A COMPREHENSIVE AND HARMONIZED METHOD FOR ASSESSING THE EFFECTIVENESS OF ADVANCED DRIVER ASSISTANCE SYSTEMS BY VIRTUAL SIMULATION: THE P.E.A.R.S. INITIATIVE

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ABSTRACT

The assessment of real-world effectiveness of advanced driver assistance systems (ADAS) is gaining importance as more and more systems enter the market. Many different approaches have been developed. Therefore, the automobile industry, universities, and automotive research institutes in Europe have started an initiative for cooperative research. A ‘Harmonization Group’ was established in 2012 whose motivation is the development of a comprehensive, reliable, transparent, and thus accepted methodology for quantitative assessment of these systems by virtual simulation.

The harmonization group focuses on prospective analysis, which has the objective to estimate the expected safety benefits of current and beyond-state-of-the-art applications. Commonly used methods for prospective analyses are FOT's, subject studies in driving simulators, on closed test tracks or on open roads, and virtual analyses by means of simulation. Currently, the basis for an assessment by virtual simulation can be obtained either from reconstructed real-world crashes or from generic synthetic scenarios derived from realistic distributions of pre-crash conditions and traffic. Simulations allow for large number of cases and thus are capable of fulfilling the requirements posed by a sound sample size calculation. Simulation is certainly not a sole generic solution for all kinds of research questions, but it represents an integrative method to combine different knowledge areas in order to achieve an overall effectiveness result. It offers a promising combination of speed, flexibility, reproducibility, and experimental control.

The expected outputs of the group activities are the following:

- Identification of research questions (e.g. what changes in traffic safety can be expected due to the introduction of system X in country Y?);
- Definitions and metrics of the effectiveness (e.g. % reduction in fatal/injury crashes in a specific country/Europe; total reduction in fatalities over a period depending on a penetration rate);
- Structure for the assessment procedures including a description of the required sub-processes and the procedures to be followed;
- Description of the basic abstract models that are used in the simulation: driver, vehicle, road, traffic, and safety systems. The driver model is used to simulate various driver responses to inputs from the environment and the signals of the ADAS in various driving situations, traffic conditions, cars, and environments;
- Examples of the assessment of several ADAS (e.g. Lane Departure Warning, Advanced Cruise Control, Automated Emergency Braking).

The paper is a methodological paper presenting on-going activities of the Harmonization Group, so-called P.E.A.R.S. (Prospective Effectiveness Assessment for Road Safety), that involves more than 30 institutions in

Europe. Applied results will come once the harmonized framework is completed and the validation tests on several driving assistance systems have been shown successful. Further the document is set up to deliver the appropriate input for a draft proposal of an ISO or SAE standard.

This activity is an opportunity to harmonize methodologies used for assessment of ADAS in Europe. The involvement of non-European based stakeholders allows for a worldwide harmonization impact. A comprehensive assessment theoretical framework as well as concrete techniques should become available for wide usage by all stakeholders involved in ADAS effectiveness assessment.

INTRODUCTION

Improved automobile sensor and inter-vehicle communication technologies are spurring the conception and development of novel **A**dvanced **D**river **A**ssistance **S**ystems (ADAS) including functions of active safety. Those possibly influence road safety. However, deploying such systems based purely on “engineering intuition” (without prior impact assessment) is neither risk-free nor cost-effective: Risks are associated with unintended system behavior (classically: false-positive system actions, i.e., if the system reacts, but ideally should not have reacted) or misuse by end-users, for example. Thus, in order to design assistance systems that will most effectively reduce the number of crashes and their severity, there is an urgent need for reliable safety performance assessment during development, prior to deployment, as well as assessment after market introduction. In addition to automobile manufacturers and suppliers, academia and research organizations, public policy makers, consumer organizations, as well as regulatory agencies and insurance institutions are key stakeholders in safety assessment. Assessment techniques likely to be accepted by all stakeholders should provide targeted, quantified, and verified safety performance prediction.

Ideally, a “gold standard” to quantify potential safety benefits of ADAS would be direct estimation of mortality and injury impacts in the field and direct measurement of unintended system behavior including their consequences. But estimation of ADAS safety benefits from, e.g., accident statistics, requires long observation periods (due to slowly increasing penetration) and is confounded by multiple parallel influences on these statistics; unintended actions need to be measured not just once, but for each algorithmic threshold setting. The main application for retrospective analysis is assessment of existing solutions. Development of new functions requires prospective analysis.

