SIMULATION OF REAL CRASHES AS A METHOD FOR ESTIMATING THE POTENTIAL BENEFITS OF ADVANCED SAFETY TECHNOLOGIES

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ABSTRACT

Since secondary safety systems have been implemented in modern cars successfully, the development of primary safety systems becomes more and more important. That causes the necessity of useful methods to estimate the benefit of these advanced safety systems. In this paper a new method for the benefit estimation of advanced safety systems by simulating real world crashes is presented.

The bases of this simulation are real world crashes out of the GIDAS (German In-Depth Accident Study) database, including reconstruction data, accident sketches and safety systems specifications.

The result of this method is a comparison between the simulated real accident scenario and the predicted accident scenario using a virtual prototype of the safety system. Using this comparison it is possible to estimate the benefit for the single case as well as the global benefit for all cases. The simulation will be done with a car dynamic simulation program. Therefore, interactions between sensor systems, brakes and steering controls can be considered.

Furthermore, it is also possible to simulate crash involved cars with more than one safety system. The benefit will be estimated regarding accident avoidance and/or accident mitigation based on all available cases in GIDAS.

Another possibility of such a simulation is to find out potentials of the further development of advanced safety systems or to develop new activating strategies by checking up parameters like yaw-angle, lateral acceleration or steering wheel angle.

This paper explains a method for the estimation of potential benefits of primary safety systems and exemplified results.

The paper offers the possibility of a dynamic simulation of real world accident initiations with and without virtual safety systems. The results provide detailed information about useful combinations of advanced safety systems.

THE GIDAS DATABASE

For this paper accident data from GIDAS (German In-Depth Accident Study) was used. GIDAS is the largest in-depth accident study in Germany. The data collected in the GIDAS project is very extensive, and serves as a basis of knowledge for different groups of interest. Due to a well defined sampling plan, representativeness with respect to the federal statistics is also guaranteed. Since mid 1999, the GIDAS project has collected on-scene accident data in the areas of Hanover and Dresden. GIDAS collects data from accidents of all kinds and, due to the on-scene investigation and the full reconstruction of each accident, gives a comprehensive view on the individual accident sequences and its causation.

The project is funded by the Federal Highway Research Institute (BASt) and the German Research Association for Automotive Technology (FAT), a department of the VDA (German Association of the Automotive Industry). Use of the data is restricted to the participants of the project. However, to allow interested parties the direct use of the GIDAS data, several models of participation exist. Further information can be found at http://www.gidas.org.

METHOD

The origin for a good benefit estimation of advanced safety systems should be a kind of comparison. The basis of such comparisons is derived from Hannawald [2]. The comparison that is used for this paper is shown in Figure 1.

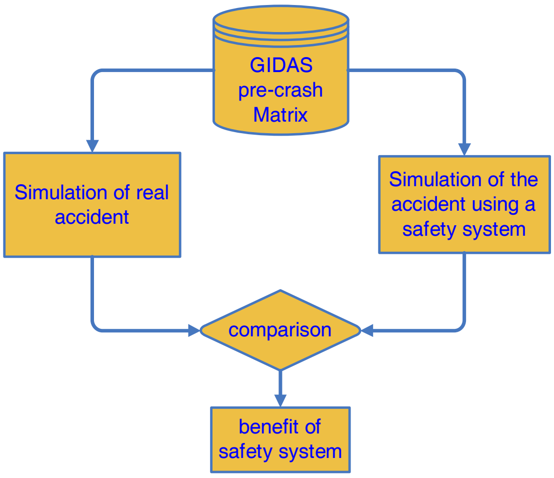

Figure 1. Scheme of comparison

All relevant information is taken out of the pre crash matrix. Then the simulation is processed with and without an active safety system. The results are then compared to each other to find the benefit of the implemented safety system. Furthermore, every block will be explained on its own.

The pre crash matrix

The pre crash matrix is a cluster of information about the accident scene and the movement parameters of the participants. For explanation, the content of this matrix is divided into two parts. The first part of information in this matrix is the geometrical information of the accident scene which comprehends the geometrical positions of lane borders, lane markers, view obstacles and drivelines of each participant. An example accident sketch, shown in Figure 2, is taken to show this process graphically.

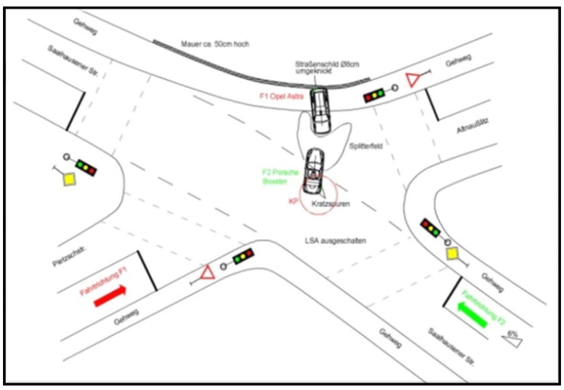

Figure 2. Accident sketch

The extracted geometrical information is shown in Figure 3.

