Automated crash computation of passenger car accidents based on the GIDAS database

M. Wagner, L. Hannawald, H. Liers*

* Verkehrsunfallforschung an der TU Dresden (VUFO) GmbH, Semperstraße 2a, 01069 Dresden

Abstract

For the estimation of the benefit and effect of innovative Driver Assistance Systems (DAS) on the collision positions and by association on the accident severity, together with the economic benefit, it becomes necessary to simulate and evaluate a variety of virtual accidents with different start values (e.g. initial speed). Taken into account the effort necessary for a manual reconstruction, only an automated crash computation can be considered for this task.

This paper explains the development of an automated crash computation based on GIDAS. The focus will be on the design of the virtual vehicle models, the method of the crash computation as well as exemplary applications of the automated crash computation. For the first time an automated crash computation of passenger car accidents has been realized. Using the automated crash computation different tasks within the field of vehicle safety can be elaborated. This includes, for example, the calculation of specific accident parameters (such as EES or delta-V) for various accident constellations and the estimation of the economic benefit of DAS using IRFs (Injury Risk Functions).

NOTATION

E_{ges}	Overall Energy
m	Passenger car mass
EES	Energy Equivalent Speed
F	Force (Deformation)
s	Distance (Deformation)
E_{def}	Deformation Energy
E_n	Maximum Deformation Energy
S_n	Maximum Distance (Deformation)
EES_{voxel}	Energy Equivalent Speed of one voxel
$E_{voxel,k}$	Deformation Energy of one voxel

Motivation

Within the process of increasing the traffic safety many new driver assistance systems (DAS) are developed. Most often an accident scenario with the highest relevancy is identified and therefore a system is adapted to avoid an accident or at least to mitigate the accident severity. So far systems like the antilock braking system (ABS©) or the electronic stability program (ESP©) have helped to decrease the number of accidents or their severity.

With ambitions to have no road traffic fatalities in 2050 and to develop cars for autonomous driving the importance of testing DAS in regards to their actual performance in real accident scenarios, as well as the estimation of the benefit of such a system, is constantly increasing.

Therefore the DAS has to be assessed at least before the market launch, if not even before the launch of production. In the best case this is already done during the development process of the DAS.

Additionally a large number of realistic accidents with detailed information is needed to test the performance of DAS. Since the activation of a DAS most often leads to a change of the collision parameters (e.g. collision speed and constellation) of the participants, the necessity of a new reconstruction of the whole accident arises. Due to the fact that a manual reconstruction is time- and resource-consuming the only considerable way to assess DAS during the development process is to do so with an automated crash computation.

During a series of different projects the VUFO has started to develop an efficient tool, called Automated Crash Computation, which uses the information of real accidents provided by the GIDAS database.

Virtual Vehicle Models

The Automated Crash Computation uses virtual vehicle models with information about the EES which is available in the GIDAS database. The creation of such models has been explained in great detail in previous publications [1, 2]. For this paper only the main steps to create virtual vehicle models from the GIDAS database will be summarized.

These steps are the following:

1. 3-dimensional description of the deformation values of each car
2. Creation of a 3-dimensional vehicle model
3. Merging of the deformation information with the 3-dimensional vehicle model
4. Merging the 3-dimensional deformation vehicle model with information on the deformation energy
5. Merging all information from every energy vehicle model by car type

In the GIDAS database there are deformation values available for every deformed car. The single deformation values are coded in the database using standardized schemes for every car type. Figure 1 shows an extract of these schemes.

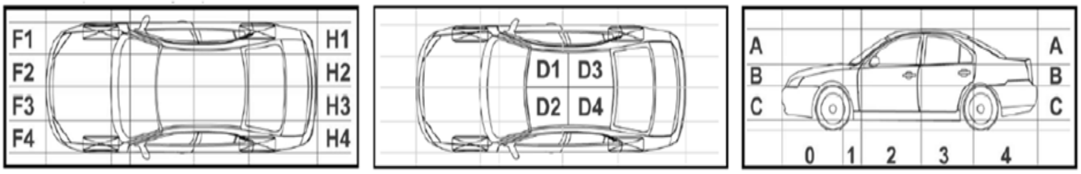

Figure 1. GIDAS schemes for car deformations

For each zone of the car a single deformation value (deformation depth) is coded. Therefore a linear interpolation between the values is done to extract a deformation line of the car. This concludes step number one.