Hence, a methodology is required that can predict mortality and injury reduction as well as newly induced risks in traffic. Furthermore, the prediction of the effect on near crashes and crashes with material damage will be increasingly relevant for highly automated driving applications (e.g., with regards to acceptance, liability aspects).

Many recent projects, initiatives, and organizations have been working on aspects of safety assessment for various kinds of systems (e.g., TRACE [1], eIMPACT [2], EuroFOT [3]). Research activities on the field of traffic safety and safety impact have been conducted in the recent years as a result of the introduction of the ADAS into the market, e.g., ADVISORS [4], DaCoTA [5], IMVITER [6], interactIVe [7], PReVENT [8]. Although major steps have been taken in the assessment of safety systems, none of these projects describe a comprehensive methodology (ranging from the effectiveness in crashes via the interaction impact in traffic up to economic costs) in order to determine the real life impact of technology-based safety solutions. However, most of the projects focus either on the calculation of the safety impact on a general level, e.g., the number of a particular accident type addressed by the safety solution, or provide a methodology for the detailed analysis of specific crashes, e.g., car-to-car crashes. For development as well as assessment, a worldwide consensus and acceptance regarding methodological questions is required. Harmonization and standardization are essential for stakeholders and decision-makers for fundamental decisions.

This paper describes the objectives and recent progresses in the international P.E.A.R.S. (Prospective Effectiveness Assessment for Road Safety) group consisting of different kinds of stakeholders. The basic motivation is the creation of a generally accepted and applied methodology for quantitative assessment of road safety as a result of ADAS in vehicles. The joint effort of many stakeholders in early stages gives a chance to concentrate and discuss the state of the art, join forces for further research, and enable acceptance before standards are finally defined. History in vehicle safety strongly suggests worldwide standards instead of regional initiatives for assessment. P.E.A.R.S. thus is an open platform focusing especially on the following issues:

- Definition of research questions regarding assessment of ADAS;
- Evaluation of current methods regarding their potential to answer those research questions;
- Definition and agreement on a suitable assessment methodology and process;
- Practical description of the process steps and hints for implementation;
- Worldwide communication and standardization.

METHOD

Development of a sound method for predicting the safety impact of ADAS functions requires three major steps (Figure 1. Top):

A. Identification of relevant analysis goals and related safety metrics precisely capturing the safety impact of ADAS functions while being amenable to model-based assessment in the function development phase;
B. Development and validation of a model-based assessment method quantitatively evaluating a functional design with respect to the metrics identified, where the term "model-based" is taken in a broad sense, covering the full range from statistical models to executable specifications and arbitrary blends thereof;
C. Definition of reporting standards for conveying the findings obtained to all kinds of stakeholders.

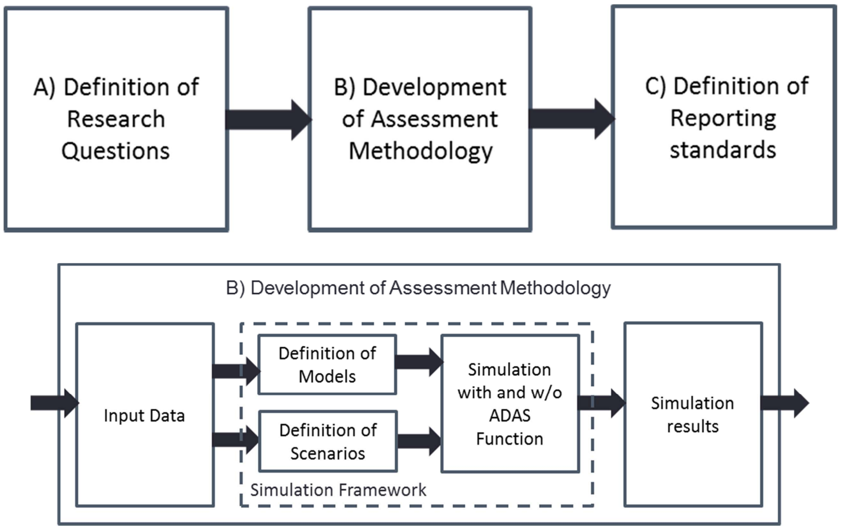

Figure 1. Overall process for developing a methodology for prospective assessment of ADAS.