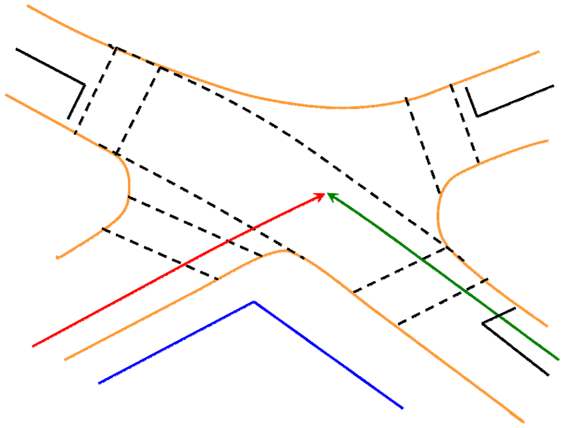

Figure 3. Extracted information of the accident sketch

After extracting the geometrical coordinates and layers the data is then converted into a readable .txt or ASCII file.

The next step in generating a complete pre crash matrix is the compilation of the movement parameters of the GIDAS database out of the reconstruction data. Using this reconstruction data it is possible to create an X,Y(t) matrix of all participants in the accident. The method for the calulation of the pre crash accident phase and the development of an X,Y(t) matrix was described by Erbsmehl in [1]. The pre crash matrix used in this paper is a combination of the digital accident sketch and the X,Y(t) matrix of the participants.

Simulation of the real accident without safety system

The next step in Figure 1 is the foreward simulation of the real accident.

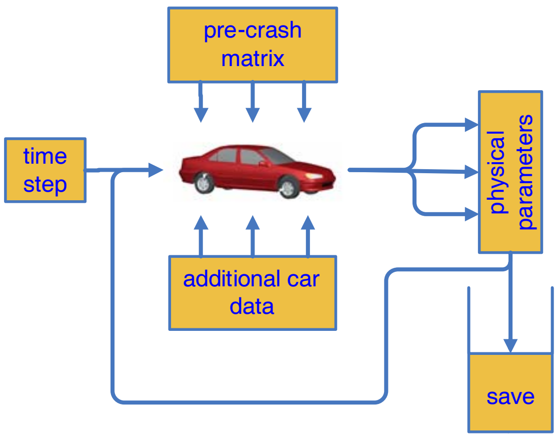

Figure 4. Simulation of the accident without safety system

In Figure 4 a short scheme of the simulation and the working process is illustrated. The simulation starts about three seconds before the crash. After the start of the simulation the time value is increased slowly by 0.001 sec. In every time step the complete vehicle dynamic is calculated regarding the actual physical car parameters. This calculation is done for every participant of the accident. CarSim in combination with Matlab Simulink is used as dynamic car simulation program. As shown below some addidtional car parameters are used as well.

Aditional car parameters - are needed to complete the input for the dynamic simulation. These car parameters are:

- car dimensions
- road conditions (tire contact)
- information about tires
- rear, front or all wheel drive
- braking system

Physical parameters - are the result and the input for the next time step of the dynamic car simulation. These simulation parameters are saved in every time step for later comparisons. The list of the saved parameters can be edited as well. For the current simulation the following parameters are used.

- current car position
- current car speed (x,y,z)
- current car acceleration
- current yaw angle
- current steering angle
- current brake cylinder pressure

Result - is a compact file, which contains all physical parameters depending on the time to collision (TTC) or simulation time. The graphical result of such a simulation is shown in Figure 5.

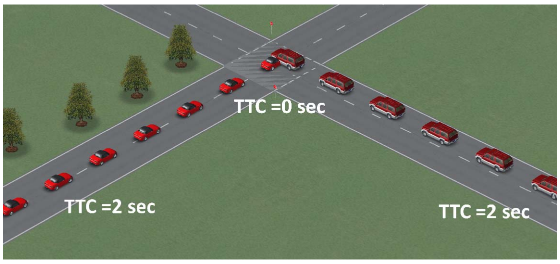

Figure 5. Result of simulation without safety system (car positions)

Simulation of the virtual accident using a safety system

All described input variables are now used to simulate the virtual accident scenario using active safety systems.

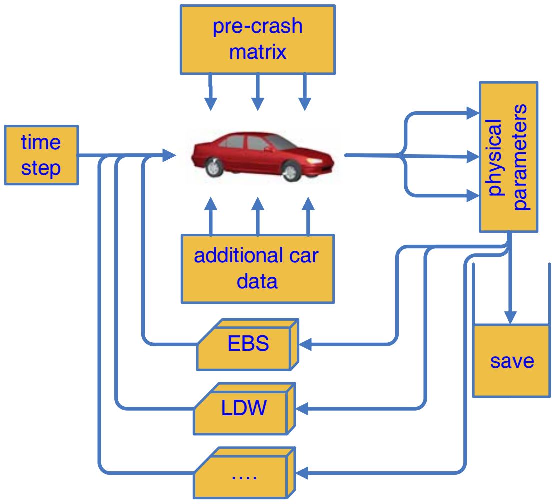

Figure 6. Simulation of the accident using active safety systems

In Figure 6 a similar scheme as shown in Figure 4 is presented. The only difference between the two schemes is the blocks like EBS (emergency brake system) and LDW (lane departure warning). These blocks represent a number of user defined safety systems which can be integrated into the striking car, for example. Those safety systems react to physical parameters as well as to environmental parameters because they are implemented into the closed loop of the simulation. There is no need for pre-defined field of operations or pre-defined effectiveness values for the systems. For the simulation in the current study, only an emergency brake system is implemented.

