MULTIVARIATE BENEFIT ESTIMATION OF FUTURE VEHICLE SAFETY SYSTEMS

Dr.-Ing. Hannawald, Lars*, Prof. Dr.-Ing. Brunner, Horst*
*Verkehrsunfallforschung an der TU Dresden GmbH, Zellescher Weg 24, 01217 Dresden

ABSTRACT
Over the last decades the number of traffic accident fatalities on German roads decreased by 77% down to 4968 in the year 2007. This positive development is due to optimisations of vehicle safety, roads and infrastructure and medical rescue issues.

Up to now mostly the optimisations of secondary safety measures lead to this effect on vehicle safety. Since some years more and more driver assistance systems are available and lead to a further reduction of all accidents. These new systems are often comfort systems and have not primarily been developed to increase vehicle safety. In contrast to secondary safety systems primary safety systems are able to mitigate and avoid accidents. So in the future it is important to estimate the benefit of these systems in reducing accident numbers as well.

Current benefit estimation methods mostly focus on a single system only and not on the combination of systems. In this paper a new method for a multivariate benefit estimation based on real accident data is developed. The paper describes the basic method to estimate the benefit of primary and secondary safety systems in combination. With the presented method the benefit will not be overestimated as it would be by a simple addition of the benefits of single systems. The model will be validated by a multivariate prospective benefit estimation of different vehicle safety systems in comparison to single benefit estimations of the same systems. For this the German In-Depth Accident Database is used. The results show the importance to implement the interactions of safety systems in the estimation process and rate the overestimation by a simple addition of the single system benefits. The validation includes primary and secondary safety systems in combination. The validation is done using more than 3500 real accidents which were initiated by cars. This sample out of the GIDAS database is representative for the current accident situation in Germany.

The paper shows the necessity of a multivariate estimation of the benefit for existing and future safety systems.

MOTIVATION

The number of traffic fatalities decreased by 77% to a minimum in 2007. In comparison to that the number of persons who have been injured in traffic accidents in Germany decreased by only 25% and the number of accidents has increased by 53% to about 2,3 Mio accidents with personal injuries. Therefore an optimization of traffic and vehicle safety is still a very important matter. (1)

New vehicle systems are often comfort systems and have not been developed to increase vehicle safety only, while secondary safety systems only operate during a collision. In contrast to secondary safety systems primary safety systems are able to both mitigate and avoid accidents.

Current benefit estimation methods mostly focus on a single system only and not on the combination of systems.

In the following example of a real world accident, the motivation of this study will be further explained.

The following accident happened:
On November 10 at 5:50 p.m. the driver of vehicle 1 drove on a rural road. In a left curve the driver left the lane to the right unintentionally. After an over-reaction of the driver, the vehicle swerved into the oncoming traffic and collided with the right side of the car with vehicle 2. In the collision the unbelted driver of vehicle 1 suffered serious injuries due to an impact on the right A-pillar. (figure 2 and 3)
The driver of vehicle 1 had a blood alcohol concentration of 2.4 ‰. (4).

The accident site was measured on the spot by the traffic investigation team (figure 1).