In addressing these questions, P.E.A.R.S. takes advantage of the broad expertise provided by its assembly of relevant stakeholders featuring diverse backgrounds. Particularly, in addition to the regular exchange on working group meetings and the General Assembly, an inquiry was sent out to over 30 organizations that had so far contributed to the P.E.A.R.S. project. The objective of the inquiry was to gain feedback through all participants on general topics like relevance of certain research questions, applied methods and tools, and data utilized. Further specific questions were formulated on the currently used simulation setup (if available), previous assessments for specific ADAS functions, and interpretation of the results for certain operational regions. In a conclusive question, the participants were asked about their expectations on the P.E.A.R.S. project.

Precise Definition of Research Questions by Means of Pertinent Analysis Goals and Metrics

The precise definition of Research Questions covers the work of identifying a terminology for efficient communication on prospective assessment of ADAS functions, followed by detailed definitions and delimitations of the possible assessment scopes. Also, metrics to be used in the Reporting as well as assessment targets are defined.
The P.E.A.R.S. group hereby follows a combined top-down and bottom-up approach. The aforementioned inquiry provided valuable input to ongoing research questions, but still they are also derived by a top-down-approach in a more general way. By the comparison of both approaches, what is used today and what could be applied in the future, missing scopes are identified and taken into account in present and further research.

Development of an Assessment Methodology

The development of the Assessment Methodology is by far the most comprehensive task in the project covering a number of subtasks as illustrated in Figure 1(Bottom).

As a means of coordinating work within P.E.A.R.S., thereby also fostering cross-fertilization between different working groups, experiences from work in the different subtasks were compiled by means of the inquiry. From this together with a literature review, a state-of-the-art concerning the Assessment Methodology can be identified, forming the basis of a plan for further research effectuated by the joint program.

The general approach is to join models of traffic scenarios including road layouts, behavioral models for the traffic participants, and models for vehicles and their embedded safety functions in a heterogeneous co-simulation of their joint dynamics. To avoid investing computational and analytical efforts, for example, into situations unaffected by an ADAS function, the dynamic simulation focuses on potentially hazardous situations, called a *Scenario*, until the moment of collision or the moment that the collision has been avoided or mitigated thanks to an ADAS function. For a number of scenarios, the results of simulations with and without ADAS function can then be compared on different metrics as previously defined, providing a *conditional* assessment of the safety impact conditioned on the scenarios. Statistical background quantifying exposure and coverage, among related figures, can then be exploited for assessing the overall safety impact of the suggested safety function.

Soundness of the method hinges on identification of *Input Data* for both creation of scenarios and for development of dynamic models (e.g., driver-vehicle) combining tractable simulation with empirical validity for the research questions at hand. P.E.A.R.S. addresses that problem by comprehensively listing possible data sources and evaluating them in terms of quality, representativeness, scalability, and real-world relevance. As for the scenarios definitions, both current and future ADAS functions are taken into consideration, aiming at scenarios able to rigorously assess both their possible positive and negative effects.

For the dynamic simulation, the simulation framework, its sub-models, and required distributions for (input) parameters, have to be defined. This includes research on state-of-the-art simulation tools for pre-crash simulation and investigations on the respective strengths and limitations. A generic structure for such a framework has been defined. This structure comprises the required sub-models like vehicle model, safety system model, environment model, etc.

Additionally, possibilities for coupling the models have been looked at like High Level Architecture [24] and Co-Simulation. Different modeling depths including required parameters for each modeling depth were defined. Activities for defining requirements on different models have been started. Finally, research on state-of-the art processes to generate required distributions and parameterizations has been undertaken.

The simulation results have to contain the pre-defined metrics addressing the research question, either as a direct output or after post-processing. P.E.A.R.S. puts a strong focus on the processes to document the validity and accurateness of the applied framework and simulation models.

Definition of Reporting Standards

Different kinds of stakeholders will need different information for strategic decisions on traffic safety concepts. The number of avoided or mitigated accidents is a resulting metric close at hand, but further analyses can provide estimations of the number of avoided injuries of different severities. Also, a fleet penetration model can be considered for the assessment of the total effectiveness of ADAS functions. The P.E.A.R.S. approach will provide methods for generating such focused reports as well as for characterizing their confidence.

The definition of reporting metrics and standards is aligned with P.E.A.R.S. definition of research questions.

EXPECTED OUTCOMES

This section deals with the expected outcomes of P.E.A.R.S. Therefore, the results achieved so far are presented as well as the results that can be expected from the group in the future. The section is divided into four sub-parts dealing with the main steps within an effectiveness assessment of ADAS: definitions of the addressed research questions, selection of appropriate metrics, conduction of the effectiveness analysis as well as the specification of the used simulation models. However, before the different steps are discussed first let's have a closer look on P.E.A.R.S. targeted applications.