The second step includes the creation of a 3-dimensional vehicle model. For this a pre-defined 3-dimensional matrix of 120x40x40 cells (voxel) and a specific vehicle shape are needed (Figure 2).

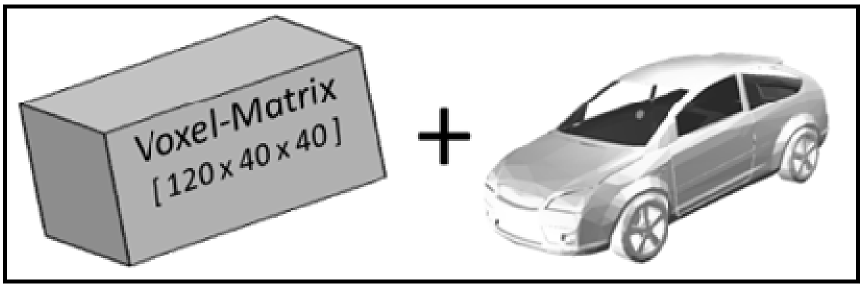

Figure 2. Voxel-Matrix and basic vehicle model

The merging of the vehicle shape and the voxel-matrix to a 3-dimensional vehicle model (Figure 3) concludes this step.

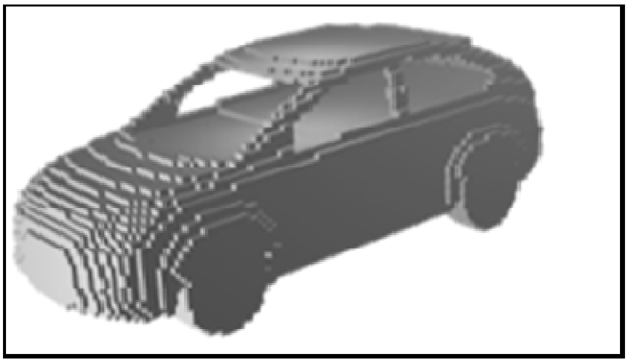

Figure 3. 3-dimensional vehicle model

Currently there are four different car types available (Figure 4):

1. Van
2. Sedan
3. Hatchback
4. Station wagon

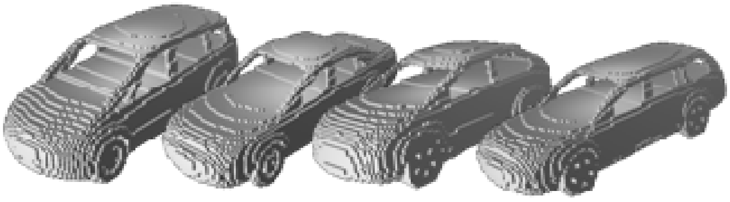

Figure 4. Available car types as voxel models

In the third step the interpolated deformation lines and the 3-dimensional vehicle model are merged to calculate the 3-dimensional vehicle deformation model. An example of such a model is shown in Figure 5. With this the deformed area of the car as well as the deformed voxel of the vehicle model can be identified.

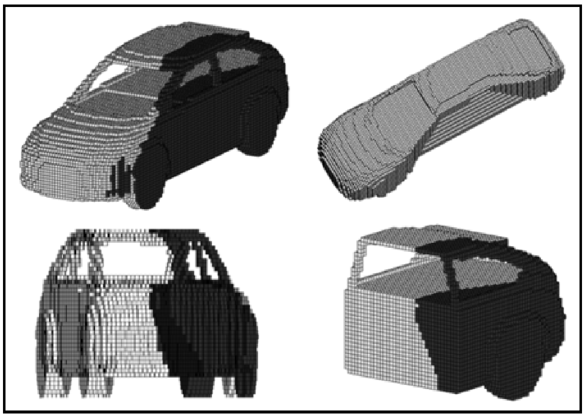

Figure 5. Example of a 3-dimensional vehicle deformation model

In the fourth step the information in regards to the deformation energy during the collision is extracted from the GIDAS database and added to the vehicle deformation model. The deformation energy is coded as a speed value, called EES (energy equivalent speed). Using the vehicle mass (m) it is possible to calculate the kinetic energy before the crash. The deformation energy (E_{ges}) is assumed to be equivalent to the deformation energy.

$$E_{ges} = \frac{m}{2} * EES^2 \qquad [1]$$

To distribute the energy among the previously as "deformed" identified voxel and without the knowledge of the actual distribution of material stiffness, certain assumptions have to be made.
The main assumption is that the deformation force increases over the deformation distance until the maximum deformation depth is realized (Figure 6).

