Tool box for the benefit estimation of active and passive safety systems in terms of injury severity reduction and collision avoidance

H Liers, L Hannawald*

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

Abstract

The evaluation of the expected benefit of active safety systems or even ideas of future systems is challenging because this has to be done prospectively. Beside acceptance, the predicted real-world benefit of active safety systems is one of the most important and interesting measures. Therefore, appropriate methods should be used that meet the requirements concerning representativeness, robustness and accuracy.

The paper presents the development of a methodology for the assessment of current and future vehicle safety systems. The variety of systems requires several tools and methods and thus, a common tool box was created. This toolbox consists of different levels, regarding different aspects like data sources, scenarios, representativeness, measures like pre-crash-simulations, automated crash computation, single-case-analyses or driving simulator studies. Finally, the benefit of the system(s) is calculated, e.g. by using injury risk functions; giving the number of avoided/mitigated accidents, the reduction of injured or killed persons or the decrease of economic costs.

MOTIVATION

There is no doubt that efforts in the field of passive safety have increased the level in traffic safety. Many seriously and fatally injured persons could be saved by passive (secondary) safety measures in the last decades. The benefit of such systems can be evaluated by comparatively simple methods because they only act in accident situations. Comparing vehicles with and without system in similar accident constellations (e.g. with a retrospective analysis on the basis of real accident data) will bring reliable results for the benefit of passive safety systems.

Since the 1990s another field of vehicle safety became more and more important – the active (primary) safety. The focus in vehicle safety is continuously changing from passive to active safety. Due to the fact that active safety systems are able to avoid or mitigate accidents new methods are required for the benefit assessment because systems change the entire situation whilst passive measures “only” affect the consequences of a crash. Furthermore, the linkage of passive and active safety systems (commonly named as integrated safety) is another important fact that has to be considered.

The benefit of few active safety systems, which are already frequently available in the current fleet (e.g. ABS, ESC or brake assist), can also be estimated in a retrospective manner. However, the evaluation of the expected benefit of new/current systems or even ideas of future systems is challenging because this has to be done prospectively. Beside acceptance, the predicted real-world benefit of active safety systems is one of the most important and interesting measures. Therefore, appropriate methods are necessary which should provide reliable results.

The Traffic Accident Research Institute at the University of Technology Dresden (VUFO) has many years of experience in the benefit evaluation of safety systems. One experience says that the large variety of systems and their combinations requires a several tools and methods. The VUFO tried to integrate all of them in a common tool box. One important fact is that in future not only the real system benefit in accident situations should be evaluated but also the user acceptance should be considered. Therefore, still other methods or at least other data sources are necessary.

METHODOLOGY

At first the scope has to be described in short. It is well known that traffic safety is not only a matter of car manufacturers and their suppliers. A lot of other parties from different scientific fields are also developing and providing measures for an enhanced traffic safety, represented by the 4 E's – Engineering, Education, Enforcement and Encouragement. However, the developed toolbox is primarily focused on vehicle-related safety measures (i.e. especially passive, active and integrated safety).

In general the question about the possible benefit of a new safety system arises before or during the development process. For existing systems the same question may be asked after a certain time on the market. The biggest challenge for a standardized benefit estimation process is the large variety of existing or future systems. Another frequent problem is the availability of appropriate data and reliable assumptions about the functionality / effectiveness of safety measures. The most evaluation methods can be described by the following process scheme (Figure 1), independent if the benefit in the accident scenario or the acceptance should be evaluated:

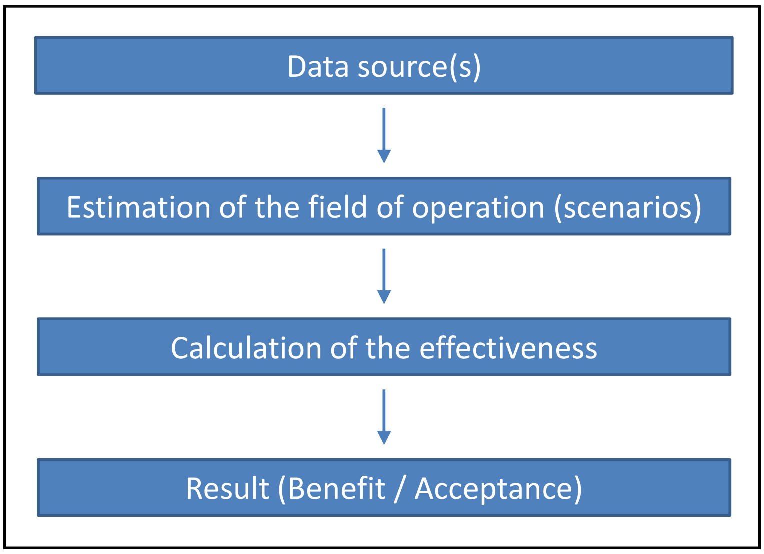

Figure 1. Principle scheme of benefit estimations for vehicle safety measures

Every main step contains various modules and methods and will be described in the following paragraphs.