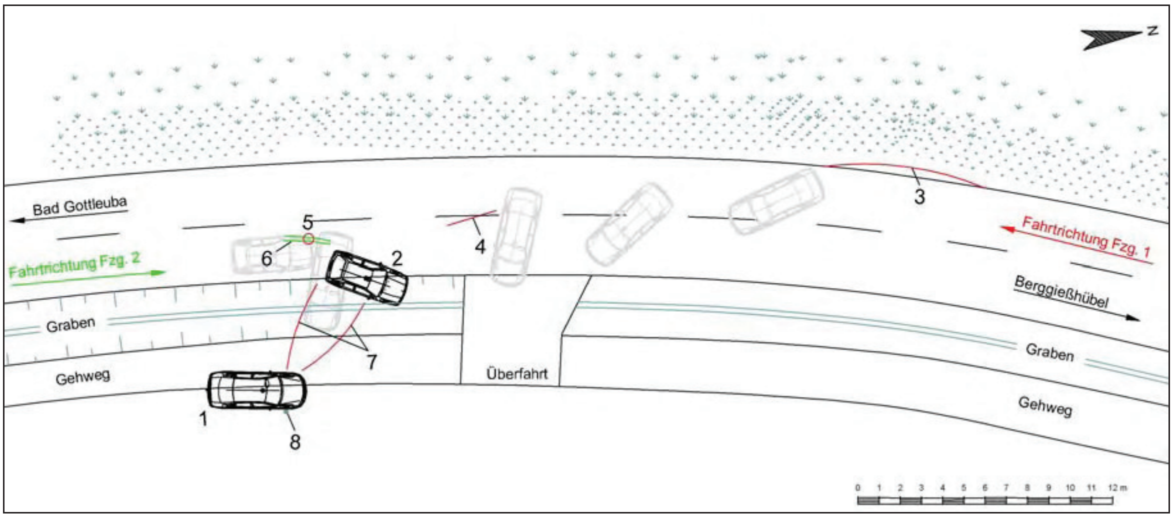

Figure 1: Accident sketch of a real world accident of GIDAS (4)

The serious injuries of the driver of vehicle 1 are shown in figure 2.

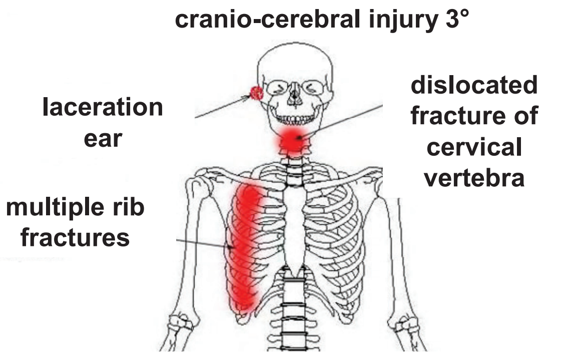

Figure 2: Injuries of the driver of vehicle 1 (4)

In correlation to these injuries the injury causing part could be identified (figure 3). The driver was thrown through his car and hit the right A-pillar.

Figure 3: Injury causing part for the injuries of the driver of vehicle 1 (4)

In the single case analysis of this accident the following systems were found to possibly avoid or mitigate this accident:
- a breathalyzer system (AAT), that does not allow an engine start if the driver has an alcohol concentration in breath
- a lane departure warning system (SVW), that gives a warning to the driver if an unintended lane departure is likely
- an electronic stability control (ESP), that could avoid or mitigate the swerving sequence into the oncoming traffic
- a seat belt reminder system (GURTW), that could help to remind the driver to use the seat belt and therefore mitigate the serious injuries caused by the movement inside his car

For all of these systems a mitigation or complete avoidance of the accident could have been possible. Yet it has to be considered that each accident can only be avoided once and a simple addition of all single system efficiencies will lead to an overestimation of the benefit for all systems.

DEVELOPMENT OF THE MULTIVARIATE ESTIMATION MODEL

Benefit estimations for safety systems can be done in a retrospective analysis, if the system is already in the market and the number of systems in the accident database is high enough. Otherwise it is only possible to appraise the benefit of a system in a prospective analysis. (Figure 4)

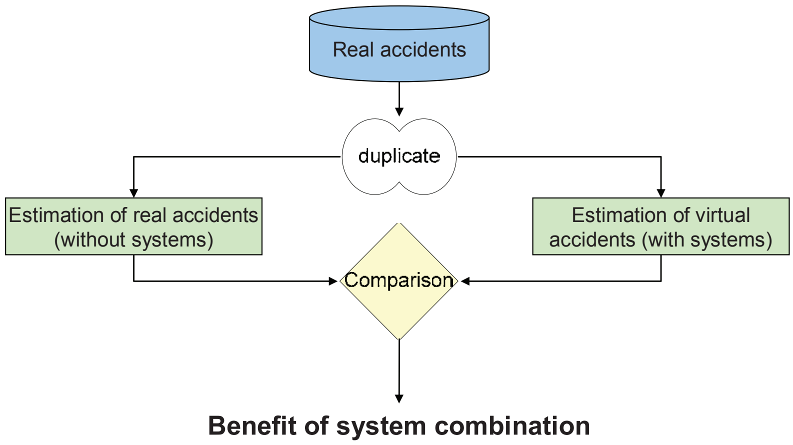

Figure 4: Prospective estimation of benefit of safety system (2)

