. The evaluation is accomplished for different abstraction levels based on real world accident data by a case by case analysis. The effectiveness analysis includes the influencing variables established from the testing and the function definition (Figure 3). Only with the integration into the development process is it assured that all results of the other development steps are included and a requirement based system development regarding the total system effectiveness in real world road accidents is enabled.

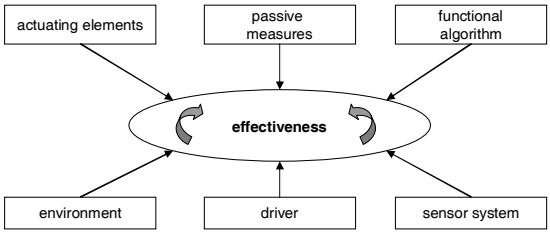

Figure 3: Influencing variables on the effectiveness of integrated safety systems [6]

Method to evaluate the benefit of integrated safety systems

To integrate the effectiveness analysis in the development process consisting of the function definition and testing a new method is presented here (Figure 4). This method allows an assessment of the integrated safety system taking into account all relevant influencing variables (Figure 3) and thus provides a realistic forecast of the system's effectiveness in real world accident scenarios.

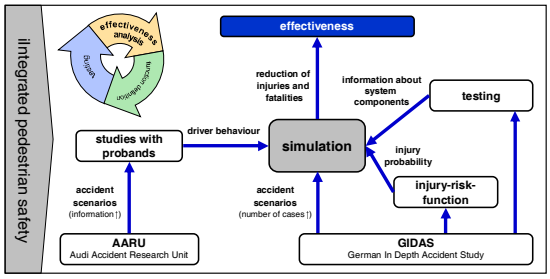

Figure 4: Method to evaluate the benefit of integrated safety systems

To achieve this goal the information from studies of probands, component testing and the injury criteria are combined in the central block of the simulation. Testing means the analysis of system components or their interaction in a realistic test environment or the real world. These include e.g. the testing of sensor systems, functional algorithms or different braking actuating elements. A particular challenge describes the driver integration. For this reason the driver reactions to various warning strategies were identified with the help of studies with probands. The cognitions from component testing and studies with probands are integrated into the simulation in form of models in order to achieve a realistic total system model. The goal is to assess the benefit of integrated safety systems in real world accidents. Because of that all process steps are based on real accident data, which are taken from different databases. Here information of the accident databases of the AARU (Audi Accident Research Unit) and the project GIDAS (German In Depth Accident Study) are integrated. In the sequel to this article the central block of the simulation and the system design based on saved injuries or fatalities are explained.

Levels of system evaluation

The goal of an integrated safety system is to protect the pedestrian (Figure 5). The strategy to achieve this goal consists of collision avoidance and collision mitigation which depends on the effectiveness of the subsystem components and their interaction with each other. An objective assessment of the system's effectiveness requires the consideration of all influencing variables (Figure 3). The actuating elements which are represented as e.g. braking systems or driver warnings are directly influencing the collision course. These are just preceded by the passive measures and their effect on the occurred collision. To activate the actuators only at specified situations, the triggering is computed by functional algorithms acquiring information from the environment or vehicle internal sensor systems.

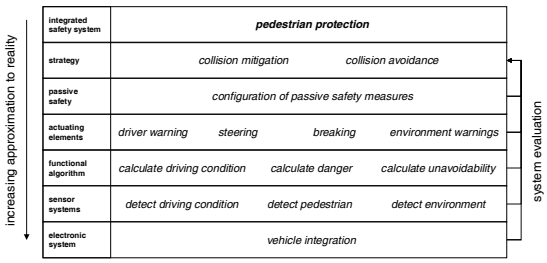

Figure 5: Levels of system evaluation

The complex interaction of the system components and the impact of changing subsystem parameters regarding the effectiveness cannot be analysed without a structured assessment. The simulation method enables the calculation of the effectiveness for individual system components or combinations from the strategic point of view. That means the assessment is carried out on different levels of system modelling always against the strategy level (Figure 5). In the process the approximation to reality increases with the number of subsystem components included (Figure 5). With this approach an identification of the relevant subsystem parameters or the subsystems themselves influencing the effectiveness is possible. The assessment results can be quantified based on both technical and injury parameters. A technical parameter to quantify the achievement of objectives for pedestrian safety for example is the collision speed. Parameters describing the injuries can be defined by the number of seriously injured pedestrians or fatalities. The effectiveness of a safety system can be quantified as the difference between the technical or injury based results of two system configurations. This implies high performance models of the system components. Possible specifications of a level-based system evaluation are shown in Figure 6. Different system modelling states can be identified e.g. model, ideal or not relevant.