Data source(s)

The basis for a reliable evaluation of any safety measure is the selection of appropriate data. Depending on the desired reliability of the entire process, the used data should meet several requirements. The most important are:

- representativeness (sample criteria of the data)
- quantity (e.g. number of accidents and/or situations)
- level of detail (available parameters)
- currentness
- availability
- accuracy

In the field of vehicle safety, national statistics have the advantage of being representative. However, the level of detail is comparatively low. On the other hand side, in-depth accident databases mostly contain very detailed information. Their disadvantage is that the data is derived from particular investigation areas with possible regional influences.

For that reason an appropriate weighting procedure should be part of the data handling. This step is important for non-representative data sources like in-depth accident databases, naturalistic driving or FOT data. Furthermore, an extrapolation to more than one country seems to be important because the majority of car manufacturers is selling their products in many markets. For that reason, the "data source" box also contains an extrapolation module. Such a module is exemplarily used in the Euro NCAP Advanced Award Protocol, where the accident numbers out of GIDAS are extrapolated to the EU-27.

Another challenging fact is the continuous change in the traffic and accident scenario. Fortunately, the most European countries show decreasing numbers of fatalities. However, historical accident and traffic data cannot easily be used for longer forecasts because everything is changing over time: traffic and mobility, the vehicle fleet, population (demographic change), infrastructure, laws etc. Especially the current equipment and development of active safety systems will strengthen these trends. The mentioned aspects can/should be addressed by further weighting processes if needed.

The following picture gives an overview about the first step (Figure 2).