The emergency brake loop - is based on two input values. The first input value is the information whether there is an object in the field of the sensor for the emergency brake system and whether it is detected. The second input value is derived from the geometrical position and the speed difference of both cars. It is checked whether they are on a direct collision course or not. If the collision is unavoidable and the other accident participant is in range of the sensor and detected as well, then the emergency brake loop raises the pressure in the main brake cylinder and the car begins to brake. If the situation is not longer dangerous, the emergency brake loop reduces the brake pressure. To check whether the second participant is in the field of the sensor a detection module is used.

The detection module - of the EBS loop is constructed by using the following scheme.

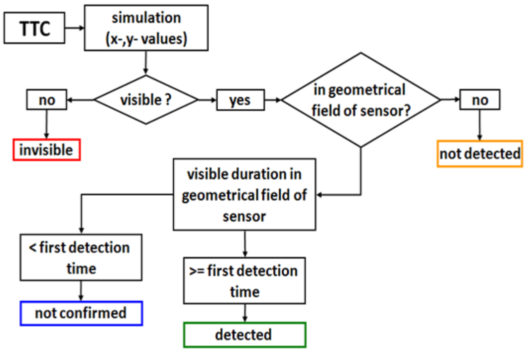

Figure 7. The detection module

In Figure 7 the time to collision (TTC) is the first input value for the detection module. The TTC is the same as in the iteration step during the simulation and also called simulation time. In every iteration step the position of the opponent car is checked regarding the visibility condition. For checking the visibility condition, four detection lines are drawn from the position of the sensor on the equipped car to the corners of the opponent.

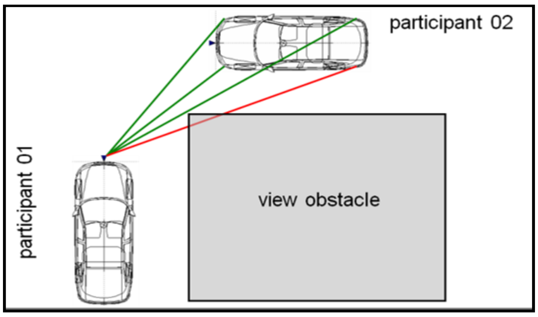

Figure 8. Detection lines

In the situation shown in Figure 8, three of four detection lines do not intersect the view obstacle, so the criteria for the visibility of participant 02 to participant 01 is fulfilled. If more than one detection line intersects the view obstacle, participant 02 is not visible to participant 01. In this case, the detection module ends and a detection for this TTC or iteration step is not possible. Otherwise the next request is done by the detection module. It is checked, if the position of the opponent is in the geometrical field of the sensor. To answer this request, the information about the used sensor characteristics is defined with:

- beam angle
- range
- initial detection latency
- trigger time
- number of sensors

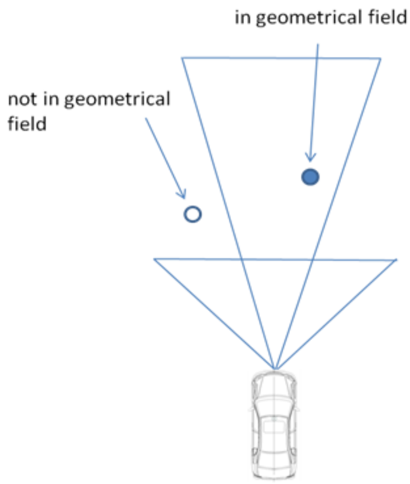

Figure 9. Geometrical field of the sensor

If the opponent is not in the geometrical field of the used sensor system, the detection module is again not able to detect the opponent. Otherwise the next request by the detection module refers to the duration of the visibility. If this duration is shorter than the initial detection latency of the sensor system, the opponent is again not detected. If all these terms are fulfilled the equipped car is able to detect the opponent.

The collision course - must be regarded too. Additional input variables are needed to calculate the collision course. These are the current movement vector of the opponent, the own movement vector, the current steering angle (if the option of evasion is considered), the maximum deceleration and the speeds of both participants. All this information is extracted out of the current simulation, as described in the physical parameters, and the collision course is calculated.

Results - of the simulation with embedded safety systems are given in the same way as the simulation results of the real accident. This is the basis for a comparison.

Comparison

After simulating the accident with and without an embedded safety system the following information is available.

- collision speed of the participants
- collision position of the participants
- avoidance of the accident

At first, an example for accident avoidance is displayed in Figure 10. Here, an original crossing accident is utilized.

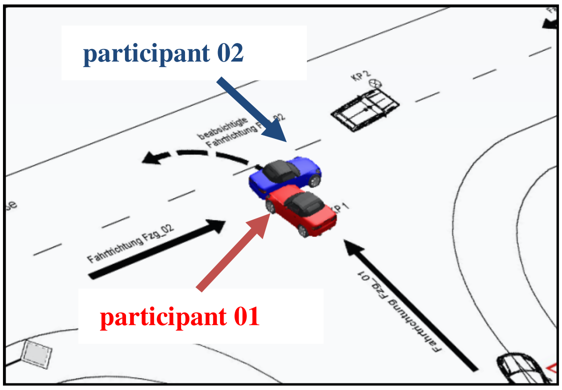

Figure 10. Collision position crossing accident (original)

In this case the accident can be avoided with the embedded emergency brake loop, illustrated in Figure 11.