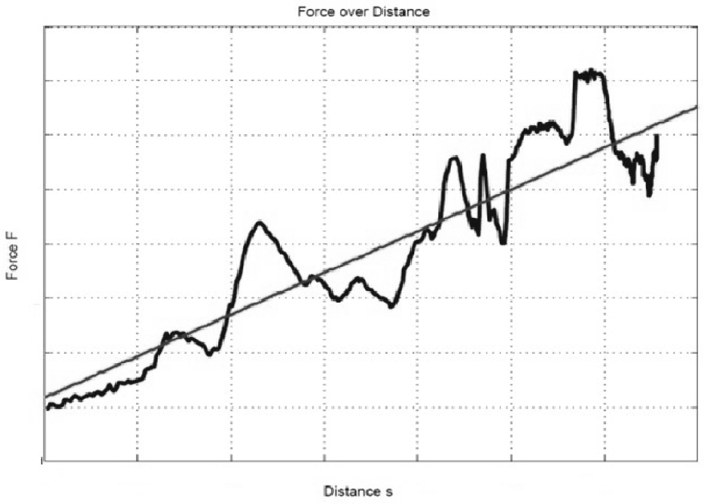

Figure 6. Force over distance (qualitatively)

This conclusion is drawn from the observations made during real world crash tests [2]. Furthermore, if the deformation force is increasing linear, then it integration, the deformation energy, increases quadratic (Figure 7).

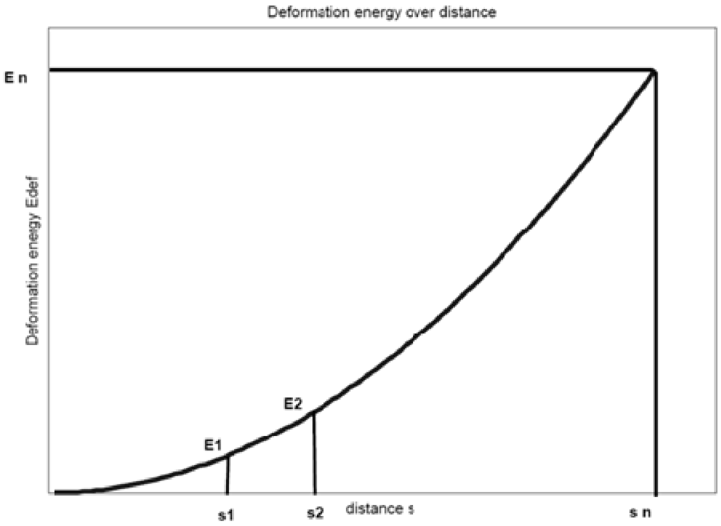

Figure 7. Deformation energy over distance (qualitatively)

Additionally the direction of the impact pulse has to be considered. This information can also be drawn from the GIDAS database and is known as "VDI1". This parameter is distributed into 12 parts (Figure 8).

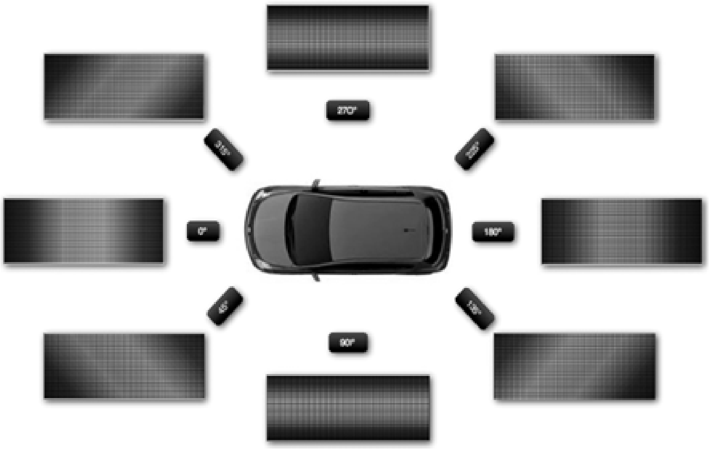

Figure 8. Distribution matrices according to VDI1

Using the direction of the impact pulse and the deformation energy from GIDAS as well as a specific algorithm [2] each voxel of the vehicle deformation model is assigned a specific deformation energy value.