Outcome 1: The ADAS covered by P.E.A.R.S.

In the recent years, different ADAS functions have been developed and introduced in the market. Examples are Adaptive Cruise Control (ACC), Advanced Emergency Braking Systems (AEB) or Lane Keeping Assist (LKA). Within the group of ADAS functions, different types of ADAS functions can be identified. One distinction that can be made is that some ADAS aim to improve comfort, while others aim to improve safety, for example ACC and AEB, respectively. However, all functions have an impact on traffic and by this also on road safety. This applies also to comfort-oriented ADAS, although this is not their main objective, as indicated by [9] [10].

Next to the ongoing development of ADAS functions, also functions addressing a higher level of automation are developed. These functions are capable of taking over both the longitudinal and lateral driving task from the driver. First applications have already been introduced to the market for specific driving modes, e.g., traffic jam assist, e.g. [11] or [12]. For these functions, the driver still needs to monitor the function and take over in case the function reaches its functional limits. These functions are classified by the SAE definition [13] as partial automated. Demonstrations by, e.g., Google [14] have already provided an outlook on functions addressing higher levels of automation, which can be expected in the future. For these functions the driver does not need to monitor the driving task any longer.

Since all functions cover different driving scenarios and situations, it needs to be decided on which set of functions the P.E.A.R.S. harmonization group focuses. Within the group it has been decided to focus on ADAS including active safety functions as well as automated driving functions. Active safety functions act shortly before an imminent collision and aim to either avoid or mitigate the consequences of an accident. This decision was also reflected by the results of the inquiry which shows the interest in effectiveness assessment for different ADAS (highest interest for effectiveness assessment were detected for AEB Warning function, in particular AEB function addressing conflicts with Pedestrian or Bicyclist and rear-end conflict with other vehicles) and automated driving functions (Table 1).

Table 1.
Interest in effectiveness assessment of different ADAS and automated driving functions according to the inquiry (6: high interest; 1: low interest; n = 26).

Function	Mean Rating	Function	Mean Rating
Pedestrian AEB/Warning	5.4	Lateral lane keeping	4.0
Bicyclist AEB/Warning	5.3	Active cruise control	3.9
Vehicle rear-end AEB/Warning	5.0	Active headlamps	3.1
Vehicle turning / crossing AEB/Warning	4.9	Other DAS	3.6
Lane departure warning / lane keeping system	4.8	Partial automated driving (SAE level 2)	4.7
Lane change warning / assistant	4.8	Conditional automated driving (SAE level 3)	5.0
Overtaking assistant function	4.7	Highly automated driving (SAE level 4)	5.0
Blind spot detection function	4.2	Full automated driving (SAE level 5)	4.9
Other ADAS	3.7		

Outcome 2: A structuration of the Research Questions underlying the effectiveness assessments

The typical start of an assessment process of an ADAS function is the definition of the relevant research questions [15] which defines what and why should be assessed within the assessment beforehand. Since P.E.A.R.S. aims at a standardization of effectiveness assessment, all research questions by all contributors must be taken into consideration before the harmonized method developed in P.E.A.R.S. can tackle them.

Five main objectives to conduct effectiveness assessment have been identified:

- Quantification of safety effects (positive and negative);
- Prioritization of systems / functions during development;
- Optimization of system design regarding components / sub-functions / parameterization;
- Detection of design issues in early stages to improve the benefits by respecting possible side effects;
- Argumentation of business case and anticipation of regulations / consumer testing.

Investigation on the research questions showed that many of the initial ones were formulated in a short way, not very precise. Thus, the actual meaning of the research question can only be interpreted. Examples for such research questions are “What is the effectiveness of AEB?” or “How many lives can be saved by function XY?”.

If results between different studies should be comparable, the research question needs to be more precise and already describe what should be assessed, how the effect is measured, which region and time horizon of prediction is considered for the assessment. Therefore, a second round of investigations made the research questions more precise and some of them could be formulated the following way:

1. What are the potential safety benefits of driver assistance systems (ADAS) in the short term, mid-term, long-term, considering that there are a lot of other road safety actions not engineering-related :
- for each sub categories of ADAS modes (information, assistance, delegation, partially automated, automated) whether they are automated and/or cooperative;
- for each sub categories of ADAS functions (braking, speed management, lateral control, lighting, parking, etc.) whether they are automated and/or cooperative;
- for an optimized selection of ADAS functions (package or combination of ADAS).