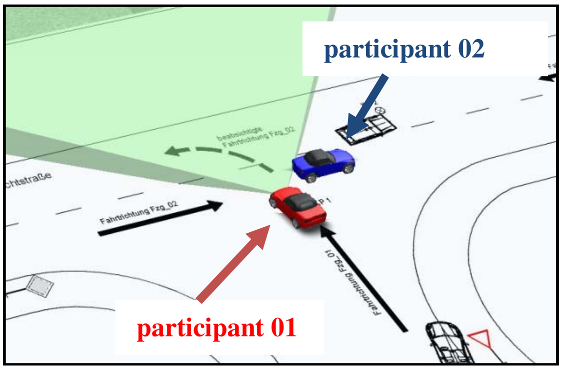

Figure 11. Collision position crossing accident (virtual)

The accident is avoided if the speed of the striking car is zero and its position is in front of the collision position of the original accident. The accident is also avoided if the striking car passes the original collision position later than the second participant. If the accident could not be avoided, a closer look at the collision speed and the new collision position is necessary. For this case it is important whether the speed reduction is achieved for the striking car or not. The accident in Figure 12 could not be avoided using the embedded emergency brake system.

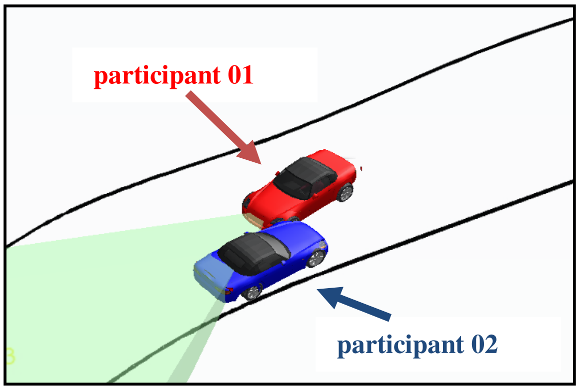

Figure 12. Frontal accident with speed reduction

The collision speed of the right (red) striking car can be reduced by 10 km/h, which is shown in Figure 13.

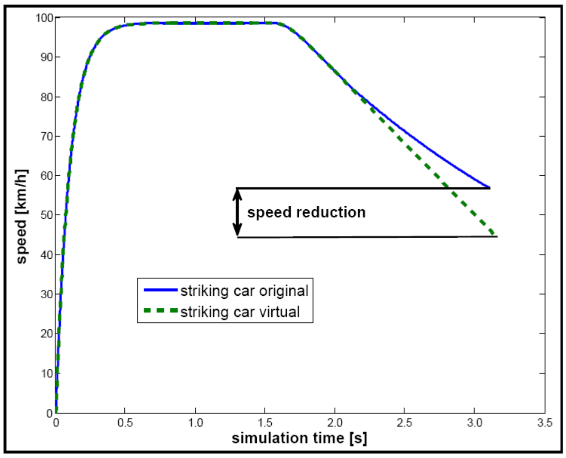

Figure 13. Speed reduction of the striking car

If the accident could not be avoided and there is no speed reduction of the striking car, the embedded safety system has no effect on the accident severity.

EXEMPLIFIED RESULTS

Three accidents are analyzed with the described emergency brake system to show the possibilities of this estimation method.

Sensor geometry

For the simulation two sensor geometries are used. The first sensor covers a range of 100 meters with a beam angle of 20 degrees and the second sensor covers a range of 50 meters with a beam angle of 120 degrees.

The turning off accident

A turning off accident is taken from the GIDAS database. The pre crash matrix is built out of the accident sketch in Figure 14 before the accident is simulated.

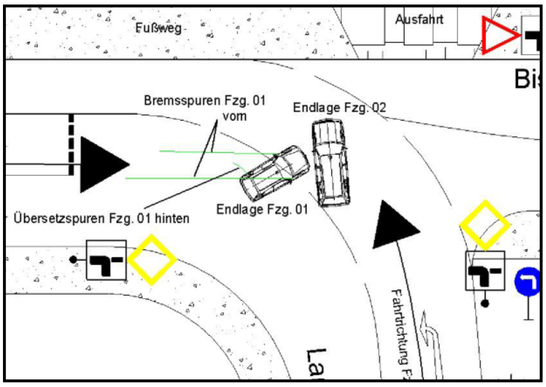

Figure 14. Accident sketch turning off example

<u>The simulation of the real accident</u> - delivers the collision position shown in Figure 15.

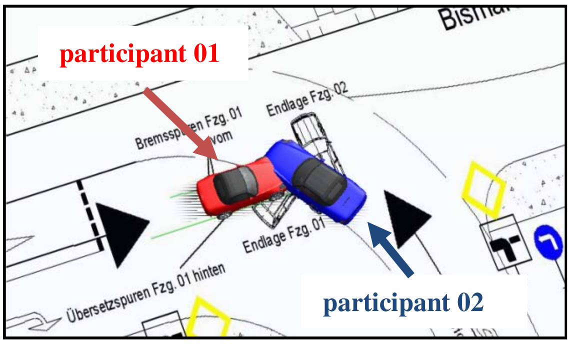

Figure 15. Simulated collision position real accident

The speed function for the participant one, of the accident, is shown in Figure 16.