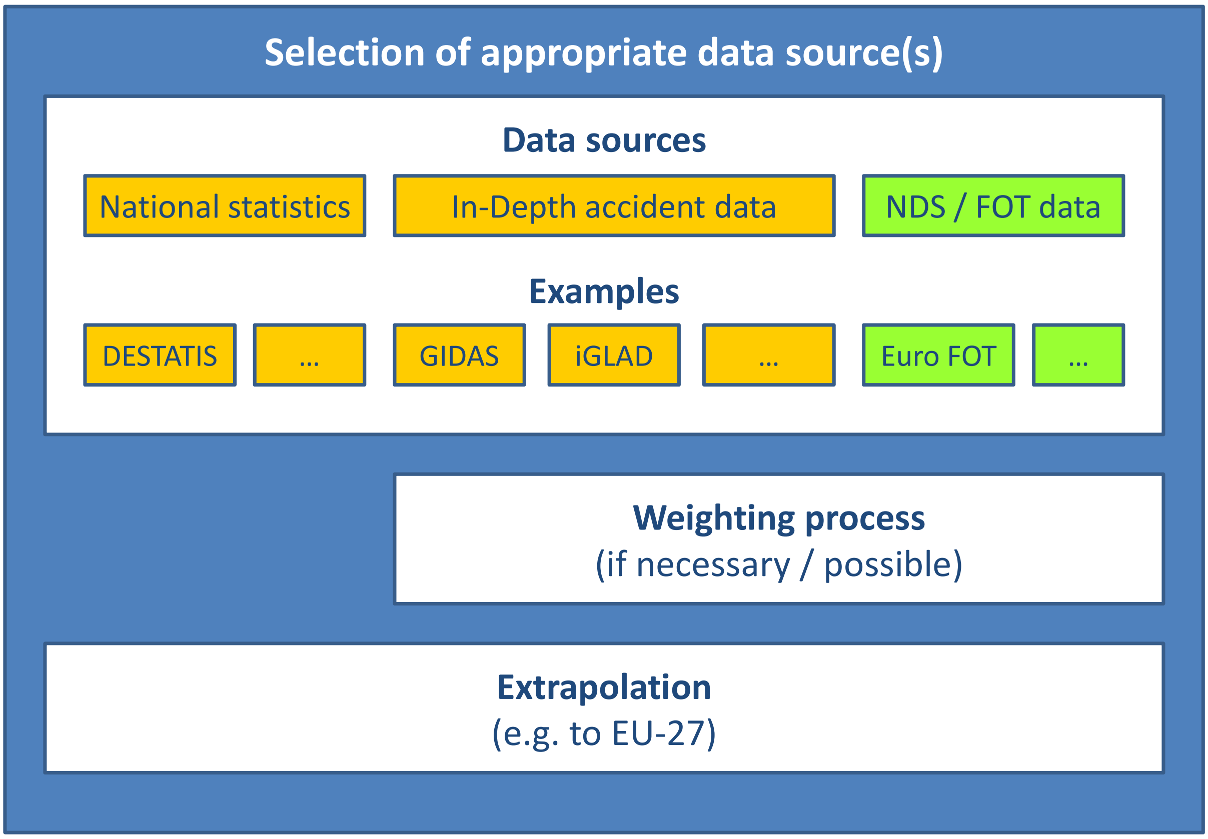

Figure 2. Content of the Data source box

Field of operation / Scenarios

Usually the benefit of a measure can be described as the product of the field of operation and the effectiveness (level of efficiency). In the second part of the benefit estimation, the field of operation is estimated. It is defined by all situations and scenarios in which a system or measure should generally act. For passive systems these are mostly certain collision types (e.g. frontal impact) whilst the system of active safety systems are certain situations (normal and critical ones). However, the field of operation is not depending from particular system specifications. As an example, the field of operation of a Lane Departure Warning (LDW) system is described as the sum of all unintended lane / road departures. The actual benefit of such a system in the real traffic scenario is limited by several circumstances that are grouped to the effectiveness.

These are for example the presence and condition (soiling, snow coverage etc.) of lane marks, the angle of lane departure, condition (e.g. soiling) of the sensors and also the reaction of the driver (depending on the HMI).

Mostly, scenario catalogues are used for the definition of the field of operation. One frequently used catalogue is the HUK Accident type catalog which contains nearly 300 different critical situations. As mentioned above for the LDW system, the field of operation can also be easily described by words. The real challenge is to identify these situations out of accident databases, NDS or FOT data. Mostly, the published data of national traffic accident statistics are not sufficient enough to make appropriate estimations of the field of operation.

Furthermore, it is important to consider the fact that one critical situation or accident can be in the field of operation of many safety systems. One example: An intoxicated driver leaves the road unintentionally, reacts with too hard steering (oversteering) and finally, skids against a tree. This case will be in the field of operation for several systems like alcolock, Lane Departure Warning (LDW), Electronic Stability Control (ESC) and several passive safety measures (e.g. airbags, belt pretensioner etc.). In such cases, the chronological order of system activation is important to avoid the overestimation of benefits.

One the one hand the estimation of the field of operation is used to identify relevant situations and/or accidents where systems are able to act. On the other hand, it gives a factor that is finally used to calculate the benefit of a system in the entire accident scenario. As an example, the maximum possible benefit of all active and passive safety measures for passenger cars in fatal car-to-bicycle accidents is below 50%, because all other fatally injured cyclists died in single accidents or collision with truck, trams, busses, PTW and other participants. Furthermore, the field of operation of forward looking safety systems has to be further reduced by excluding all cases where the ignition was not switched on (e.g. parking vehicle) or the cyclist collided with the rear end of the passenger car.

Calculation of effectiveness

In this part of the benefit estimation the actual system or system combination is evaluated. Therefore, different tools and methods are available. The challenge is to identify and to use appropriate tools depending from the system itself. In the field of vehicle safety a large variety of safety measures are already available on the market or become currently developed. Due to the complex interaction between the human (driver, pedestrian, occupant), the machine (vehicle) and the environment the benefit estimation is challenging, especially with regard to active safety systems that possibly avoid or mitigate accidents.

Therefore, the toolbox was structured into the three levels of the Haddon Matrix (Driver / Vehicle / Environment). Furthermore, the action/performance of safety systems in different phases of the situation should be considered. Thus, a differentiation between the pre-crash phase and the crash/post-crash phase was done.

The main goal is to model the behavior/action/condition of the driver and the vehicle in every phase of the situation/accident. Therefore, different methods can be used. In general, all available tools were categorized into three main groups of tools:

- Simulation tools
- Statistical approaches / methods
- Estimation

The combination of the three levels of the Haddon Matrix with the different phases of the situation and the three tool groups allows a categorization of available methods for the benefit estimation of vehicle safety measures. The following figure gives an overview about the toolbox for the calculation of benefit.