	system components characteristics					
levels of evaluation	actuating elements	functional algorithm	sensor system	driver	passive measures	environment
evaluation level I	model	ideal	-	ideal	model	model
evaluation level II	model	ideal	ideal	ideal	model	model
evaluation level III	model	model	ideal	ideal	model	model
evaluation level IV	model	model	model	ideal	model	model
evaluation level V	model	model	model	model	model	model

Figure 6: Exemplary specifications of a level-based system evaluation

The influencing factors of passive measures are always implemented as a model. Without consideration of these an evaluation of integrated safety systems is not possible, because these systems consist of a combination of passive and active measures. The environment parameters are also implemented as a model for every accident scenario. An idealisation of the environment parameters would be possible, but assuming e.g. limiting friction for every accident scenario, the effectiveness analysis would no longer relate to real world accident data. In the first step of a total system evaluation, only the subsystem consisting of actuating elements is conducted as a model. The other components have an ideal behaviour or are not relevant. Assuming the functional algorithm as ideal, the actuating elements are always triggered to the specified point of time to collision. This evaluation step is independent of the pedestrian detection by the sensor system. On this level of evaluation the requirements to the actuating elements can be deviated, because only the influence of this subsystem component is considered. If the result of this evaluation step is indicating little benefit, a substantiated decision continuing the system development based on these actuation elements is possible. The addition of further modelled subsystem components are just leading to a decreasing effectiveness. In a second evaluation step an ideal sensor system can be comprised. An ideal sensor system could be characterised by range or angle of aperture and systematic effects like cycle time or lines of sight obstruction. In this case the actuating elements would be triggered if the addressed object is located in the sensor system's field of vision. During further steps evaluating the total system components, these are integrated step by step as a model. Every evaluation step enables an identification of the relevant subsystem parameters reducing the effectiveness and structured optimization loops. Because of that the subsystem models require a high quality deviated by real world testing and validation as the simulation itself. Because of that the accident simulation program PC-Crash [11] is used to model and simulate the accident scenarios. To integrate braking systems,

pressure or deceleration gradients are used. The functional algorithm is integrated by a Simulink/Stateflow application development system. Considering realistic models of the sensor system, models characterising the sensor system technology are included and also validated by real world measurements. Driver integration constitutes a particular challenge because driver reactions on defined warning strategies strongly diversify and depend on the situation triggered there. Therefore the driver is included as a probabilistic model gaining from studies with probands. These studies are carried out with the simulation and testing method Vehicle in the Loop [1].

SIMULATION

Generating accident scenarios

Analysing the effect of safety systems on the collision course through case by case studies requires runnable simulation scenarios based on real world accident data. In the first step the original course effecting the collision must be reconstructed. For this purpose the kinetic quantities of the vehicle and pedestrian, the impact location and the environment at the place of collision have to be modelled in detail. By this means, runnable accident scenarios according to a real world accidental database are preserved. Equipping the vehicle with a virtual integrated pedestrian safety system, the influence of this system on the original collision course can be analysed during the next evaluation steps. The creation of simulation scenarios in general, results from defining basic scenes that are parameterised with defined values of an accident database (Figure 7).

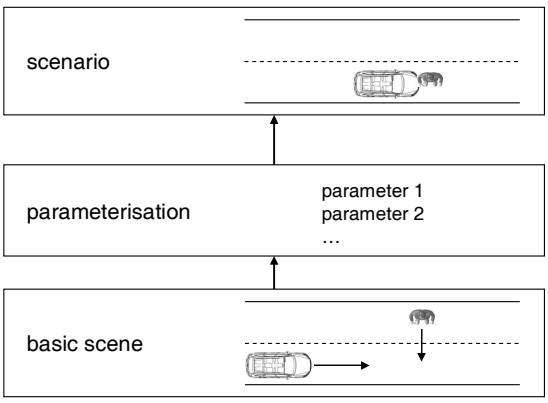

Figure 7: Generation of accident scenarios from basic scenes

One the one hand, values of the GIDAS accident database are used to parameterise the basic scenes. In this way runnable real world accident scenarios are created. On the other hand a multiplicity of fictitious single cases is generated by using stochastic parameters to set the basic scenes (Figure 8). Both methods generate a collection of single scenarios whereby the GIDAS