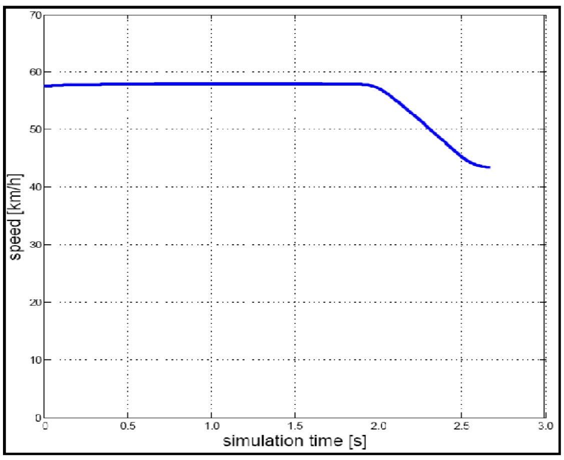

Figure 16. Simulated speed function of participant one of the real accident

<u>The simulation of the virtual accident 1</u> - under the use of the first sensor system (range 100m, beam angle 20°) delivers the collision position shown in Figure 17.

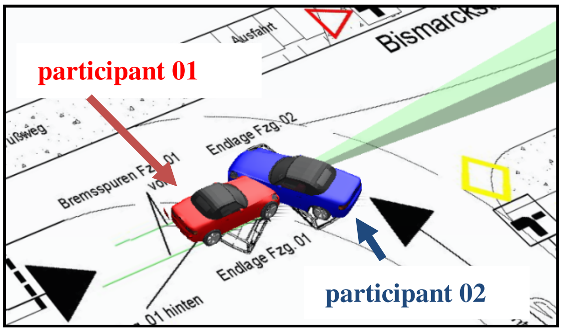

Figure 17. Simulated collision position virtual sensor 1

The speed function of participant one of the simulated accident with an embedded emergency brake under the use of sensor system one is compared to the speed table of participant one of the simulation of the real accident.

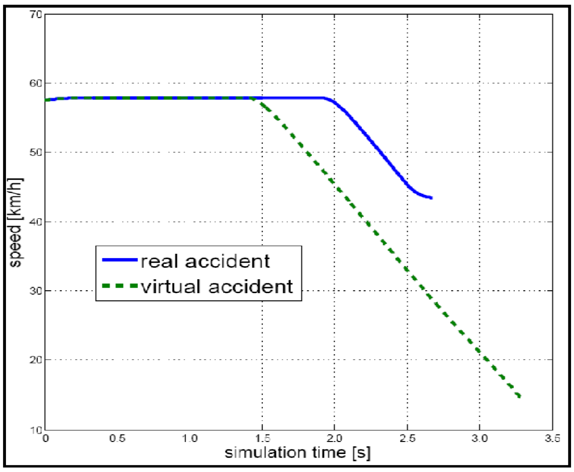

Figure 18. Simulated speed function virtual accident 1

Figure 18 shows the speed tables of the striking car in the real and the virtual accident. The speed reduction by using the emergency brake system and sensor system one is 28 km/h at the time of collision even though the striking car brakes in the original accident.

The simulation of the virtual accident 2 - under the use of the second sensor system (range 50m, beam angle 120°) delivers the collision position shown in Figure 19.

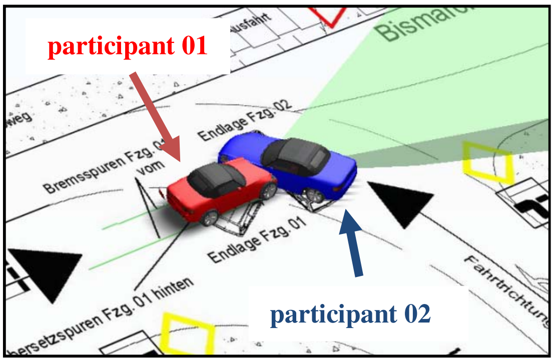

Figure 19. Simulated collision position virtual sensor 2

The speed function for the simulated accident with an embedded emergency brake under the use of sensor system two is also compared to the speed table of the simulation of the real accident.

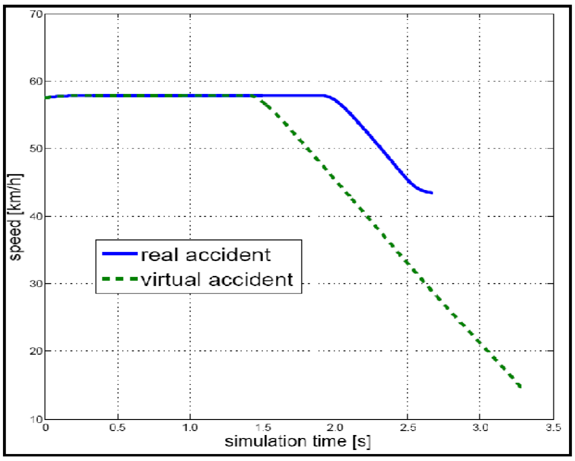

Figure 20. Simulated speed function virtual accident 2

Figure 20 shows the speed table of the striking car in the real and the virtual accident with sensor two. The speed reduction by using the emergency brake system and sensor system two is 28 km/h at the collision as well, because the used sensor system is not able to detect participant two earlier than the sensor system one.

The crossing accident

For the second comparison a crossing accident is taken out of the GIDAS database. The pre crash matrix is build out of the accident sketch in Figure 21 before the accident is simulated.