In this prospective analysis the real accident will be compared with a virtual accident, simulated with the expected benefit of the safety system or system idea. The calculation of the difference between the real accident scenario and the virtual accident scenario is one possibility to estimate the benefit of the safety system. That way the global benefit of the single system can be estimated for all cases in the dataset using an automated case by case analysis.

Benefit estimation for single safety system

In the following figure 5 the estimation of real accidents without a safety system is shown.

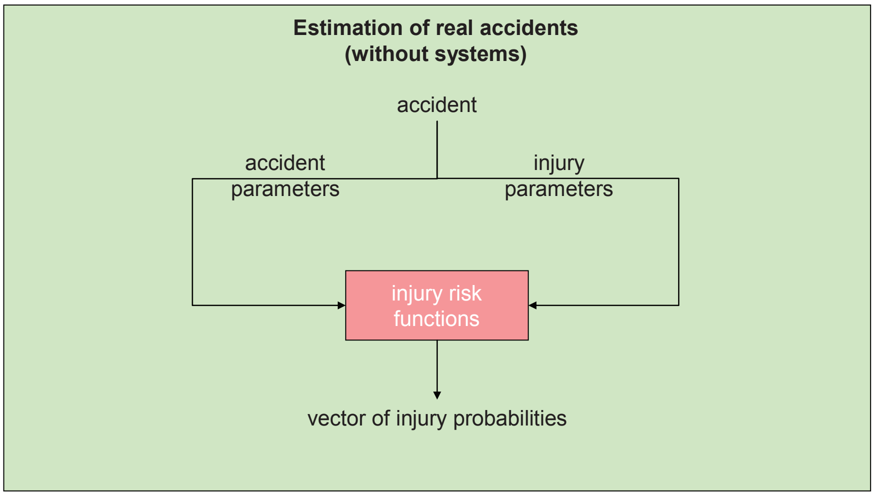

Figure 5: Development of the estimation model – real accidents

In this estimation process an injury risk function is used to calculate averaging probabilities of binary injury severity of the persons. The calculation process of the injury risk functions is shown in figure 6.

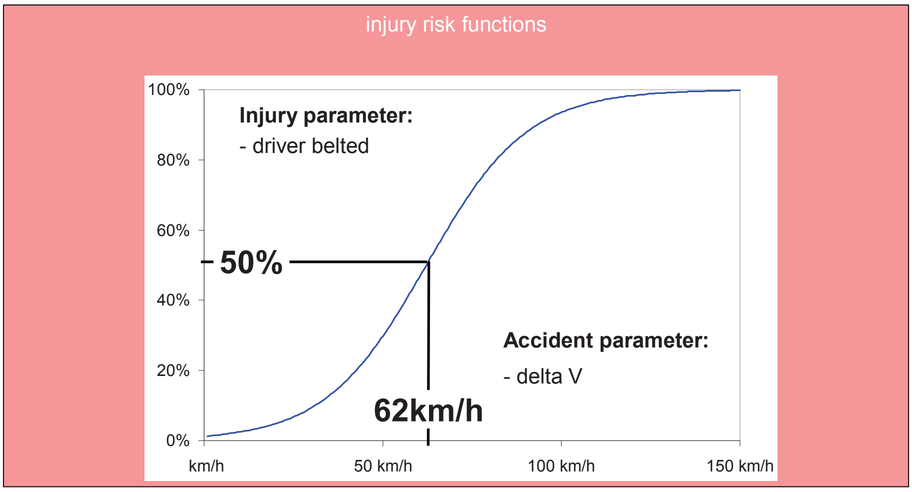

Figure 6: Development of the estimation model – injury risk function

In this estimation step the accident parameter (e.g. delta v of the car) is used to estimate the probability of a given binary injury severity (e.g. probability to be MAIS2+ injured)

After the estimation of real accidents, all accidents have to be analysed again in the estimation of virtual accidents. Therefore a simulation of the accident and injury initiation is done (figure 8).