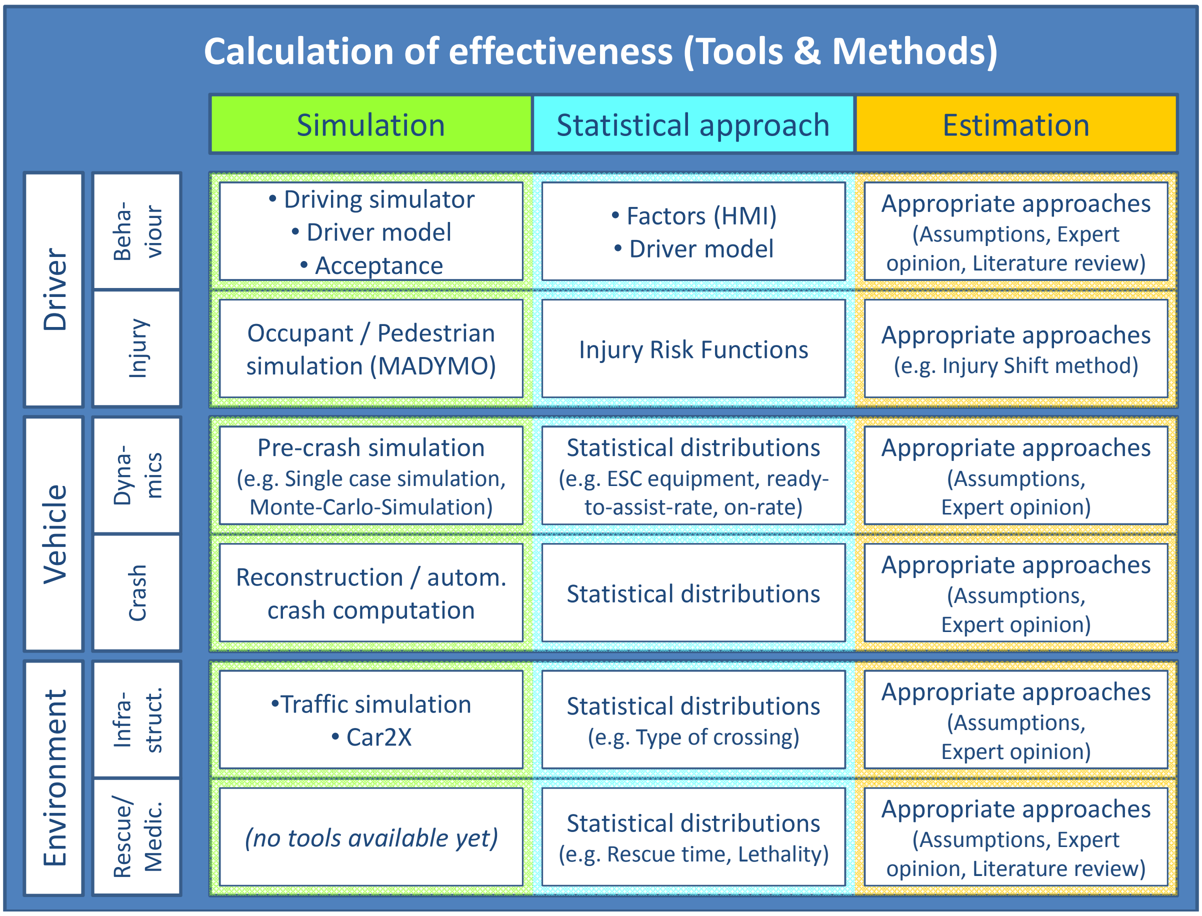

Figure 3. Toolbox for the calculation of effectiveness

In the field of simulation a lot of methods are available to model the single influences in traffic and/or accident situations. Mostly, appropriate software is already available (e.g. reconstruction programs to reconstruct/simulate the crash, simulation tools for the pre-crash simulation of single accidents). It can be assumed that these tools are more accurate than the majority of statistical methods or the estimations. The advantage is that the performance of safety systems is mostly analyzed by a case-wise simulation (often automatically done for thousands of datasets). So, the particular circumstances of single situations can be considered (see example below).