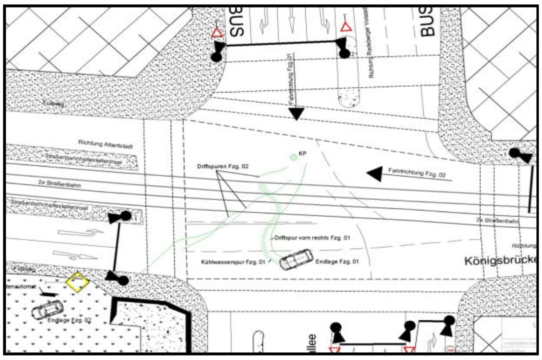

Figure 21. Accident sketch crossing accident

The simulation of the real accident - delivers the collision position shown in Figure 22.

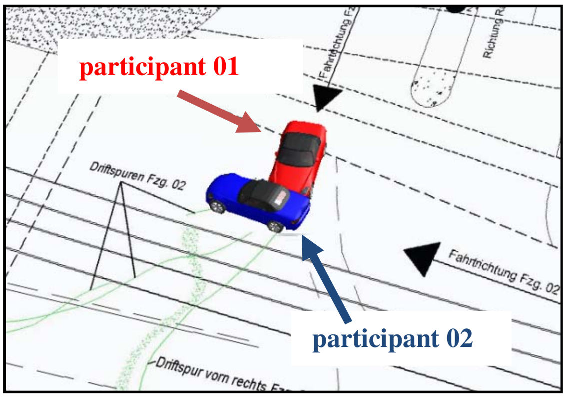

Figure 22. Simulated collision position real accident

The speed function of participant one is shown in Figure 23.

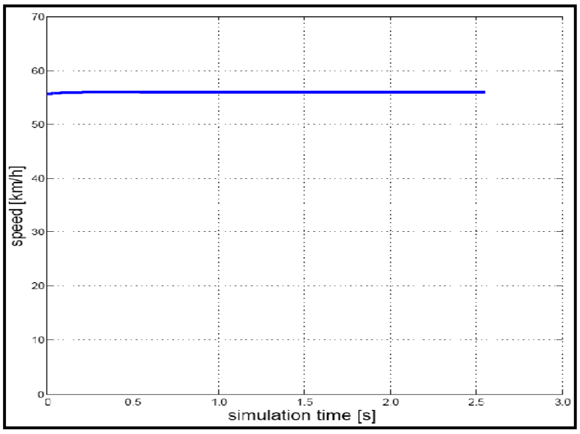

Figure 23. Simulated speed function real accident

In this case the striking car did not brake.

The simulation of the virtual accident 1 - under the use of the first sensor system (range 100m, beam angle 20°) delivers the collision position shown in Figure 24.

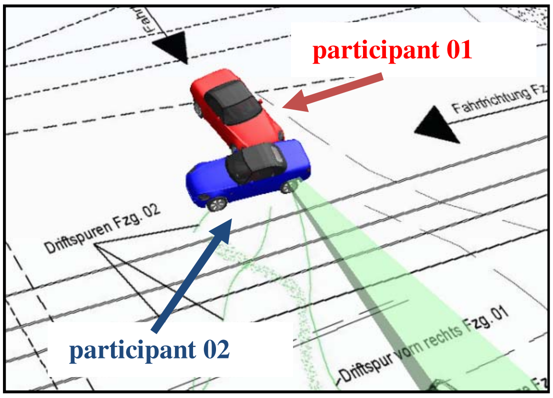

Figure 24. Simulated collision position virtual sensor 1

The speed function for the simulated accident with an embedded emergency brake under the use of sensor system one is compared to the speed table of the simulation of the real accident.

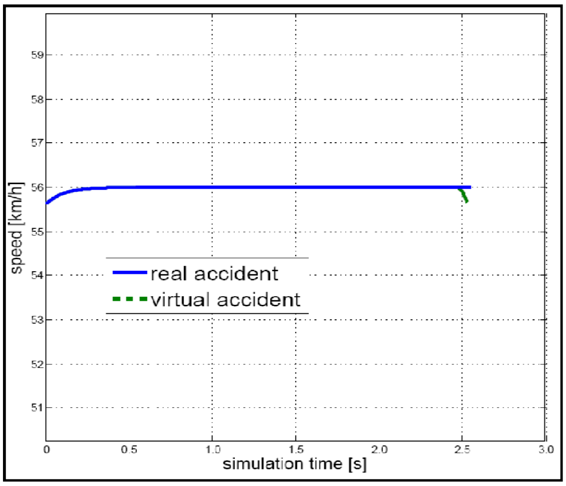

Figure 25. Simulated speed function virtual accident 1

The benchmark in Figure 25 shows that the striking car brakes just a short time before the impact and reduces its speed by approximately 1 km/h.

<u>The simulation of the virtual accident 2</u> - under the use of the second sensor system (range 50m, beam angle 120°) delivers the collision position shown in Figure 26.