Safety benefits could for example be defined the following way :
- How many lives could be saved if x% of the fleet is equipped with the y safety package compared to a baseline fleet;
- How many injuries of AIS “i” or ISS “j” could be mitigated if x% of the fleet is equipped with the y safety package compared to a baseline fleet;
- Reduction in risk to be fatally injured if x% of the fleet is equipped with the y safety package compared to a baseline fleet.

Reduction in risk to be injured AIS “i” or ISS “j” if x% of the fleet is equipped with the y safety package compared to a baseline fleet over n years,

… in each country and in all Europe, for different road users, categories, for different crash types, on different conditions (night / day ; road use ; urban / rural),

...considering a certain level of passive safety in cars (to be defined in the baseline)

2. What are the societal and economic benefits of driver assistance systems in the short term, mid-term and long-term? What are the externalities (side effects) linked to the development of driver assistance systems? What are the optimized parameterizations of technical aspects of safety functions if one wishes to reach the maximum safety benefit?

In order to standardize the research questions for the effectiveness assessment, the inquiry proposed all contributors to fill in table 2.

Table 2.
Research questions for the effectiveness assessment (6: high interest; 1: low interest; N = 26).

Research questions	Mean Rating
What are the potential safety benefits of driver assistance systems (ADAS) in short term (<5yrs) considering that there are a lot of other road safety actions	5.0
What are the optimal parameterizations of technical aspects of safety functions if we wish to reach the maximum safety benefits?	4.9
What are the potential safety benefits of driver assistance systems (ADAS) in mid-term (5-10yrs) considering that there are a lot of other road safety actions	4.8
What are the externalities (side effects) linked to the development of driving assistance systems?	4.2
What are the potential safety benefits of driver assistance systems (ADAS) in long-term (>10yrs) considering that there are a lot of other road safety actions	4.1
What are the societal and economic benefits of driver assistance systems in short term (<5yrs)?	3.6
What are the societal and economic benefits of driver assistance systems in mid-term (5-10yrs)?	3.3
What are the societal and economic benefits of driver assistance systems in long term (>10yrs)?	2.9

The results indicated there seem to be a higher interest in short term effects compared to long term effects. Furthermore, economic aspects seem to play a minor role in the effectiveness assessment compared to the quantification of the safety effects. However, this could be due to the current composition of members in P.E.A.R.S. The second most important aspect of the effectiveness assessment is the parameterization of functions.

Furthermore, the research questions will be clustered into different categories:

- the kind of effect that is quantified by used metric;
- the function, respectively the type of functionality under study. Here, also the penetration rate of the considered function must be mentioned;
- the considered scenario (e.g., maneuver, accident types, traffic participants, type of road…);
- the considered region and time horizon of prediction.

By combining these different categories, various but harmonized research questions can be generated. Examples of precise research questions defined by the construction kit are:

- Relative change in accidents due to pedestrian AEB (100% penetration rate in passenger vehicles) in urban pedestrian situations in Germany (short term = 2 years in the future);
- Absolute reduction of MAIS3+ injuries due to AEB (50% penetration rate in cargo vehicles) in highway rear-end accidents (excluding two-wheelers) in EU28 (midterm = 5 years in the future).

Outcome 3: Harmonization of the Assessment Metrics

The effect of an ADAS function can be analyzed in different ways. In order to come to a standardized assessment for the effectiveness of functions also the metric used for this assessment needs to be harmonized. Similar to the research questions also here P.E.A.R.S. has taken a bottom-up approach. Different available metrics that have been used by the different partners have been collected and clustered. The effect of a function can be described - independent of the metric used - in two ways: in absolute numbers or in relative change compared to a baseline scenario. An overview on the different metrics is given in Table 3. In the second step it has been determined by means of the inquiry how often a certain metric is used by the different partners, see also Table 3.

Table 3.
Overview on metrics to determine the effectiveness of in-vehicle safety function (N=26).