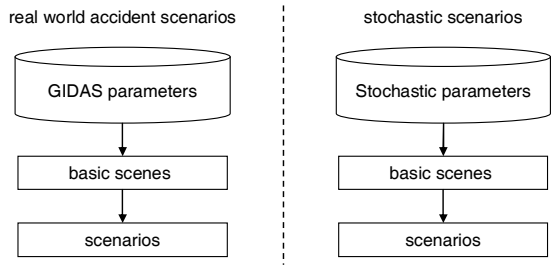

Figure 8: Different simulation databases

cases always effect a collision. The cases built on stochastic parameters also include non-collisions. So these cases must be processed for further evaluations e.g. separation of the collision from non-collision scenarios. As an essential difference to the import of original GIDAS scenarios, the stochastic method generates accident scenarios not included in GIDAS and also apparently unimaginable ones.

Sensor equivalent accident scenes

An effective generation of runnable case by case accident scenarios requires a new approach to achieve a high level of detail with a similar high level of atomization. That's why sensor equivalent accident scenes (SEAS) are created (Figure 9). These scenes can be derived from the specific feature that different accident scenarios often deliver an equivalent view for the sensor system. The sensor system's view is influenced by several environment parameters e.g. road design and layout, approximation direction of the pedestrian or lines of sight obstructions. By combination of these criteria, sensor equivalent accident scenes can be deviated by assigning the single accidents from the database to these.

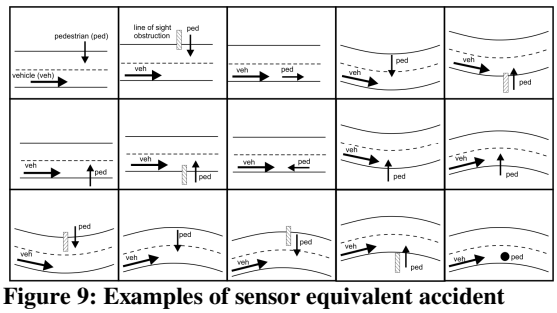

Figure 9: Examples of sensor equivalent accident scenes

For example there is no difference for a sensor system assuming a rectilinear motion of the vehicle, whether the pedestrian approaches from the left

side at a crossroad, straight road or other intersections as long as no information of the characteristic environment features provided by the sensor system are pulled up for situation classification. Sensor equivalent accident scenes can roughly be grouped in straight road and turn or intersection accidents. Straight road accidents comprehend pedestrians crossing at intersections as long as there is no turning off by the vehicle. Sensor equivalent scenes for turn accidents include collisions occurring on a non rectilinear trajectory of the vehicle or at turning off. Every sensor equivalent accident scene for single accidents from the database is assigned to comply with the sensor system's view of the SEAS by using several parameters of the GIDAS accident database. One of these variables is represented by the type of accident *UTYP*. An explicit interpretation of the collision course by the accident type on its own is not possible. For that reason other parameters are comprised. These are for the vehicle *RICHT* defining the direction the vehicle moved in before the collision. Further *RICHTVU* describing the vehicle's line passed through before collision and the parameter *RICHTUE* defining the design and layout of the road at collision [2]. Combining these three parameters, the design and layout of the road can be suggested. Adding the accident type, the collision course is defined explicitly. Using only the accident type to classify a sensor equivalent accident scene, accidents that never happened that way were allocated to a SEAS type, which indirectly effects a falsification of benefit assessment in further evaluation steps.

Semi-automatic generation of accident scenarios

For the creation of runnable accident scenarios two approaches are applied. On the one hand, all straight road accidents are reconstructed semi-automatically by using basic scenes derived from sensor equivalent accident scenes. For that reason, several basic scenes have to be created and parameterised by values of the GIDAS database.