With these steps a 3-dimensional vehicle energy model is created for each car in the database. Now a mean energy value for each voxel and certain car types could be calculated. But due to the variation of cars within the database and therefore also the variation of the level of passive safety (e.g. stiffness of the compartment) a distinction has to be made between:

1. The year of construction
2. The vehicle mass

This leads to the following four groups of vehicle energy models available at the current time for the Automated Crash Computation:

1. Younger, light vehicles
2. Younger, heavy vehicles
3. Older, light vehicles
4. Older, heavy vehicles

The definition of the borders of each group (young/old, light/heavy) can be easily adapted according to its distribution among the cars taken from the GIDAS database [2].

Methodology of the crash computation

The Automated Crash Computation can basically be divided into the following parts:

1. Pre-Process
2. Crash-Simulation
3. Post-Process
4. Assessment

The purpose of the Automated Crash Computation tool is to assess a DAS during its development using real world accident scenarios. Therefore the simulation results, including the new crash constellation (position of the cars) and other relevant parameters (yaw-angle, velocity), are needed as an input for the crash computation.

Furthermore the vehicle energy model is transferred into an EES based model using the mass of each car. If necessary, additional data can be retrieved from databases like GIDAS. The collection of all this data and the preparation for the simulation is done during the pre-process of the tool (Figure 9).

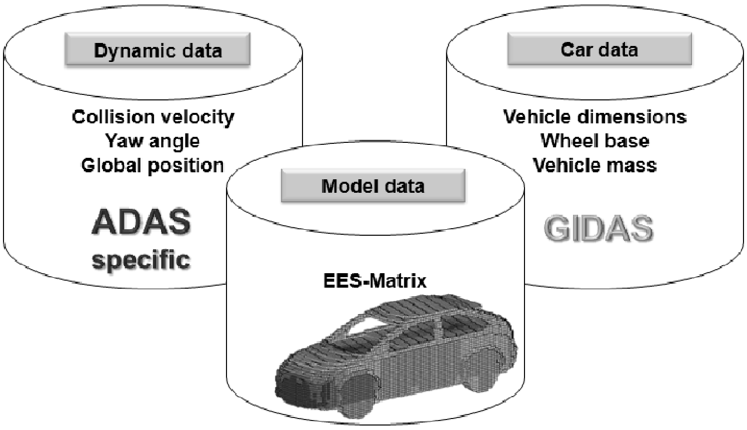

Figure 9. Overview of the pre-process

Then the simulation follows. Within this step the two energy vehicle models are being “crashed” (Figure 10).

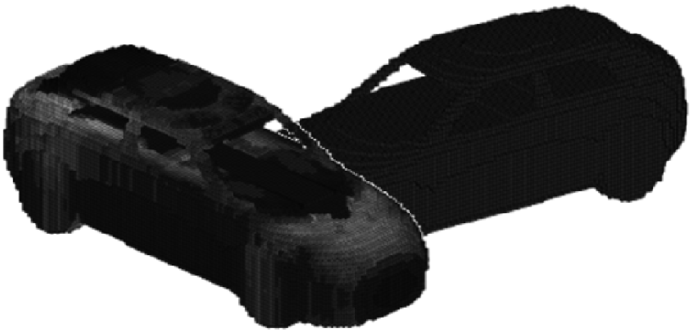

Figure 10. Position of the cars before the crash

In every step of the computation the two vehicle models are driving into one another and the voxels that overlap each other are being compared in regards to their EES-value (Figure 11).