Method	Type of metric	How often is the metric used by partners? (Mean value;1: never used … 5: 6 always used)
Avoidance of accidents	Absolute	5.2
Avoidance of injuries	Absolute	4.9
Avoidance of critical situations	Absolute	3.9
Changes in injury severity distributions (MAIS, fatality, ISS, etc.)	Relative	4.8
Changes in health aspects (functional years lost, etc.)	Relative	2.2
Changes in economic aspects (property damage, economic costs, etc.)	Relative	2.1
Percentage of triggered (critical) events	Relative	3.3

The most frequently used metrics are the absolute number of avoided accidents and the number of avoided injuries. For the relative indicators the change in injury severity is analyzed most often. Health aspects, like functional years lost as well as economic aspects are more seldom used so far.

Outcome 4. A harmonized assessment process

Today different approaches for the effectiveness assessment of in-vehicle safety functions or ADAS functions are known. Table 4 provides an overview of different methods that have been applied in the past. Each approach has advantages as well as disadvantages with respect to the required effort, the appropriateness to answer the research questions, and the accuracy of the results. They will be investigated during the P.E.A.R.S. initiative. In order to get to a standardized approach for the effectiveness assessment of ADAS, P.E.A.R.S. collected different known assessment approaches, and, by means of the inquiry, assessed how often the different approaches are currently used for effectiveness assessment and which are the most common approaches for this purpose. The results are given in Table 4.

The results indicated that the most common approach is simulation, combining different techniques. Therefore, in P.E.A.R.S. it has been agreed to choose the general approach ‘virtual simulation’ as the basis for a harmonized approach for effectiveness calculation. A basic concept of a virtual simulation approach is given in Figure 2. P.E.A.R.S. seeks for a more detailed specification of the different steps. This includes the definition of minimum requirements for input data as well as the description of requirement for the used simulation models.

Table 4.
Overview on method to determine the effectiveness of in-vehicle safety function (n = 26).

Method	Examples application	How often is the method used by partners? (1: never used … 5: always used)
Prospective statistical analysis based on crash data	TRACE [17]	4.4
Retrospective statistical analysis based on crash data	Effect of ESC [16]	4.3
Physical test	Assessing Forward Collision Warning [22],	3.7
Driving simulator	Daimler brake assist [21]	3.2
Field test	euroFOT [10]	3.2

	Examples application	Yes	No
Do you make use of virtual simulation in your assessment of system effectiveness?	rateEFFECT [18], Effectiveness Assessment of active Safety Systems [19], interactIVe SIMPATO [20],	21	6

Outcome 5: Description of the conceptual simulation models

The conduction of simulation of certain driving situations requires a reproduction of the real world in the virtual simulation environment. This is typically done by different models that aim to represent the influencing parts of the reality under consideration and that run within a simulation framework.

Thus the first question is: what aspects of driving situations need to be modeled in order to simulate the function behavior for the effectiveness assessment. Also here a bottom-up approach has been taken by P.E.A.R.S. State-of-the-art simulation frameworks and models have been identified and their strengths and limitations have been listed.

As shown in Figure 2, the observer model and guiding model are required in order to run the simulation and to ensure at each point of time the appropriated simulation model is used as well as to ensure that the simulation models are used in the correct order. The scenario model describes, as the name already indicates, the scenario that should be analyzed. This description includes longitudinal and lateral controls (e.g., velocity, steering) of the involved traffic participants. It is linked to the traffic model that describes the characteristics and behavior of the other involved road participants and the environment model that describes the characteristic (road characteristics, traffic regulations, (temporarily) static objects, illumination, and weather). Traffic models were classified by on structure, included components, validity, and their nano-, micro-, meso-, or macroscopic modelling approach.