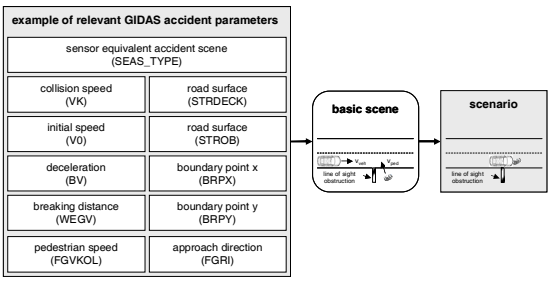

Figure 10: Generating accident scenarios

On the other hand, the remaining SEAS for turning accidents have to be modelled manually. The generation of straight road accidents is carried out automatically by comprising further parameters of the GIDAS database exceeding the allocation to sensor equivalent accident scenes. The additional values have to be selected according to an explicit definition of the collision and in the same manner that the effectiveness of an integrated safety system can be evaluated. A summary of exemplary parameters needed to be imported to set the straight road basic scenes is shown in Figure 10. Combining the vehicles' and pedestrians' kinetic quantities and the acknowledgment for the exact impact location of the pedestrian at the vehicle, an explicit modelling of the collision course is possible by calculating the basic positions of vehicle and pedestrian out of the parameters from the GIDAS database as described before. The exact position of the line of sight obstruction for the GIDAS accident can only be extracted by the sketch of the accident. For this reason the position for the line of sight obstruction in the accident scenario is set manually. Information about the road surface or other environment parameters is retained for system evaluations in further steps. For example, the road surface affects the transferable braking decelerations individually for every accident scenario. Turning or crossroad accidents strongly vary in regard to the possibility of generic modelling and setting basic scenes by GIDAS parameters. The variation of turning accidents is nearly indefinite and can thus be carried out manually calling for a detailed accident modelling.

Accident scenarios from stochastic parameters

In-depth databases like GIDAS are only available for a few countries in the world. In most countries, accidents are recorded centrally in national statistics by a federal statistical office. It is not feasible to generate runnable accident scenarios out of these databases so an evaluation of safety systems based on case by case studies is not possible. For this reason the second method to generate accident scenarios, as described before, can be applied (Figure 8). This method describes the parameterisation of basic scenes by stochastic sets of values. In this way a multiplicity of various and also non-collision scenarios can be created. To assess the effectiveness of an integrated safety system, the evaluation is focused on the potential to avoid or mitigate collisions. That is why the non-collision scenarios have to be separated before this database can be used for further analysis. Weighting the stochastic accident database according to the national accident statistics enables a system evaluation for countries with non in-depth accident databases. Using this method, the correlation between weighted accident scenarios according to global statistics and in-depth accident data, the global statistic results have to be proven at

first. To check this correlation, the global distribution of the GIDAS accidental parameters and the runnable GIDAS accident scenarios are used.

Open-loop- and closed-loop-simulation

An evaluation of integrated safety systems on the basis of different system modelling levels (Figure 6) demands different simulation methods. These are represented by an open-loop- and closed-loop-simulation. The selection of a specific method depends on several factors which are explained consecutively. The open-loop-method is characterised by pre-simulated driving situations in consequence of the implementation of different measures to definite time increments. The results of the pre-simulated driving situations are archived in a kind of look-up table. The simulation is based on time series of the original accident trajectory. Such a trajectory is shown in Figure 11. In the upper diagram the trajectory is represented by a velocity-time-chart und in the lower as a velocity-distance-chart. From the velocity-time-chart can be recognized that the vehicle, beginning from t=0, is moving with a constant velocity. At the point $t=t_b$ the vehicle introduces a braking manoeuvre. The collision occurs at the point $t=t_{coll}$ with a collision velocity of $v=v_{coll}$. Based on this exemplary trajectory and the charts in Figure 11, the method of the open-loop-simulation is explained. To pre-simulate driving situations, the simulation must be stopped at specified time increments, and instead of the original nominal trajectory, a measure is implemented and simulated with the current momentums. This means that a sub-simulation is carried out. This measure could be emergency braking [12]. In this special case the simulation is stopped at the point t_i and emergency braking is simulated. For this sub-simulation the current simulation parameters at the point t_i are set as the basic values for the sub-simulation. In this case, that would be the current velocity because other factors are not considered in this simple explanation. Through the implementation of the braking measure with a sharp deceleration characteristic, a new nominal trajectory is generated at the point of t_i (Figure 11). For this trajectory different parameters are archived e.g. the collision velocity, collision occurring or final positions of the objects in the simulation. At the point t_{i+1} the same braking action is implemented and simulated again and the new results are archived. The braking action is simulated through the whole chronological sequence of the scenario at definite time increments. All these steps are independent from the triggering strategy of the technical system and must be understood as pre-processing for the generation of simulation data. Whether or when emergency braking is triggered in this scenario is not relevant at this point. This method generates an accident scenario data file, which is the basis for the effectiveness of emergency braking for every simulated time t_i. This method is executed for every single accident scenario in the database and for every action that should be assessed. For the two sub-simulations at the point t_i and t_{i+1}, shown in Figure 11, the collision based on the nominal