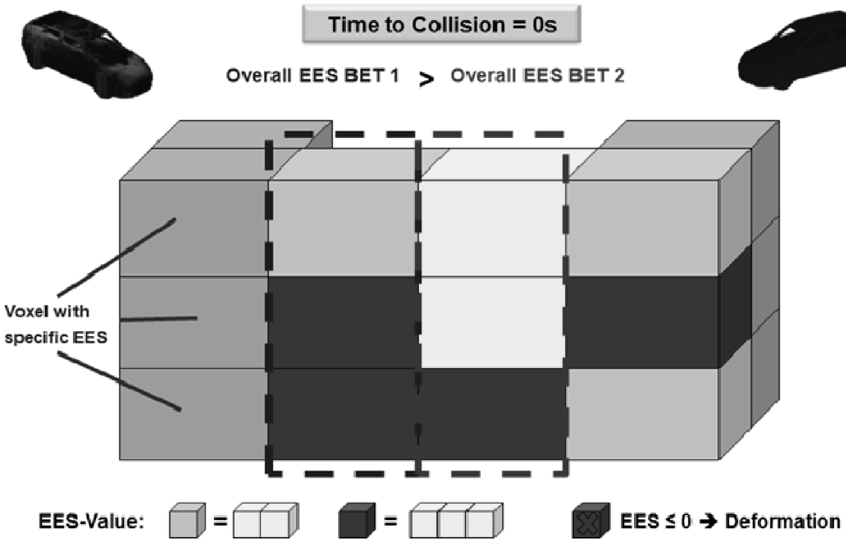

Figure 11. Voxel matrizes before the crash (example)

Then the values are subtracted from one another and if a voxel has a negative EES-value it is deleted from the voxel-matrix of the energy vehicle model (Figure 12).

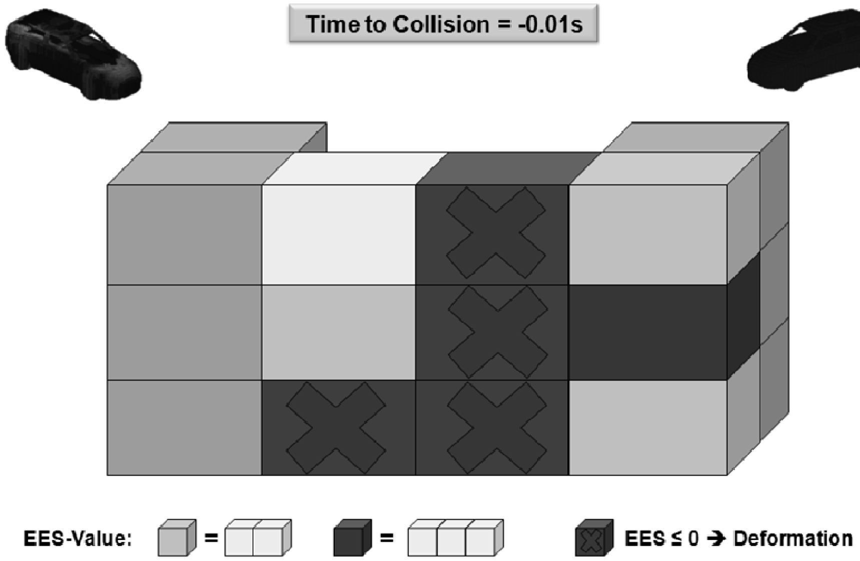

Figure 12. Voxel matrizes after the first computation step (example)

After a specific abortion criterion is reached, the computation is stopped. The resulting deformations of both cars can be seen in Figure 13.

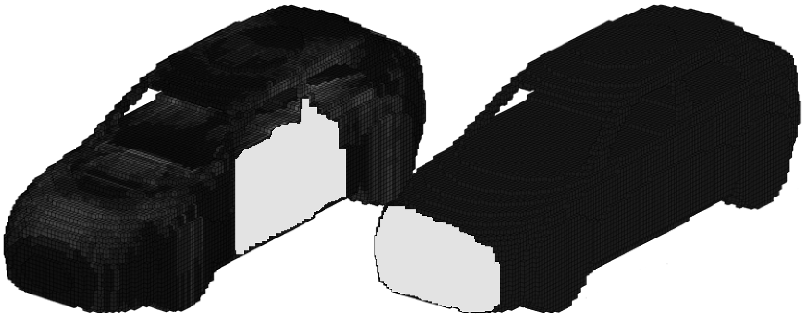

Figure 13. Resulting deformations of the cars (example)

During the post-process further crash parameters (point of impact and impact plane) are being calculated (Figure 14).