Statistical methods are often used if simulations are either not possible (e.g. due to missing models) or too effortful (e.g. costs). One example is the modeling/simulation of injuries. Although the existing models become more and more realistic and a lot of validation work is done it is still not possible to make robust predictions of the injury severity of persons in traffic accidents. This is not surprising due to large amount of factors that influence the actual injury outcome (e.g. for pedestrians: collision speed, impact points, vehicle model, age, height, gender, pre-existing illness, clothing, muscle tension, secondary impact etc.). For that reason, statistical approaches are useful to evaluate the effect of safety measures on the basis of existing data (like real accident databases). In case of the prediction of injury severities Injury Risk Functions are used as appropriate tool. However, the disadvantage of statistical methods is that particularities of single cases are not longer considered.

Finally, there is a box called estimations. These are approaches where either no simulation or statistical method is possible/available/useful, where the effort should be consciously limited or where data is missing As an example, nobody can predict the expected misuse rate of an alcolock system (e.g. by letting other people blow into the device). Here, assumptions or so-called expert opinions have to be used. In some cases, the accuracy of such estimations is rather good (depending on the experience of the estimator). Mostly, different tools have to be linked to calculate the effectiveness of a system. It is also possible that some boxes are not necessary (e.g. the environmental aspects).

EXAMPLES

Finally, the process of a benefit estimation should be displayed exemplarily with a current safety system. In the example alternatives methods in different tool boxes with different levels of accuracy and effort are mentioned. Additional explanations are given if necessary.

The example system is an emergency braking system with a radar based detection of possible collision partners and a warning function. Thus, it will not react on pedestrians and probably not on bicycles what has to be considered in the field of operation. Many of these systems combine a driver warning (optical, haptical and/or acoustical) with an autonomous braking action if the crash cannot be avoided and/or the driver did not react to the warning.

Several tasks will occur during the estimation of effectiveness. The most important are:

- Modeling of the driver behavior/reaction due to the warning function (at a certain TTC) → knowledge about driver behavior necessary (including misbehavior)
- Evaluation of the changed crash constellations due to the driver reaction and/or the autonomous braking → new crash parameters like collision speed, Δv, impact point (e.g. involvement of passenger compartment), EES, angle of impulse etc.)
- Estimation of the radar system and the involved algorithms depending on the visibility of the collision partners, systems latencies, geometrical characteristics of the radar sensor(s) etc.
- Prediction of the expected injury severity of all involved occupants due to the changed crash parameters

The following figures show the single areas of the tool box with alternative methods for the single tasks within the benefit estimation of the example safety system. In Figure 4 the methods for the driver behavior and injury prediction is shown. For many active safety systems the driver plays an important role because the vehicle tries to communicate with him by optical, haptic or acoustical information. Thus, the driver has to perceive this information and he should react in an appropriate way. However, he will do this (or not) depending on his individual reaction time and he will also react individually (steering moment, braking with different intensity, accelerating etc.). The modeling/description of this behavior is very challenging because of the numerous influencing parameters (e.g. age, gender, experience, drowsiness and attention of the driver as well as the type/performance of the HMI). The use of driving simulators is a good method to do research on this topic; however, it is mostly very expensive and needs a lot of time if many study participants should be considered. Therefore, statistical approaches or even estimations can help to reduce costs and time.

Later in the evaluation process the injury severity has to be predicted if the safety system was able to mitigate the crash severity. This is done with Injury Risk Functions because there are no simulation models available yet that can predict the overall injury severity.