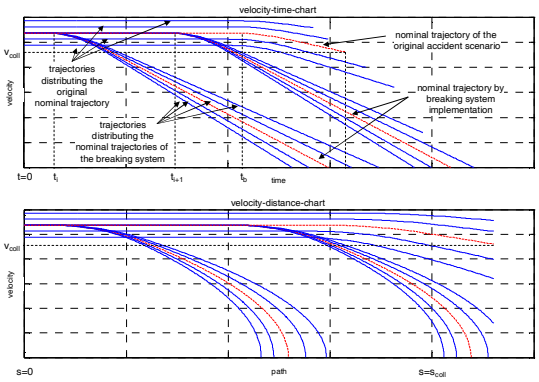

Figure 11: Time series vehicle trajectories

trajectory is prevented. This simulation method can be used for probability analysis as well. For this case not only one sub-simulation is carried out at definite time increments but several, which derive from a covering of the sharp deceleration characteristic with a parameter distribution. A band of sub-trajectories is thus generated, which disperse about the nominal sub-simulation trajectory. It can also be ascertained that not all sub-trajectories can prevent the collision compared to the nominal trajectories. As a consequence, the sub-simulations can be used to define a collision probability that is defined as the number of collisions based on the whole number of sub-simulations for a specific point t_i. The collision probability is a new parameter for a technical assessment concerning the effectiveness of an integrated safety system. To make the probability results out of the sub-simulations comparable with the nominal accident scenario, the original scenario parameters must also be distributed. The probability background can be interpreted via the technical system's own variability because of system internal or external effects. As described before, the pre-processing generates accident scenario data files as a kind of look-up table, in which the effectiveness of an emergency braking action for every simulated time t_i is disposed. To identify the effect of the simulated actions, only the scenario specific points t_i when an action is enabled, have to be detected. To assess just the actuating elements with ideal algorithm behaviour, the action always gets triggered to the specified time to collision. For every accident scenario, the action effectiveness for the point t_i, which is equal to the scenario specific time to collision, can be extracted from the look-up tables.

Another use case is to analyse the algorithm behaviour based on the nominal trajectory of the accident scenario und analyse the time of classification of a critical situation. Latency or

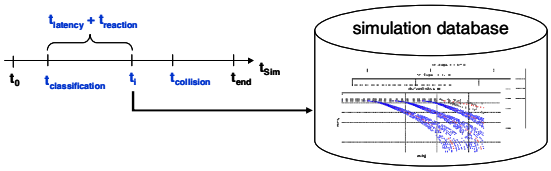

Figure 12: Evaluating action effectiveness including pre-simulated databases

reaction times can also be considered, so the triggering point t_i can be extracted as shown in Figure 12. To accomplish the system assessment in a separate post-processing step turns out to be very efficient. Through look-up tables, it is possible to replace a run-time computation with fast search operations. The savings in terms of processing time can be significant because retrieving a value from memory is often faster. Further, the simulated actions can be reused discretionally and it is possible to regard probabilistic considerations to achieve stochastic confirmed benefit statements. First of all the simulation data for the post processing step have to be created. This step requires a one time simulation effort. For more complex or interlacing actions which affect earlier measures than emergency braking regarding the chronological sequence until collision, it has to be considered that there might be feedback by driver engagement or environment behaviour. For measures triggered a short time before collision such as emergency braking, the feedback can be neglected. To assess complex measure combinations with an estimated feedback, a closed-loop-simulation is required. A closed-loop-simulation calculates the complete system behaviour for every simulation step. That means the information detected by a sensor model is conducted to the algorithm calculating the current behaviour of the safety system whether a fire or a non firer situation is existent. If there is a non-fire scene the loop is passed through again. If there is a fire scene, a warning actuating element could be triggered. The triggering of a warning actuator occurs quite a long time before collision. That means that the situation can be affected by driver engagement, the pedestrian leaving the critical area or by the sensor system. For driver modelling the closed-loop-simulation comprehends a probabilistic driver model created from studies with probands. For this purpose the distribution of driver behaviour for every single warning strategy analyzed in the studies is included. From distributions of e.g. reaction time and corresponding braking deceleration, it is possible to convey a probabilistic parameter combination and integrate stochastic driver behaviour into the simulation. This means that triggering a warning actuator leads to a simulation stop at the point of triggering and the simulation is processed several times with different sets of parameters. Further it is possible to integrate sensor models, algorithms and actuator models as described before in both simulation methods. Both simulation methods deliver technical collision parameters like collision speed or impact location. To calculate the benefit based on injuries or fatalities it is necessary to convert the technical parameters.