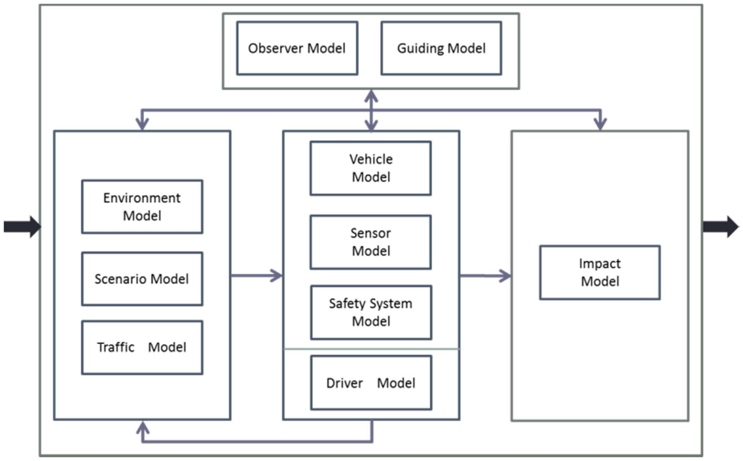

Figure 2: Setup of Simulation Framework

Further important models next to the scenario model are the driver, the vehicle as well as function models. If required, a driver or vulnerable road user model for other traffic participants can also be used. The behavioral models are used to represent how a driver reacts to the stimuli that he / she receives from the environment, other vehicles, traffic participants, and traffic signals in the traffic stream, or from inside a vehicle. The classification for behavioral models includes characteristics such as model structure, requirements, validity, and usability for different driving tasks. Based on the required complexity of the assessment, the driver model can include a description of driver behavior in critical situations, driver recognition (e.g., HMI, warnings), and driver response (e.g., latency times, steering, braking). Models should consider statistical distributions in intra- and inter-personal behavior, representing temporal driver state and preferred driving style, respectively.

The vehicle model describes all relevant parameters of the vehicle under test in the required degree-of-freedom. This model can include parameters for the chassis, suspension, tire, steering, and vehicle dimensions, depending on the degree-of-freedom used. Within the vehicle also the safety function needs to be modeled. The model for the function should describe the characteristics of the tested function including the system response as well as the operation regimen. The model of a function is typically a combination of one or more sensor models, a decision model (algorithm), and an actuation model (braking, steering, brake pulse, etc.), as well as - if required - communication model. Independent of the degree-of-freedom chosen for the different models, a vehicle model and function model is mandatory for the effectiveness assessment.

In case an accident occurs with the simulation also an impact model might be required, which defines an impact between two or more participants (e.g., cars, pedestrians, objects) as well as the behavior of occupants and their expected injuries. The model can contain a structure based crash model (e.g., the conventional impact model, force based models, multi-body models, and finite element models), kinematic and kinetic injury model (biomechanics) as well as statistical injury data. Depending on the metric used such a model is mandatory for the assessment.

In the next step, P.E.A.R.S. will take a top-down approach in order to specify the different models in more detail. This step includes 4 different tasks:

- Define the required input to the framework (direct or from pre-processing);
- Define the necessary output of the framework for the post-processing of simulation results;
- Describe the initialization (start condition) of a scenario simulation;
- Describe the termination criteria of a scenario simulation.

All models should not only be developed but also validated. The work is currently ongoing and a detailed description of the models is expected for end of 2015. The level of ‘granularity’ of each of the models will depend on the research questions, the degree of accuracy of the expected outcomes, and of course on the degree of availability of the data required for each model.

DISCUSSION

The P.E.A.R.S. project is an important step towards a harmonized approach on the assessment of the effectiveness of road safety measures, especially for ADAS. Input to the assessment methodology is gathered from different types of stakeholders and the project is defined as an open platform for exchange and cooperation for all interested organizations.

Within the last three years of project existence, working groups have been established covering research questions, assessment metrics, data availability and requirements, simulation framework, and model requirements and verification. Within each working group objectives were defined, appropriate actions were derived and results were presented and exchanged on the General Assembly. A constructive working flow has been established in this way.

Elaborated output from the working groups is implemented into a working document that is designed as a ‘recipe-book’. Further the document is set up to deliver the appropriate input for a draft proposal of an ISO or SAE standard. A first public available version of the ‘recipe-book’ is planned for the end of 2015.

So far, results from working group activities and an internal inquiry are available. All of the P.E.A.R.S. project participating organizations (N=32; 44% industry, 28% university, 19% research institutes, one governmental organization) responded to the inquiry. Main reasons for participation in the harmonization group are being informed about ongoing work and contribution to a common methodology. Further important is the contribution to an ISO/SAE draft proposal and a framework development. Half of the responders within P.E.A.R.S. have less interest in model development itself. For the outcome of the project all participants of the enquiry have high expectations on a common methodology and most of them have the expectation that the working document will lead to an ISO/SAE draft.

As mentioned before, near-term effectiveness is currently more in focus than mid- or long-term effectiveness. But future research will involve benefit of ADAS functions in mid-term, whereas long term evaluations becomes similar important than short term. Optimal parameterization of ADAS systems remains a key point. As for the objectives, the understanding of future accident situations and validation of systems is relevant. To date, most applied methods for evaluation of active safety-systems are prospective and retrospective statistical analysis. The majority of toolboxes for virtual simulation are own developments or based on the commercial tools Matlab/Simulink. For ADAS specific commercial tools, CarMaker is most frequently used. The majority of the responders make use of real accident data in their virtual simulations, a smaller group of users generate data stochastically themselves. Half of responders evaluate also ‘avoidance of critical situations’. Most investigated events are crashes, near-crashes, and crash-relevant conflicts, only a minority consider normal driving, but putting this data as highly important.