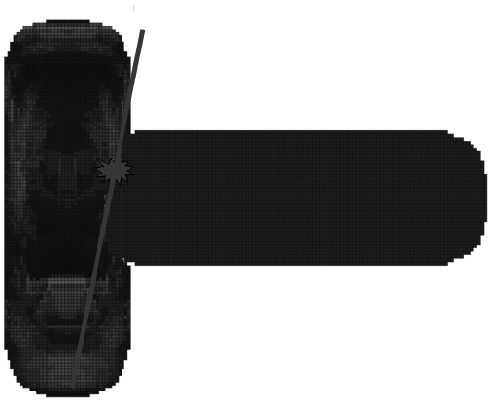

Figure 14. Resulting point of impact and impact plane (Bird's eye view of the crash)

These crash parameters as well as the input data from the simulation of the DAS is handed over to PC-Crash to computate more crash parameters (e.g. delta-v, deformation depth) which is needed to assess the DAS (Figure 15).

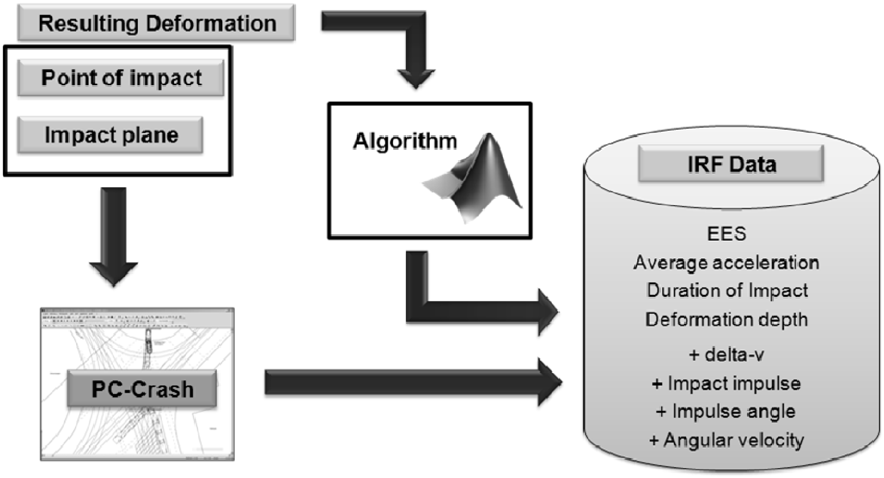

Figure 15. Overview of the Post-Process

Ultimately the data about the crash parameters which was obtained through the automated crash computation will serve as the input data for the assessment of the DAS. For the assessment injury risk functions (IRF) are being used (Figure 16).

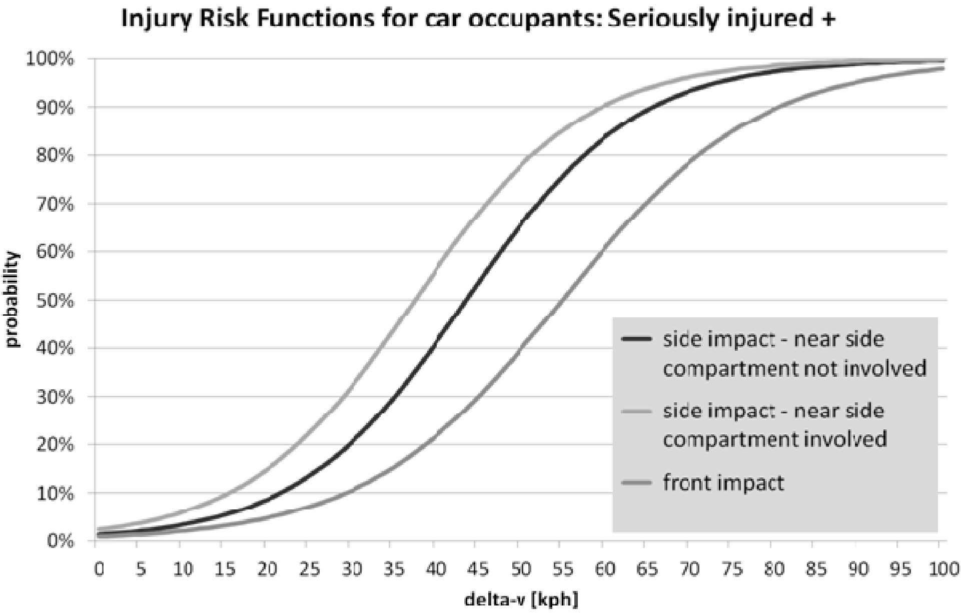

Figure 16. Injury risk functions for the assessment of DAS (example)

These IRF show the probability of different injury severities in relation to different influencing parameters. They can also be obtained from the GIDAS database. More detailed explanations about the IRF can be found in [3].