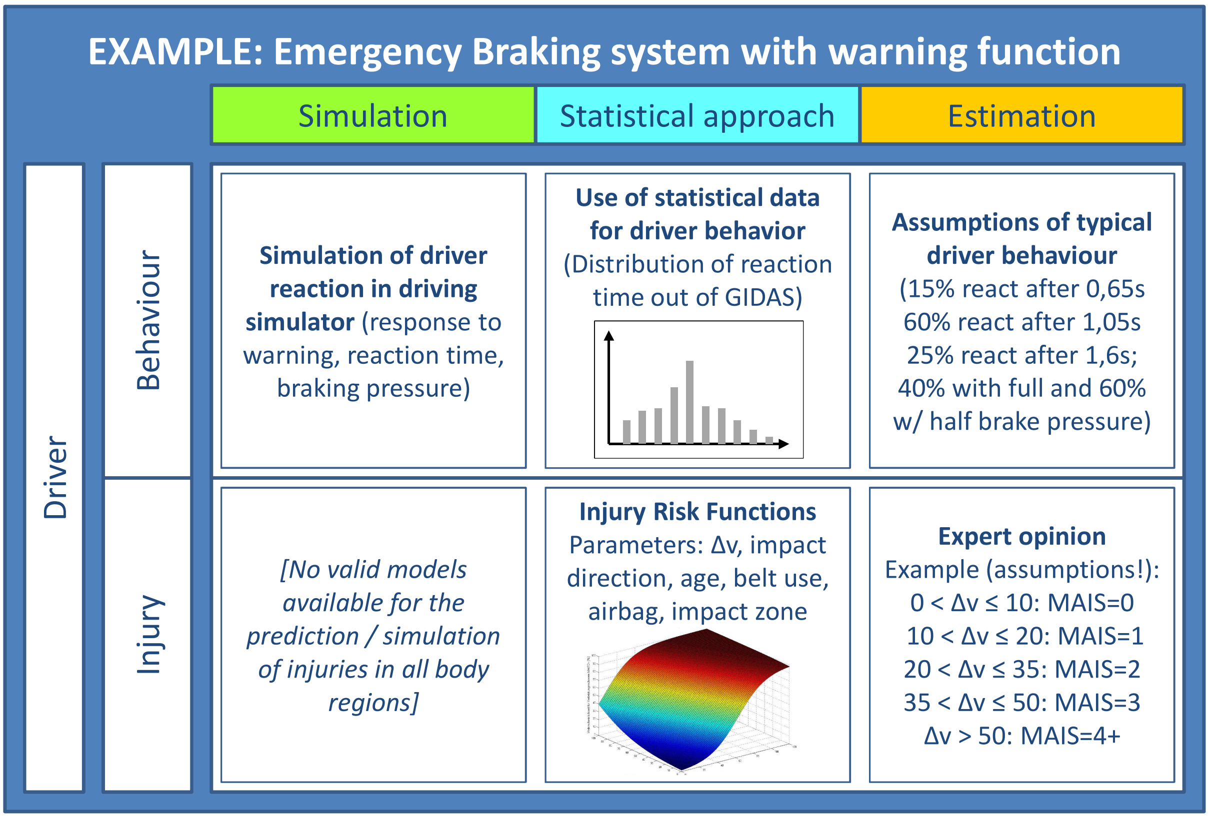

Figure 4. Application of the tool box for the example safety system (Driver box)

In the next picture all vehicle and system related actions are analyzed. Especially the evaluation of the system functionality in different situations and scenarios is a substantial part of robust benefit estimations. Therefore, simulation tools seem to be the best way as they can consider both the actual system characteristics and particularities of single cases (like view obstructions, weather/visibility, velocities, road surface etc.). Here, a linkage to other development tools is also possible (e.g. Hardware-in-the-loop).

The simulation of the system functionality results in the knowledge, which situations and/or accidents have been avoided, mitigated/changed or remained unchanged. For "simple" accident situations like car-to-pedestrian accidents or head-on collisions (longitudinal traffic) the simulation result can directly be used for the effectiveness calculation by Injury Risk Functions. For more complex situations, especially accidents in crossing traffic or skidding accidents, another step is necessary to predict the consequences of the mitigation. Due to the activation of autonomous braking systems the crash constellation will change. The equipped vehicle has a changed collision speed and due to the deceleration the collision partner is hit later, leading to another impact point. Finally, many collision parameters will be changed compared to the original accident (delta-v, EES, collision speed, impulse angle, impact point). Therefore, the new situation / crash constellation has to be reconstructed again. This can be done manually by using reconstruction programs like PC-Crash® (very high effort) or by automated crash computations (more effective, but extremely challenging).

For the chosen example of an autonomous braking system with warning function, the last box (infrastructure & rescue) is not relevant due to the fact that no interaction with the infrastructure (e.g. Car2X-communication) has to be considered.
Furthermore it is assumed that the post-crash phase (emergency call, rescue, medical treatment etc.) remains unchanged.