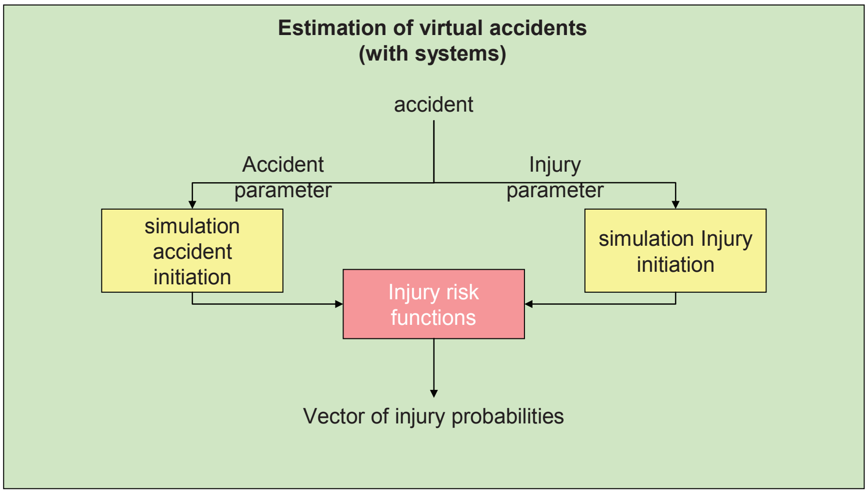

Figure 7: Development of the estimation model – virtual accidents

In the simulation process the accident and injury initiation are analysed independently. This gives the possibility to estimate a common benefit of primary and secondary safety systems.

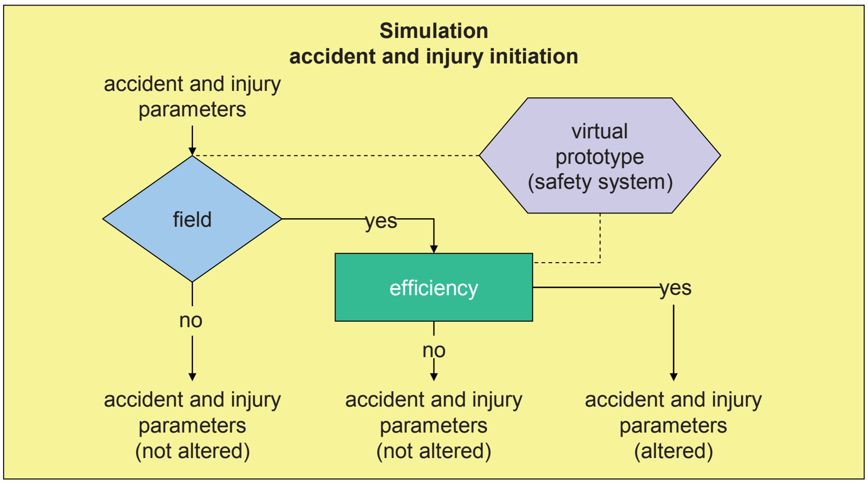

Figure 8: Development of the estimation model – simulation

For this simulation step a virtual prototype of the safety system is necessary. At first the accident is checked to be in field of the safety system. As an example, an accident is in field of the breathalyzer system if the driver had a higher alcohol concentration in breath than the defined threshold (e.g. 0,5‰). If there is no field for this system, all accident and injury parameters will not be altered.
If the accident is principally addressed by the system, the efficiency of the system will be checked. For example, a sober passenger could be used to disable the effect of a breathalyzer system. In that case the breathalyzer system will have no effect. These circumstances can usually only be appraised. If there is no efficiency assessed for this accident scenario, all accident and injury parameters will not be altered, otherwise they will be altered.

