System validation of highly automated vehicles with a database of relevant traffic scenarios

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ABSTRACT

Signing off highly automated vehicles is a key challenge for the automotive industry. Applying validation methods known from assistance systems for automated vehicles cause high test efforts. Therefore, the project PEGASUS develops a validation framework for the sign off process of these vehicles. One element of this framework is a database containing relevant traffic scenarios. This database combines different database entities and a data processing chain that deduces test specifications for the sign off process based on various types of measurement input data. The paper describes these database entities as well as the steps of the processing chain and the resulting benefits for the validation, a collective approach for the sign off on a common database and with common evaluation criteria.

Keywords: Sign off process, automated vehicles, database, scenarios, validation

INTRODUCTION

Introducing automated vehicles into the market requires the verification of their safety potential. But the safety approval is not only necessary for the sign off process of these vehicles. To enable a wide acceptance of automated driving by the whole society, the tools and methods used for the sign off process have to be embedded into a common validation framework. This framework has to answer the question what level of performance is expected from automated vehicles. Is it sufficient if automated vehicles are statistically able to reduce the number of accidents compared to human drivers or how much better should these systems be? Only based on evaluation criteria backed by all stakeholders automated vehicles will make their way from current prototype status to market products.

Besides the expected level of performance the second question is related to suitable, realizable solutions to verify that the desired performance is achieved consistently. Transferring the evaluation methods known from driver assistance systems [1], [2] would require enormous testing efforts according to statistical estimations [3]. Due to the disappearance of the human fallback level automated vehicles of level 3 and higher [4] need to be able to handle also complex traffic scenarios. Thus, it is necessary to ensure the system performance in a much wider situation space suggesting developing new methods for the sign off process.

METHODOLOGY

One way to increase the effectiveness of the evaluation of automated driving was described in [5]. The holistic approach – called circle of relevant situations - suggests a shift towards virtual testing methods increasing the situation space coverage and reducing the overall costs for the evaluation process. In addition, data of different sources, such as accident databases, field operational tests, driving simulator studies, traffic simulations or expert knowledge is stored into a database of relevant traffic scenarios enabling extractions of the recorded scenarios to the most suitable test environment [6], [7], [8], see Figure 1.

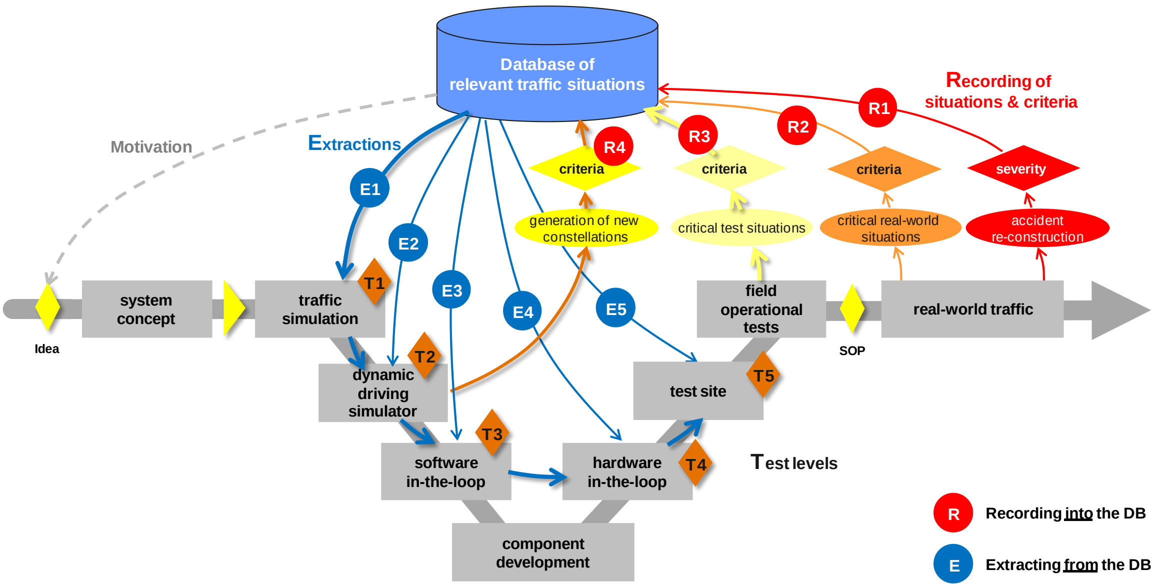

Figure 1: Circle of relevant traffic scenarios [7]

The approach is seized in the German research project PEGASUS that addresses directly the previously mentioned questions. As one element of the approach the database of relevant traffic scenarios is implemented in the PEGASUS project. The database and the related data processing chain build central elements in the generation of the test specifications deduced from the aforementioned data sources. In the following, the database concept and its embedment in the PEGASUS project, the data sources, the processing chain and its outputs are described in more detail.