SYSTEM DESIGN BASED ON INJURY SEVERITY

To quantify the effectiveness of an integrated safety system in real world accidents, two kinds of parameters can be used, as described before. These are, on the one hand, the technical parameters and on the other hand, the injury severity. The injury severity can be quantified by the number of seriously injured pedestrians or fatalities. Quantifying the effectiveness by the injury severity an injury risk function can be applied. With this function it is possible to calculate the injury severity based on the technical parameters. Generally an injury risk function is defined as the probability to achieve a defined injury severity depending on quantitative influencing factors. Through injury functions different passive safety measures can be modelled having direct influence on the form of the curves [4]. Two exemplary injury risk functions are shown in Figure 13. These curves indicate the probability e.g. for a pedestrian to suffer a MAIS2+ injury at a certain collision speed. Accumulating the injury probabilities for a MAIS2+ injury of every single accident scenario in the database, the absolute number of seriously injured pedestrians can be calculated and the effectiveness of two-system configuration identified.

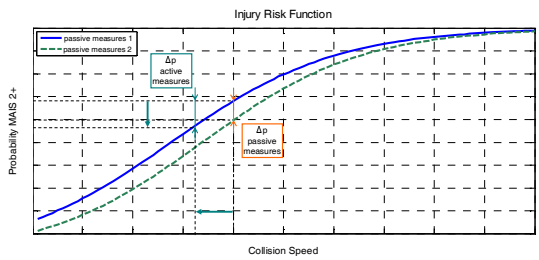

Figure 13: Exemplary injury risk functions for different passive measures

In Figure 13 the curve for passive measure 2 indicates a lower probability for a MAIS2+ injury at equal collision speed. Accordingly this curve represents more effective passive measures compared to passive measures 1. In general, the injury severity depends not just on one parameter

like the collision speed but on a number of parameters influencing the grade of injury severity e.g. impact location, pedestrian age or vehicle front characteristics. To generate injury risk functions with a high modelling quality these additional parameters have to be identified. In consequence, there are more injury risk functions depending on the influencing factors. For example, injury risk functions for young and old pedestrians or frontal and lateral impacts. On the one hand, the injury risk function can be derived directly from the GIDAS database. In this case, a model for the injury severity is gained based on the vehicles' passive measures existing in the GIDAS database. To identify the influence to injury severity for defined passive measures like prospective passive measures for pedestrians, these measures have to be modelled at first because the GIDAS database contains a huge variety of vehicles and different passive measures resulting from the date of manufacturing. To model passive measures the method of injury shift can be applied [5].

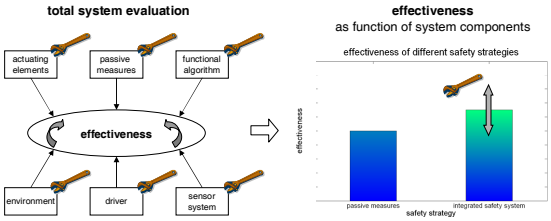

Figure 14: Effectiveness of integrated safety systems subjected to total system behaviour

With this method the expected injury reduction of a pedestrian caused by a synthetic improvement of passive measures can be modelled. Using this new distribution of injuries for every single accident in the database to generate an injury risk function, the result is a new curve with a lower probability of MAIS2+ injuries. Regarding Figure 13, the injury risk functions for passive measures 1 and 2, conveying the results of the method qualitatively. Applying injury risk curves, the effectiveness of passive measures and integrated safety systems are comparable, because a decreasing collision speed by active measures directs a decreasing injury probability for the pedestrian (Figure 13). Consequently, the described simulation method calculating the technical parameters caused by an integrated safety system on real world accident scenarios in combination with injury risk functions enables a new application spectrum designing integrated safety systems. So the effectiveness of passive and integrated system approaches can be compared during the development process (Figure 14).