In figure 9 the complete estimation model for a single primary safety system is shown.

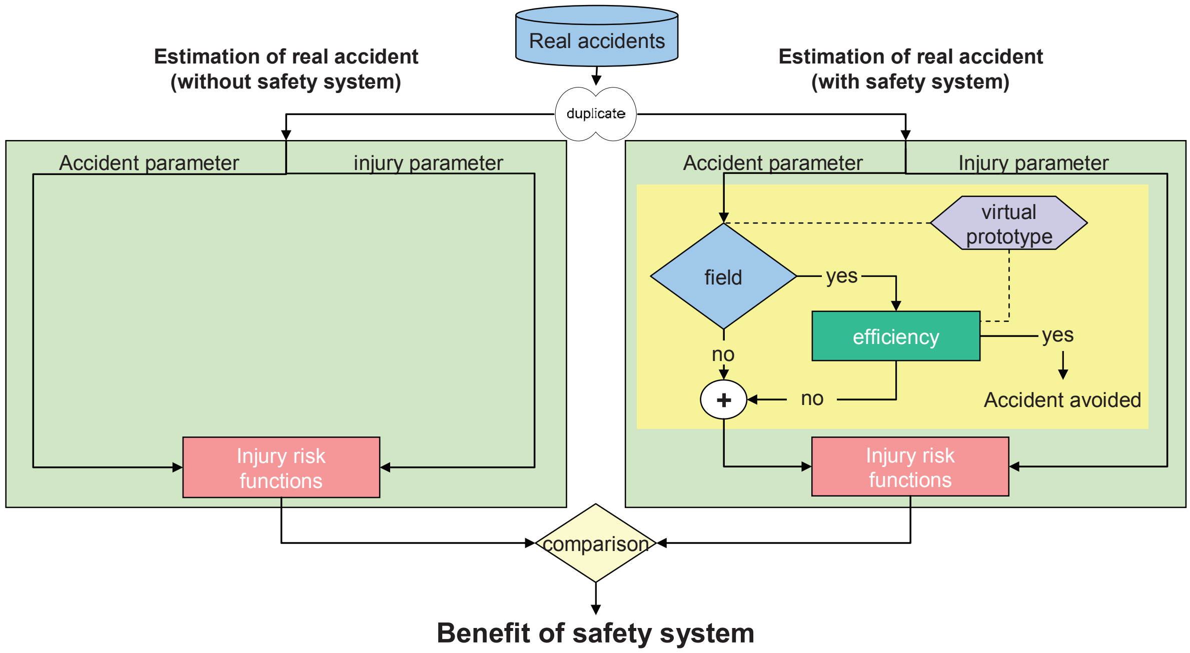

Figure 9: Development of the estimation model – single estimation of primary safety system

In figure 10 the complete estimation model for a single secondary safety system is shown.