Application Example

The VUFO was able to test the newly developed tool Automated Crash Computation within the project Ko-KOMP (Cooperating Components). The aim of this project was to examine the effectiveness of different cooperative sensor technology approaches with regard to the degree of protection that could be achieved for the road user [3].
The VUFO supported this project also in terms of assessing the simulated sensor systems (DAS) of the cooperating partners. The basis of the simulation were 35 real world accident scenarios which were extracted from the GIDAS database. From these 35 accidents about 400 virtual accident scenarios were created using a variation of specific driver parameters. An overview of the single project steps is given in Figure 17.

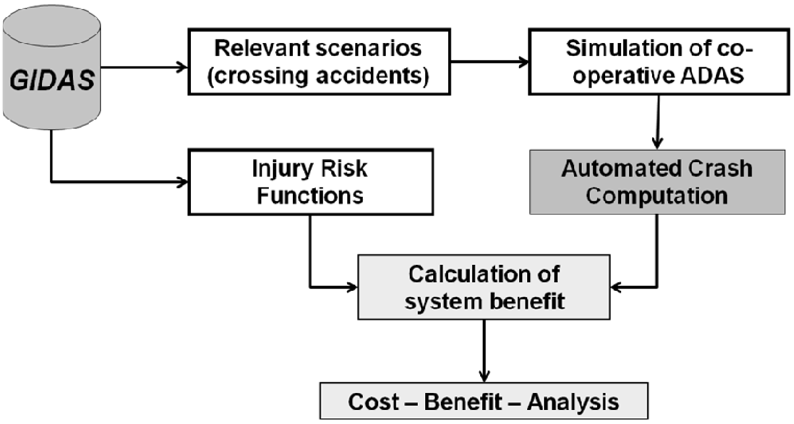

Figure 17. Overview of part of the KoKOMP-Project

By reference to an exemplary case the use of the Automated Crash Computation for the assessment of DAS will be shown hereafter.

As previously stated the tool needs an input in terms of dynamic parameters from the simulation of a specific scenario with and without the DAS. Figure 18 shows the crash constellation of an exemplary scenario without the implementation of a DAS. In this scenario the car on the left is hit on the right side and the compartment is involved.

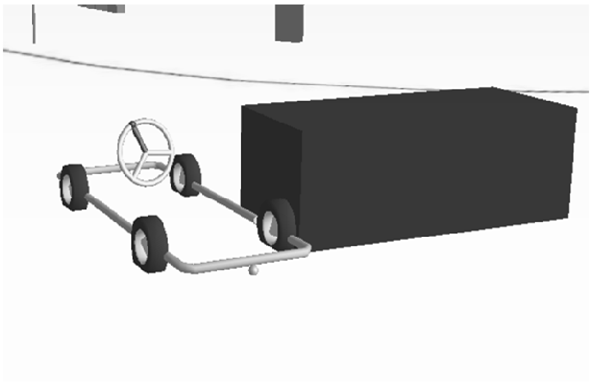

Figure 18. Crash constellation without DAS (front to side, compartment involved)

Figure 19 shows the new crash constellation of the same scenario after a DAS was implemented. Here the car on the left is still hit on the right side. But due to the DAS, which included a braking functionality, this time the compartment is not involved. Additionally the collision velocity, in comparison to the scenario without the DAS, is lower.

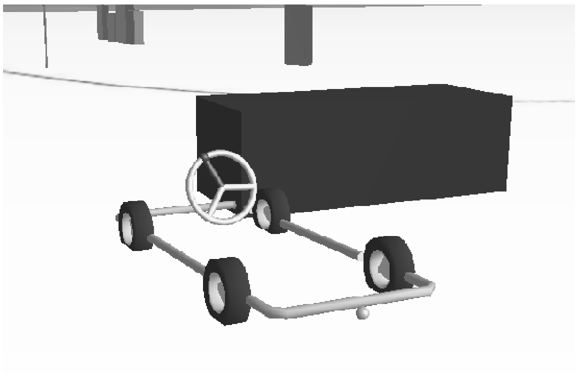

Figure 19. Crash constellation with DAS (front to side, compartment not involved)

Table 1 gives an overview of the crash parameter delta-v of this exemplary case. As it can be seen, through the implementation of the DAS in one car the delta-v of both cars is lowered for about 15kph.