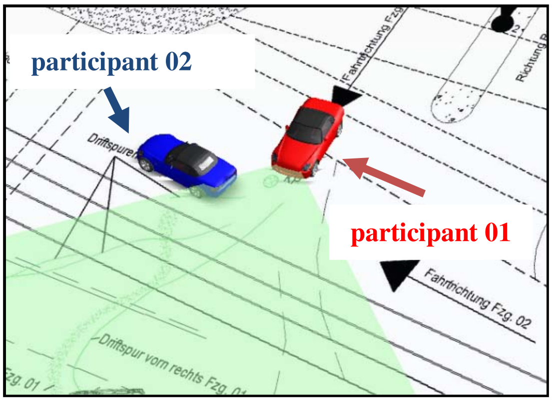

Figure 26. Simulated collision position virtual sensor 2

This collision position shows the fact that this accident could be avoided using the emergency brake system and the sensor system two. The comparison of the speed table does additionally show the speed for the striking car in this simulation.

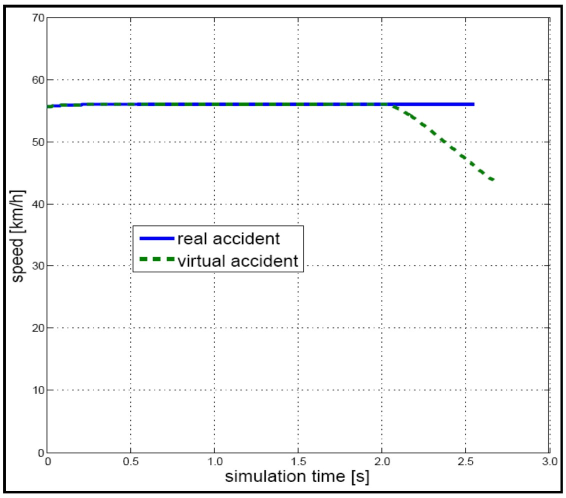

Figure 27. Simulated speed function virtual accident 2

The comparison in Figure 27 shows that the collision speed in the simulation with the emergency brake system and the second sensor system is reduced from 56 km/h to 44 km/h, if the accident could not be avoided in case of a longer opponent.

The longitudinal accident

For the third comparison a longitudinal accident is taken from the GIDAS database. The pre crash matrix is built out of the accident sketch in Figure 28 before the accident is simulated.

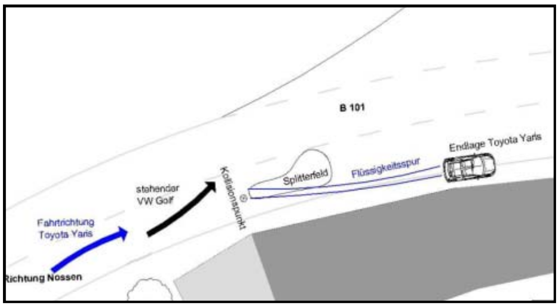

Figure 28. Accident sketch longitudinal accident

<u>The simulation of the real accident</u> - delivers the collision position shown in Figure 29.

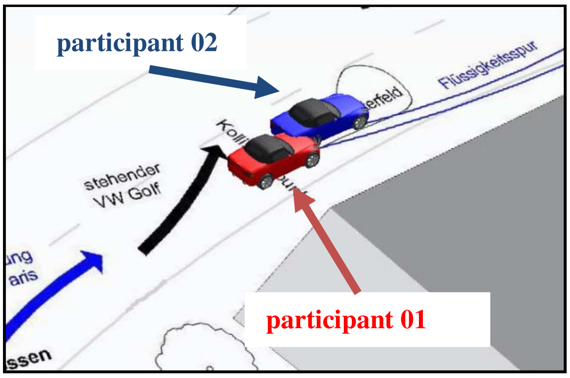

Figure 29. Simulated collision position real accident

The speed function for the participant one is shown in Figure 30.

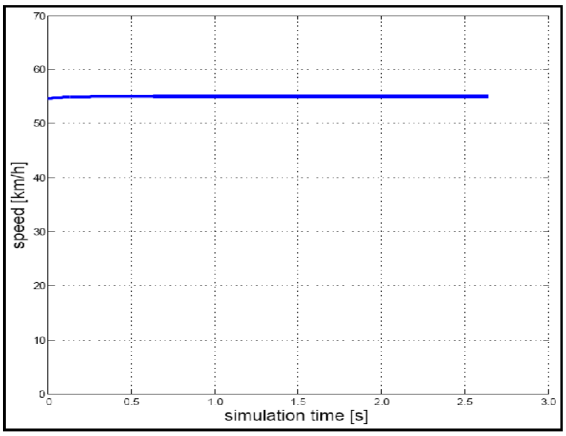

Figure 30. Simulated speed function real accident

In this case the striking car did not brake, so the collision speed is 55 km/h.

<u>The simulation of the virtual accident 1</u> - under the use of the first sensor system (range 100m, beam angle 20°) delivers the collision position shown in Figure 31.

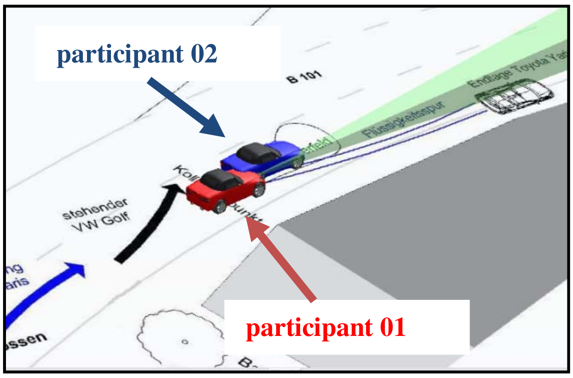

Figure 31. Simulated collision position virtual sensor 1

The speed function for the simulated accident with an embedded emergency brake under the use of sensor system one is compared to the speed table of the simulation of the real accident.