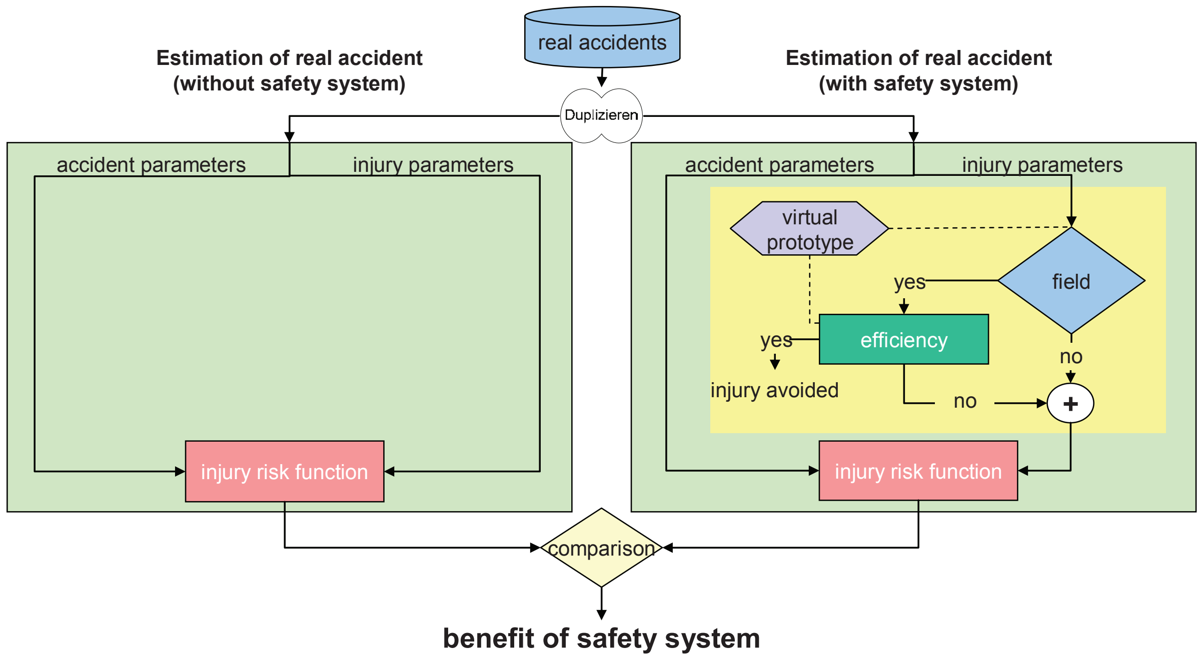

Figure 10: Development of the estimation model – single estimation of a secondary safety system

The given comparison of the estimation of real accidents and the estimation of virtual accidents delivers the benefit of this safety system.

Benefit estimation for combinations of primary and secondary safety systems

Based on the example of a real world accident (figures 1 to 3) the following safety systems or system ideas will be considered in the multivariate benefit estimation model:

- Breathalyzer system (AAT)
- Lane departure warning system (SVW)
- Electronic stability control (ESP)
- Seat belt reminder system (GURTW)

The breathalyzer does not allow starting the engine, if the driver exceeds the threshold of a maximum legal alcohol concentration in breath of 0,5‰. This system therefore operates at the beginning of the trip.

The lane departure warning system gives a warning to the driver, if the vehicle does leave the lane unintentionally. The system operates at the time of the critical situation.

The electronic stability control operates in the danger phase, when the vehicle does have a discrepancy between the trajectories of the driver's intention and the vehicle movement.

The seat belt reminder is defined as a primary safety system that reminds all occupants at the beginning of the trip to use the seat belt. The system's intention is to optimize the rate of belted occupants. A mitigation of injuries can only happen during the collision.

Safety systems operate at different times to collision. Therefore it is necessary to consider the chronological order of operation of all systems in the combination regarding the accident initiation sequence.

In figure 11 the ACEA Safety Model and the times of operation for all systems is shown.