Database concept

The database concept consists of different database entities following the data processing from (raw) measurement data over abstracted scenario clusters (logical scenarios) to test specifications for the sign-off process, see Figure 2. The basic idea is to use data from different sources (see section Data sources for the database), group the scenarios in this data to logical scenarios and to derive the test specifications for the sign-off process based on the logical scenarios. Figure 2 depicts the related database entities and their connecting data processing chain, which is described in section Data processing chain for the database.

In this data processing the coverage of the scenario information (y-axis) increases with the different database entities: While the raw measurement data provides only selective information on possible scenario characteristics for the logical scenarios, the condensation of this information in the parameter space of the logical scenarios enhances the knowledge of possible parameter combinations within a logical scenario. Deducing the test specifications information on exposure, potential severity and controllability are added for the parameter space improving the information coverage of the scenarios.

At the same time as the coverage of scenario information increases, the data volume is reduced (x-axis), especially between raw data and logical scenarios. Raw data contains also information that is of secondary importance for the logical scenarios and the parameter space. However, if it is necessary to assess detailed information it is always possible to trace back between test specification, logical scenario and raw data.

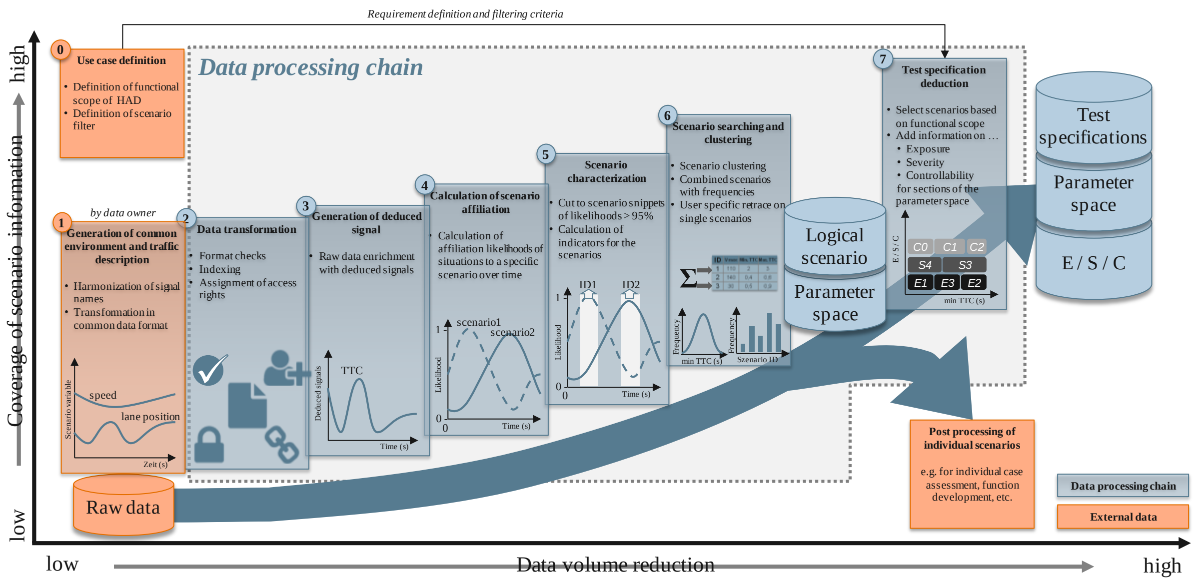

Figure 2: Database concept with different database entities and data processing chain

Data sources for the database

There are different data sources that can be used to feed the database imposing challenges to the input interface due to their heterogeneity. Currently identified data sources are listed below:

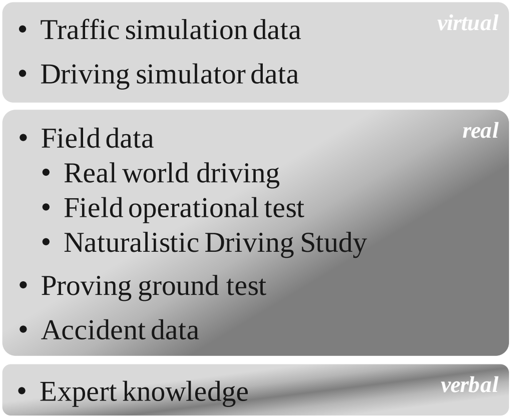

Figure 3: Categories of data sources

Traffic simulation and driving simulator data are data sources from virtual testing methods. A shift towards the use of virtual testing methods for the evaluation of automated driving increases also their importance for providing relevant scenarios. Traffic simulations can be used to vary scenario parameters to find critical scenarios in the overall situation space. Driving simulators are well suited to investigate automation risks at the interface between automation and driver/user. These scenarios are also highly relevant in the evaluation process of automated driving.

Besides these virtual testing tools serving as data input for the database, data from real world testing is a valuable data source. Especially data from field operational test [9], [10] or naturalistic driving studies [11] provide insides on critical traffic scenarios that automated vehicles have to solve when being active. Identifying such scenarios it has to be differentiated between scenarios arising from human misbehavior (e.g. speeding or undercutting of the necessary safety distance) of the ego-driver and those that are caused by the traffic environment. Only the later are considered relevant for the evaluation of automated driving since automated driving functions do not cause scenarios due to misbehavior.