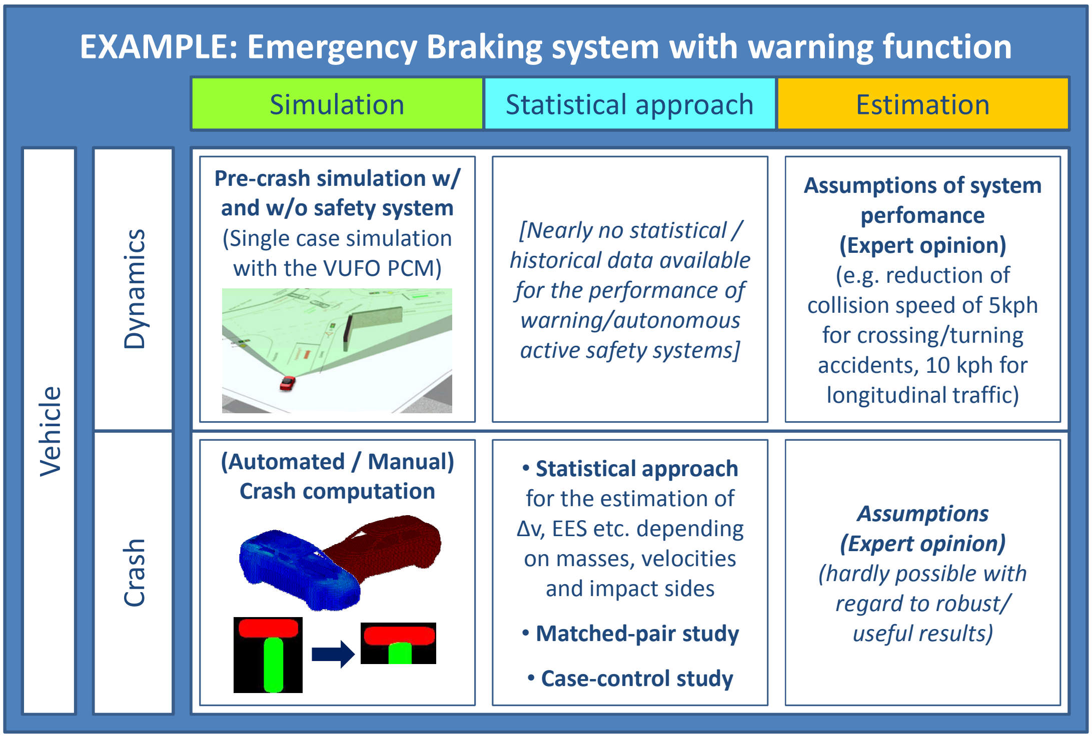

Figure 5. Application of the tool box for the example safety system (vehicle box)

The entire process for the calculation of the system effectiveness is shown in Figure 6. Nearly every active and passive safety system can be handled like the example. Depending on the system characteristics, different data sources and methods have to be used.