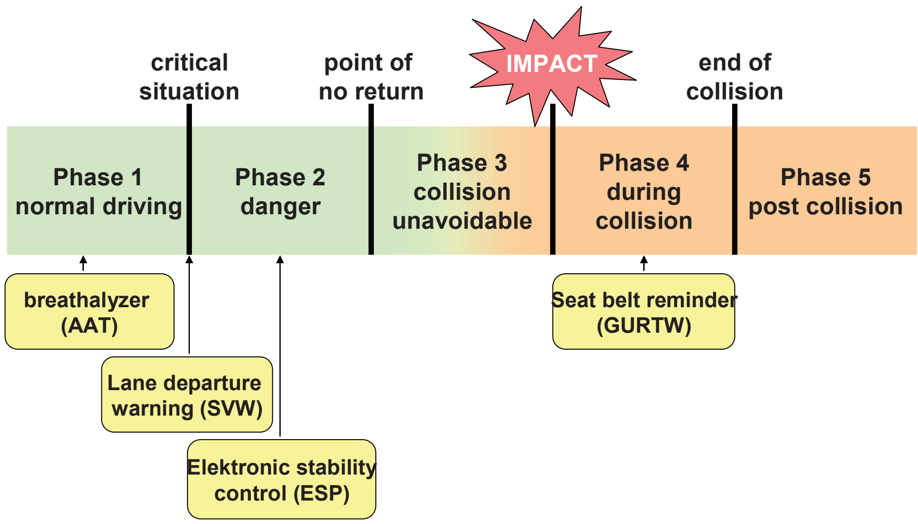

Figure 11: Development of the estimation model – ACEA Safety Model and time of operation of systems

As shown in figure 11, the first system that operates in the chronological sequence of each accident is the breathalyzer. If there is a critical situation of an unintended lane departure, the lane departure warning system gives a warning to the driver. The electronic stability control operates during phase 2 as the third system in the chronological order. Finally, a seat belt reminder will lead to the mitigation of the injury severity.

For the consideration of system combinations it is important that accidents, which are avoided by earlier systems in the simulation, are not further available for systems which operate later. Using this approach it is possible to estimate the global benefit of all systems realistically.

In figure 12 the complete estimation model for combined safety systems is shown.

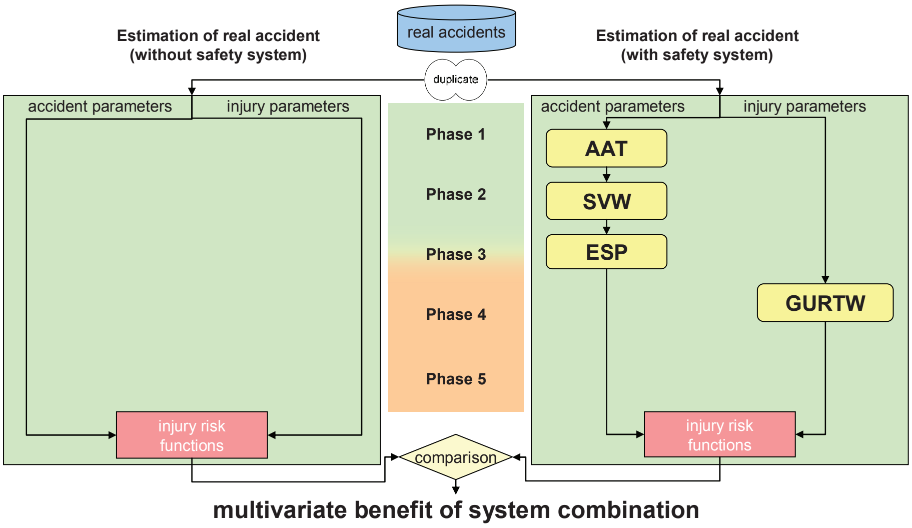

Figure 12: Development of the estimation model – multivariate benefit estimation for systems combination

The comparison of the estimation of real accidents and the estimation of virtual accidents gives the global benefit for the system combination. The correlations between these systems regarding the time of operation are considered.

The estimation model can be used for both primary and secondary safety systems. The model will estimate the benefit at the specific time of operation of each safety system. Due to the chronological order each accident can only be avoided once and the benefit of the single system therefore depends on other systems in the combination.

The overall benefit will not be systematically overestimated, as it would be by a simple addition of the single benefits of these systems.

COMPARISON OF UNIVARIATE AND MULTIVARIATE BENEFIT ESTIMATION

For all systems in the multivariate model an automated case by case analysis is performed using the dataset of GIDAS (July 2007). The dataset consists of 3789 accidents caused by cars. For all of these accident causing cars a 100% equipment rate of all four systems is assumed. In the dataset a total of 9821 involved persons are available.