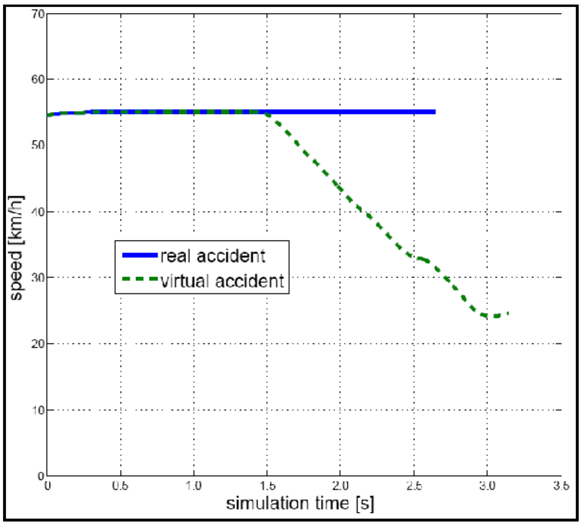

Figure 32. Simulated speed function virtual accident 1

Using the simulated speed function in Figure 32 out of the simulation it can be stated, that the participant two is not detected all the time. Nevertheless, the speed reduction makes up 31 km/h to a collision speed of 24 km/h, compared to the real accident.

<u>The simulation of the virtual accident 2</u> - under the use of the second sensor system (range 50m, beam angle 120°) delivers the collision position shown in Figure 26.

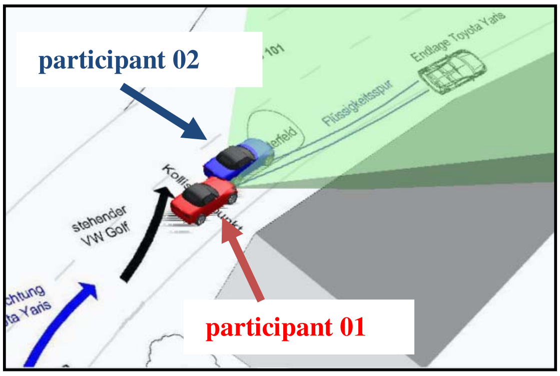

Figure 33. Simulated collision position virtual sensor 2

The speed function for the simulated accident with an embedded emergency brake under the use of sensor system two is compared to the speed table of the simulation of the real accident.

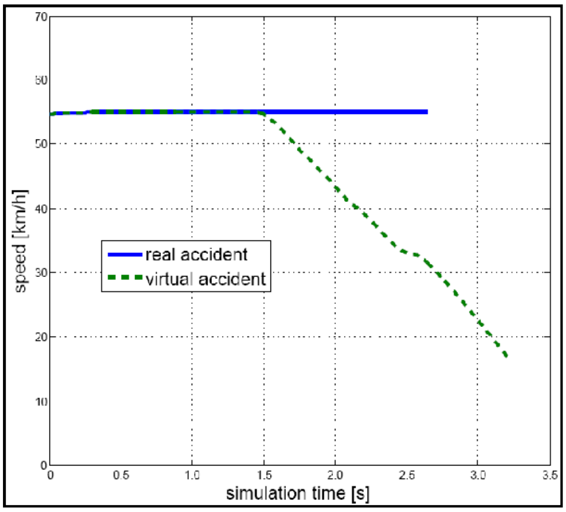

Figure 34. Simulated speed function virtual accident 2

In Figure 34 the speed function of the virtual accident two shows that the participant two is detected longer than using the first sensor system. That enables a full braking maneuver over the entire simulation time. The speed reduction for the emergency brake system combined with the sensor system two makes up 39 km/h, which results in a collision speed of 16 km/h.

ADAPTABILITY OF THE SIMULATION

The simulation method, which was explained in this paper, is adaptable for every reconstructed accident in the GIDAS database. Simulations of accidents out of other accident databases might be possible if all needed parameters out of the reconstruction dataset, the accident site dataset and out of the accident sketch are available.

CONCLUSIONS

This paper shows a new method for estimating active safety systems using a simulation. The basis of the simulation is the pre crash matrix from the accident data and the accident sketch. The original accident is then simulated without any additional system. Afterwards, the accident is simulated again with several implemented safety systems. The benefit of one active safety system or a combination of safety systems is taken out of the comparison of those simulations. The timeline of activation of the different systems or the field of operation is not needed. Using this method the benefit of almost every new safety system or combinations of safety systems can be estimated without any assumptions about the effectiveness of the safety systems. Furthermore this method can be used to find faulty activations of active safety systems and required characteristics of future safety systems.

REFERENCES

[1] - Christian Erbsmehl – "Simulation realer Unfalleinlaufszenarien der German In-Depth Accident Study (GIDAS)", October 2008, 24. VDI/VW Gemeinschaftstagung Wolfsburg, VDI Berichte 2048

[2] - Lars Hannawald – "Multivariate Bewertung zukünftiger Fahrzeugsicherheit", June 2008, VDI Reihe 12 Nr. 682