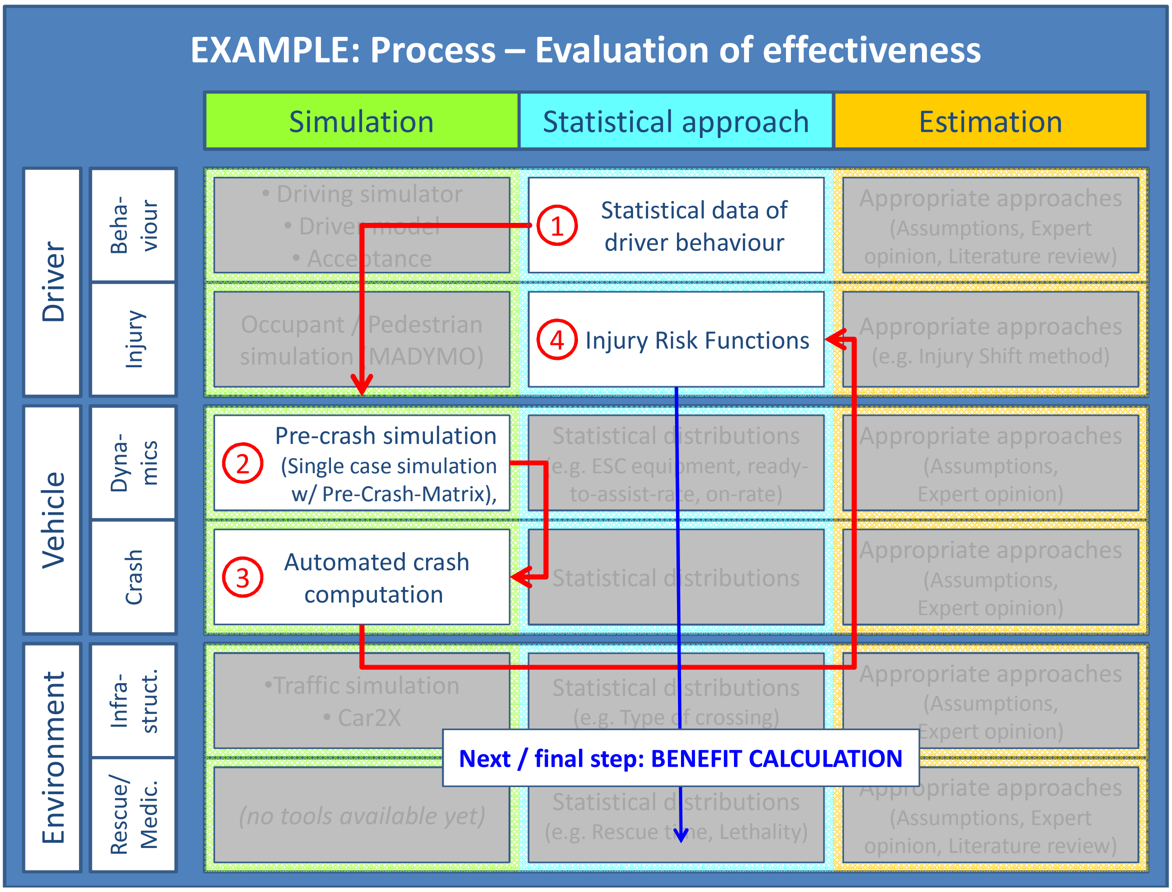

Figure 6. Process of effectiveness calculation (example)

At the end of this step there is a result out of the effectiveness calculation. Mostly, these are numbers of reduced seriously or fatally injured persons, numbers of avoided and mitigated accidents or just percentages of system activation. In the last step, the overall benefit is calculated.

Result (Calculation of Benefit / Acceptance)

Finally, all information about the data sources, representativeness, field of operation and effectiveness are linked with each other to draw a conclusion about the benefit or acceptance of a safety system. It has to be stated that the benefit is mostly oriented towards the accident scenario and thus, relatively easy to estimate. For acceptance issues the driver plays an important role due to his individual awareness of critical situations. Some drivers will need and accept assistance in an early phase of a critical situation whilst other drivers will not perceive the same situation as critical anyway. Here, a lot of research has to be done in future, involving different experts of engineering, psychology and medicine.

In the last step, the benefit of a system (or a system combination) can be further qualified, for example by calculating the robustness by doing statistical variations or tests.

In general, the term “benefit” is not clearly defined in the field of vehicle safety. However, some usual metrics are commonly used to describe the benefit of a safety system. These are:

- number/proportion of reduced fatalities/seriously/slightly injured persons
- number/proportion of addressed/mitigated/avoided accidents and/or critical situations
- reduction of economic costs

These figures can be further used to compare the benefit with the costs of a safety system (for development, testing, production, maintenance, marketing etc.). Additionally, comparisons between several systems or system configurations can be done with the presented method.

It has to be considered that some safety systems achieve a high level of effectiveness (within their field of operation) but the field of operation is comparable small (e.g. a system which effectively avoids wrong-way driving). In general, it is very challenging today to build a single safety system that is able to decrease accident and fatality numbers substantially. One reason is that the accident scenario is multifaceted. Furthermore, the effect of many technical measures is limited to special situations and/or vehicles and the market penetration of vehicles equipped with modern safety system is mostly increasing slowly.

SUMMARY AND OUTLOOK

The traffic accident research institute (VUFO) has a lot of experience in the evaluation of active and passive safety measures for vehicles. Thus, all available und useful methods have been implemented in a toolbox. This toolbox allows a standardized benefit estimation process for technical safety measures. Furthermore, this scheme can also be used for the evaluation of systems concerning acceptance issues, if appropriate data is available. The tool box was already used for the estimation of safety systems in projects like KO-FAS, sim^{TD} and aktiv. Furthermore, the benefit estimation within the Euro NCAP Advanced Award process (Phase 1 & 2) can be done with the presented tool box. Finally, lots of safety systems have been analyzed regarding effectiveness in collaboration with manufacturers and suppliers.

There are of course some limitations that should be considered. The first is that the toolbox is focusing on (technical) vehicle safety systems. It is hardly possible to adapt the methodology to all other measures in the field of prevention, enforcement or education.
In future activities the tool box should be further developed by adding additional information concerning accuracy, thresholds and robustness of the results. In addition, the implementation of other data sources is planned, especially for the evaluation of acceptance.