Just now evaluations are done for (in this order) specific European country, EU in total, USA, Japan, China and North America. In the future evaluations are desired for EU in total, specific European country, USA, China, Japan, Asia, and North America, which means that China and Asia will come more into focus.

Changes in vehicle fleet, market penetration, and driver behavior are regularly considered by half of the responders.

Except of in-car modification, the 9-safety mechanisms [23] are not much considered by half of the responders. In the future analyses focus remains on the first point of nine safety mechanisms, the direct in-car modifications. Slight increase can be seen for influence by road side application and modification of driver behavior.

At the current state most detailed models are for passenger cars, ADAS algorithms, and sensors, followed by models for driver/VRU. Highest need in increase for level of detail is seen in the environment model, driver model, and sensor model, whereas the last two have given highest priority. Over 90% of the responders see a relevant barrier in the simulation of driver behavior. Two-third of responders regularly uses robustness analysis for the evaluation of the results. More than half of the participants conduct a verification by reviewing mathematical-physical equations and by comparison against physical tests or other secondary data.

All participants conducting virtual simulation agree on the importance to implement a harmonized methodology into their own framework with specific focus on the implementation of a scenario description, driver/VRU models, and usage of high quality data.

A standardized approach for the effectiveness assessment as proposed by P.E.A.R.S. provides the opportunity to deliver a widely accepted methodology, to define requirements to input data, and thus to establish the boundary conditions for reliable and repeatable estimations of the impact of new ADAS functions. This is important for the initial step to introduce effective ADAS functions to a market and further to accelerate their market penetration. This approach will also support the comparison of different studies in the same field and provide a better understanding of traffic safety in general. Additionally, this can lead to standardization of consumer oriented assessment of ADAS functions (e.g., in Euro NCAP), since virtual simulation can deliver more distinct results on the real life effect than only a limited set of physical test scenarios.

Next to the advantages all approaches for effectiveness assessment have their limitations. This applies for the harmonized approaches itself, as defined by P.E.A.R.S., and to the generated results. First of all, the effectiveness assessment relies on the input data. Therefore, reliable results can only be determined, if the quality, which means accuracy and representativeness, of input data is ensured.

The same applies with respect to the used models. It needs to be ensured that the models describe the real behavior in a sufficient manner. The definition of ‘sufficient’ depends on the function under study, the investigated scenario, as well as the aimed quality of the results. This is, verification and validation of the simulation environment has to be considered in high priority.

Although the P.E.A.R.S. approach focuses mainly on ADAS functions operating in critical driving situations, driver assistance systems that support the driver during the normal driving process (ACC, lateral lane support), connected ADAS or automated driving functionalities can be assessed in the same framework with regard to content extension, but based on the same methodology.

As the project does not have any external funding the progress of the project is currently depending on individual contribution of the stakeholders.

OUTLOOK

So far the P.E.A.R.S. group consists of more than 30 stakeholders from the automotive industry, academia, private, and governmental research organizations in Europe. For a global harmonization approach and a worldwide standard it is necessary to involve stakeholders from all parts of the world. This would support even more the consideration of differences in environment, traffic participant mode, vehicle fleet, and road user behavior in the methodology. Additionally, the input from a broader group of stakeholders would lead to a higher acceptance and thus, spread of the methodology.

Each stakeholder has its own individual objectives and own research questions that need to be answered. Results of assessments are most easily explained, discussed and understood, when a harmonized approach is followed, and the steps that have been taken in the assessment process are well-known and agreed upon. For the common understanding, it is important that the stakeholders represent different sectors in the automotive safety arena such as vehicle industry, academia, research institutes, consumer organizations, road authorities, policy makers, and insurance companies.

Although currently a focus is taken on developing a methodology for ADAS functions which are typically automation level 1 (assisted driving), the process should not be essentially different for higher levels of automation [13]. This explains the ambition, to provide results on the short term by developing a methodology dedicated to ADAS, with the requirement that the developed process is generally applicable and easily adaptable for higher levels of automation.

The partners in P.E.A.R.S. invite organizations that are interested in contribution to the development of a harmonized effectiveness assessment methodology to contact any of the authors for more information and participation in the General Assembly and working groups.

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