CONCLUSION

Former studies indicate high potential of brake assist systems regarding the effectiveness in terms of reducing seriously injured pedestrians or fatalities in real world traffic accidents. This applies pedestrian safety in particular, because softer front end structures or measures like active bonnets illustrate limited effectiveness. Further reduction can be achieved by using integrated safety systems consisting of functional algorithms, actuating elements and sensor systems in addition to passive safety measures. To enable a requirement based system development regarding the total system effectiveness in real world traffic accidents, the effectiveness analysis has to be integrated into the function development process assuring that all results of the other development steps in terms of function definition and testing are included. An evaluation of these systems during the function development process requires new methods. A lot of information about the system's influencing factors is detected in the testing and defining process steps. This information is considered in a central simulation method including detailed models and enables a level based system evaluation. That means the influence of the system components affecting the benefit evaluation can be identified in a structured and objective way. To evaluate the system benefit on real world accident data, runnable accident scenarios from an in-depth accident database for case by case evaluations have to be created in an effective way. So a semi-automated method based on sensor equivalent accident scenes to build up the scenarios is developed. Further, it is possible to generate stochastic scenarios applied to predict the system benefit for countries with no in-depth accident information. The accident scenarios are processed in a closed- and open-loop simulation. The open-loop method is characterised by pre-simulated driving situations in consequence of the implementation of different measures to definite time increments. The system evaluation is carried out in a separate post-processing step making this method very efficient for application in the function development process. More complex combinations of different actuating elements and triggering strategies induce feedback by e.g. the driver, system components or the environment. In this case, a closed-loop simulation is required. Both open-loop and closed-loop simulation had the potential to integrate detailed models of the system components as described before. The effectiveness of a safety system can be quantified as the difference between the technical or injury based results of two system configurations. In the first step, the simulation provides technical parameters to quantify the benefit of the tested system configuration. A conversion of these to injury values requires injury

risk functions. With these functions different passive measures are modelled and the effectiveness of different system strategies can be detected. Consequently, it is possible to design integrated safety systems with regard to their effectiveness in real-world accident scenarios during the development process by using the method presented in this article. The integration of the effectiveness analysis into the development process enables a requirement based system design regarding the total system effectiveness in real world accidents contributing to achieve the goal of vision zero.

REFERENCES

[1] Bock, T: Vehicle in the Loop - Test- und Simulationsumgebung für Fahrerassistenzsysteme, Göttingen, Cuvillier Verlag, 2008

[2] GIDAS Codebook 2007

[3] Gollewski, T.: Integrale Sicherheit Herausforderungen, aktuelle Funktions- und Auslegungskonzepte aus Sicht eines OEMs, Hanau-Steinheim, Integrated Safety, 2008

[4] Hannawald, L.: Multivariate Bewertung zukünftiger Fahrzeugsicherheit, Dresden, VDI Verlag, 2008

[5] Hannawald L.; Liers, H.: Bewertung des Euro-NCAP-Fußgängerschutz-Ratings anhand von GIDAS-Realunfalldaten, Leipzig, crash.tech, 2009

[6] Roth, F.; Schramm, S.; Riedel, H.; Stoll, J.: Integraler Fußgängerschutz - Bewertungsmethoden, Bergisch-Gladbach, Praxiskonferenz Fußgängerschutz, 2008

[7] Roth, F.; Stoll, J.; Zander, A.; Schramm, S.; von Neumann-Cosel, K.: Methodik zur Funktionsentwicklung des Vorausschauenden Fußgängerschutzes, Wolfsburg, 24. VDI/VW-Gemeinschaftstagung Integrierte Sicherheit und Fahrerassistenzsysteme, 2008

[8] Press Release EU-Commission 8.10.2007 (IP/07/1453)

[9] Regulation (EC) No 78/2009 of the European Parliament and of the Council of 14 January 2009 on the type-approval of motor vehicles with regard to the protection of pedestrians and other vulnerable road users

[10] Proposal for a Regulation of the European Parliament and of the Council on the Protection of Pedestrians and other Vulnerable Road Users, Impact Assessment, Doc. SEC (2007) 1244

[11] PC-Crash Accident-Simulation Program, Dr. Steffan Datentechnik, Linz, Austria

[12] Zeit für Zukunft- Forschungsfahrt 2008, Pressemappe Volkswagen AG, Wolfsburg 2008