Participant	delta-v w/o DAS [kph]	delta-v w/ DAS [kph]
Left	36	21
Right (block)	40	24

Table 1. Overview of the delta-v (example case)

Now that the crash severity is lowered the IRF can be used to assess the DAS in regards to the decrease of the probability of a certain injury severity.
In Figure 20 this is done for an occupant on the passenger side of the car on the left from the exemplary case. For this person the crash is a near-side collision in both the scenario without and with the implementation the DAS. In this case different injury risk functions were created depending on the side of the impact (front / near side) and on the fact if the compartment was involved or not.

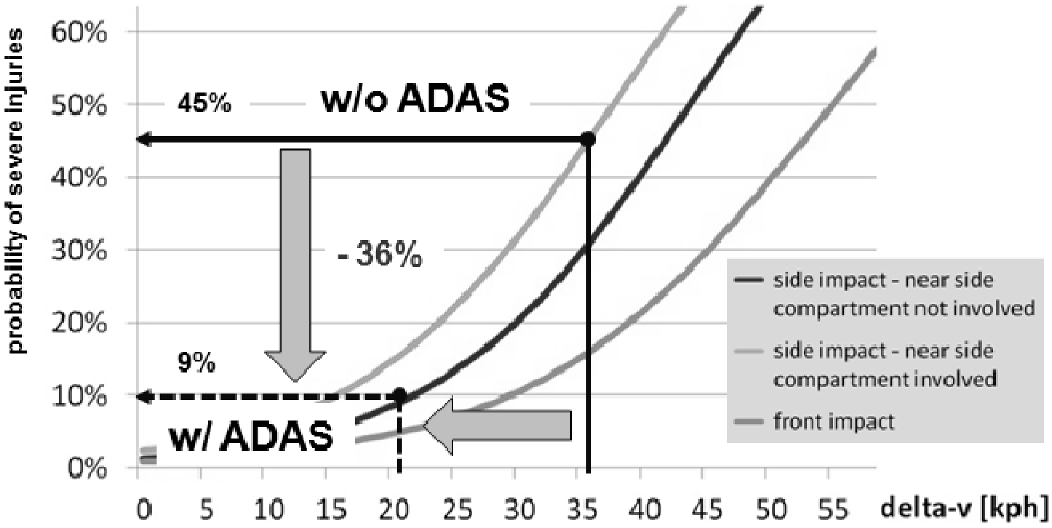

Figure 20. Usage of IRF to assess DAS (example)

For the scenario without the implementation of the DAS the probability to be severely injured for the passenger is about 45%. With a DAS this probability is reduced by about 36% to 9%.
Within the Ko-KOMP project the computation of the crash scenarios as well as the calculation of the probabilities of injury severities using IRF was done for all of the about 400 virtual accident scenarios (with and without DAS).

Summary

The simulation of accidents is a very effective method for both the development and the evaluation of active safety systems. For the evaluation of DAS in regards to their benefit in real-world accidents a crash computation has to be conducted. For this purpose the VUFO has developed an effective tool called Automated Crash Computation. It is based on virtual vehicle models with specific EES-values. These models were obtained from the GIDAS database using vehicle deformations and other parameters. Then an algorithm for the in-crash phase and the energy reduction of the participants was developed and tested.
The feasibility of the Automated Crash Computation tool including the assessment of DAS with IRF was successfully proven for passenger car accidents within the project Ko-KOMP. In this project about 400 virtual accident scenarios with new crash constellations were created from 35 real world

accidents found in the GIDAS database. All of these virtual accident scenarios were then computed and evaluated in regards to the increase of the protection level/ decrease of the injury severity for the car occupants.

Yet, further development of this new method and the tool is needed to attain more realistic results. Additionally the different car shapes available for the crash computation have to be validated and specified in more detail. Furthermore the development of a 3D crash computation is possible and the goal is to implement also the post-crash phase into the tool to be able to compute the crashes without using PC-Crash.

References

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