At first the benefit for each single system was estimated separately (figure 13, yellow fields). The results are based on the reduction rate of the number of involved persons in all accidents. The difference is additionally divided in the groups “uninjured”, “slightly injured”, “seriously injured” and “fatalities”.

After the univariate summation of the benefit for all groups (orange fields), the results of the multivariate benefit estimation are shown (red fields).

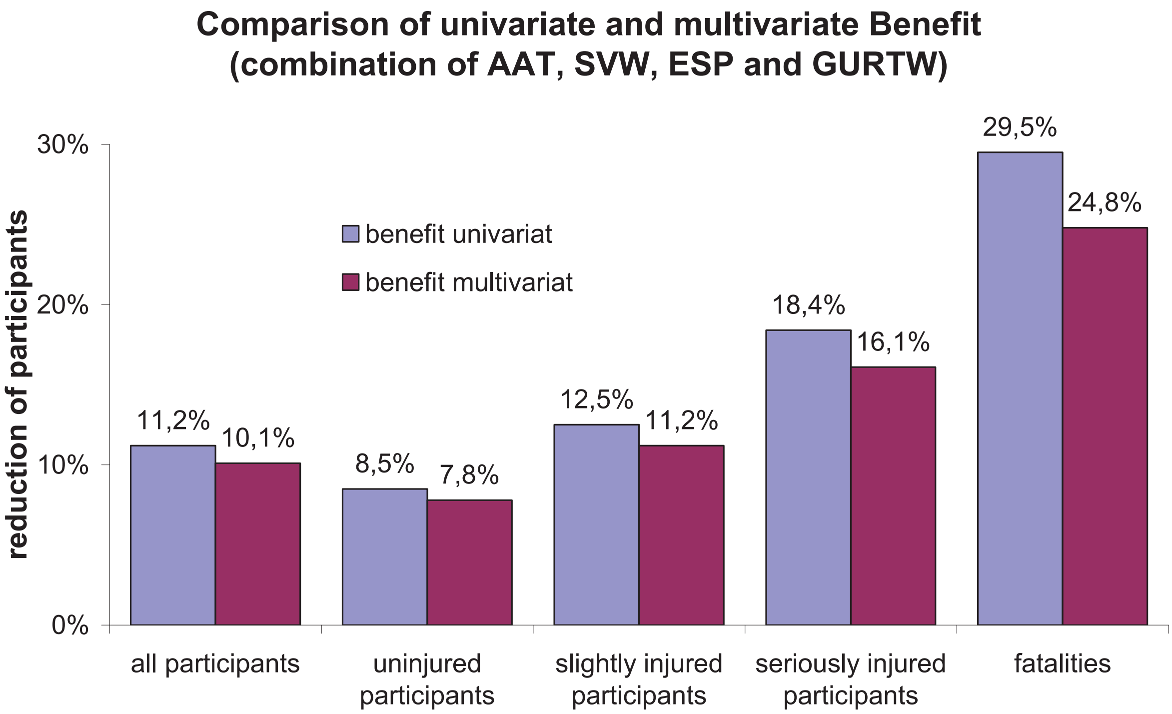

Figure 13: Comparison of univariate and multivariate benefit estimation

The univariate and multivariate analyses are based on the same assumptions for all systems. Therefore the results are directly comparable.

The overestimation of the benefit of system combinations based on the double counting of avoided and mitigated accidents can completely be prevented with this multivariate model. The overestimation of the benefit of a univariate analysis in comparison to a multivariate analysis can be as large as approximately 5% for fatalities.

SUMMARY

Safety systems are operating at different times to collision.

Each accident can only be avoided once. Thus, a multiple consideration of the avoidance of an accident will lead to an overestimation of the benefit for all systems.

With the developed model the chronological order of the systems and the correlations between the systems are considered.

The comparison of univariate and multivariate estimations of the benefit shows an overestimation of the global benefit up to 5% for the univariate estimation.

The overestimation of the global benefit will increase with the number of considered systems.

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