The same differentiation has to be done for scenarios from accident databases which can also be used as data source. Found scenarios are of high relevance due to their outcome and the intention of automated driving to reduce the number of accidents. Only in case of an effectiveness analysis both types of accidents (misbehavior of the ego-vehicle driver and other types) would have to be considered.

The third type of data sources in the group of real world data are data from proving ground tests. Like driving simulators proving grounds are often used to assess the controllability of scenarios by the human driver. Hence, its data has an important role for the definition of evaluation criteria if these are related to the performance of the human driver. Furthermore, these data can be used to complete the parameter space of a logical scenario, e.g. by a test with test subjects conducting a specific maneuver/scenario.

Expert knowledge on required test specifications complements virtual and real world data sources. Complex understanding of the interaction between different technical components for automated driving (e.g. by test engineers) help identifying scenarios challenging for sensors or the system situation interpretation. Even though expert scenarios may have an initially vague verbal description of the scenario, they can be translated into detailed descriptions with precious values for the scenario parameters, e.g. by means of virtual testing tools such as traffic simulations.

Data processing chain for the database

Taking up the previously described data sources it is necessary to process the input and transform it into the following databases, see Figure 2. The related data processing chain consists of seven steps which are shortly described in the following.

The first step ① of generating a common environment and traffic description is done by the data owner. Only the data owner is able to convert the recorded data into a harmonized format with common signal names, coordinate systems and data structure. The harmonized data format is necessary to apply a common data processing chain. In addition, the harmonization is an important step for securing anonymisation and data privacy.

Step ② is the first processing step on the data processing chain which checks the input on correct formatting, indexes the data set and assigns access rights based on the data provider requirements. Even though, the idea of the PEGASUS project is to share the database and the criteria for the evaluation of automated driving [12] it is necessary to enable user-specific access to the data sets.

Generating additional signals in step ③ is the first contentual data processing step. Here, the data is enriched with information that is commonly not directly found in the recorded data like the time-to-collision (TTC). One of the main benefits of the PEGASUS project is the fact that the algorithms in this and the following steps is cooperatively developed by all PEGASUS partners and therefore reflects a collective understanding and interpretation of the scenario.

Step ④ provides the basis for clustering the scenarios of the recorded data to logical scenarios.

To that end, scenario likelihoods are calculated as time-continuous signals meaning that for every time steps the affiliation likelihood for every logical scenario can be assessed. This step is particularly important if bigger data sets are fed into the database without previous processing regarding scenario identification. But also if the data set contains only a short time snippet directly related to a specific scenario this processing step can be used to assure that only data meeting the defined criteria for the scenario are assigned to it.

Step ⑤ marks the transition from time continuous measurement data to particular scenario events. Therefore, the scenario likelihoods are used to extract the scenario snippets, e.g. time segments with likelihoods higher than 95%. In combination with the previous step a uniform definition of start and end time for the scenarios are defined. To characterize the scenarios scalar and time-continuous indicators are calculated for each snippet.

In step ⑥ the scenarios are clustered to the predefined logical scenarios and the parameters of the recorded scenario events are transferred into frequency distributions for the parameters of the logical scenarios. The outcome of this step is therefore the database entity consisting of the logical scenarios and the parameter space for these logical scenarios, e.g. the “prototypical” cut-in scenario plus frequency distributions for the cut-in distance or the ego-velocity at the start of the cut-in.

Deducing test specifications based on the logical scenarios and their parameter spaces is step ⑦ of the data processing chain. Two tasks are fulfilled in this step: First, information on exposure, (potential) severity and controllability (by the human driver) are added to the scenarios. In doing so, a compromise between accuracy and feasibility has to be made. Choosing the sections of the parameter space for which this information should be added to small reduces the exposure (to close to zero) and increases the necessary efforts for finding the related values. However, the estimation of exposure, severity and controllability should be as precise as possible. The second task is to select scenarios (and parameters) for the test specifications based on the use case definition to match test scenarios and functional scope of the automated vehicle. The outcome of both tasks is stored in the test specification database entity.

CONCLUSION

The main goal of the database approach is to collect relevant scenarios that are commonly addressed by driving a high test mileage, condense this data to test specifications for automated vehicles and therefore to increase the effectiveness of the evaluation process and the functional safety approval. By means of the database datasets for the safety approval do not have to be created every time, but can be re-used and establish a common evaluation basis for different stakeholders. The common evaluation will therefore increase the acceptance of the evaluation and sign-off process.

The shown database concept and its implementation employ a standardized input interface which allows to process data from heterogeneous data sources in a uniform data processing chain. For the following analysis and evaluation of the input data common criteria are used that are developed by all PEGASUS partners reflecting the mutual understanding of the evaluation criteria and fostering the goal of a standardized validation and sign-off process. At the same time, the efforts for this process can be reduced.

ACKNOWLEDGEMENT

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