A Systematic Approach of Reduced Scenario-based Safety Analysis for Highly Automated Driving Function

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Abstract: This paper investigates the scenario catalog generation and scenario reduction approaches for a complete Highly Automated Driving Function (HADF). Such approaches focus on the clustering and/or grouping of scenarios by applying a simple stochastic process at an early stage of development. Dealing with an enormous number of scenarios considering Functional Safety (FuSa), Safety Of The Intended Functionality (SOTIF) including cybersecurity desires intelligent approaches for HADF's scenario reduction. The reduction of scenarios in HADF is a challenge for automotive researchers since it relates to a large number of parameters (like environmental aspects). The main contributions of the scenario generation and reduction approach proposed in this work are the following: (1) contribution to a complete scenario catalog for a dedicated HADF, (2) logical scenario optimization with parameter distribution, and (3) optimize discretization step for finding semi-concrete scenarios that can be executed. Furthermore, the optimization method incorporating the Monte-Carlo (MC) experiment with the CarMaker simulation yields a systematic approach to modeling reduced scenarios without redundancy to support safety.

1 INTRODUCTION

Various safety-related technical approaches are proposed and used in the area of HADFs. Ensuring the overall safety of the vehicle is a top priority in society and industry. The investigation of HADF focuses on Automation level 3, L3 (conditional automation driver has to take control at all the times with notice) and higher automation level 4, L4 (high automation) and/or L5 (Fully automation) (NHTSA, 2017).

Hazard Analysis and Risk Assessment (HARA) is one of the major analysis methods widely used in different safety-related sectors like road vehicle safety to capture critical scenarios, robotics, aero, rail, etc. A scenario-based extension of the HARA can be used to extend the area of consideration and to reduce misunderstandings during the development phase (Khatun et al., 2020). On the one hand, such scenario-based analysis can consider the electrical and/or electronic (E/E) malfunction and/or the functional insufficiencies in terms of identifying safety-relevant scenarios (known-safe and known-unsafe). On the other hand, indicates the necessity of tool support to find a set of unknown-unsafe scenarios by implementing parameter variation for a specific use case or set of scenarios. For an Operation Design Domain (ODD) of a HADF like Transverse Guidance is studied to establish a scenario catalog. Although scenario-based safety analysis is beneficial in so many aspects, the main drawback of scenario-based hazard analysis is the tremendous increase of scenarios according to functional and logical expressions with an exploding parameter space (the combination of logical scenarios parameters).

From the aspect mentioned above, this paper describes a research effort that aims to establish a systematic process for scenario generation, modeling, and scenario reduction approach applicable to HADFs deal with higher automation levels (L3 and/or higher).

The key contributions of this paper for a safety-relevant systematic approach are for scenario generation, scenario modeling, scenario reduction, and parameter variation as follows:
(1) How can grouping and clustering methods be applied in contribution to a completer scenario catalog at the very beginning of the concept phase? For example, parameters and influencing factors are considered to cluster the scenarios at the very beginning of the scenario-based safety analysis. (2) How

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can a scenario reduction method be used systematically for HADF during the safety analysis process? There are some reduction methods like hierarchical, continuous-based, distribution-based, etc. available. An appropriate reduction method will be proposed with modifications that can be applied to reduce the scenarios in the HADF safety analysis process. (3) What methods can be used to model a scenario and simulate (e.g. CarMaker, Monte-Carlo) the scenario in terms of the safety-critical parameter range?

The structure of this paper is as follows, section 2 provides the current status of FuSa and SOTIF. Next, section 3 describes the scenario catalog generation process during the research investigation. Afterward, section 4 introduces a proposed scenario reduction method in a systematic way for safety development. Later, section 5 exhibits the scenario modeling and analysis. Consecutively, section 6 demonstrates the simulation approach and results based on the method proposed in previous sections. Finally, section 7 summarizes the outcomes and gives an outlook for further work.

2 STATE OF THE ART

Safety is the main reason that there is no autonomous vehicle currently available on the market. The driver is still responsible for controlling the vehicle featured with advanced assist systems which exhibit the limitation of systems function and doubt about safety undermost functional safety and performance limitations. The standard ISO 26262:2018 is state of the art for road vehicle's FuSa. FuSa defines as "*the absence of unreasonable risk due to hazards caused by malfunctioning behavior of E/E systems*" (ISO26262, 2018). ISO/PAS 21448:2019 describe SOTIF as "*absence of unreasonable risk due to hazards resulting from functional insufficiencies of the intended functionality or from reasonably foreseeable misuse by persons*" (ISO/PAS21448, 2019). Nonetheless, both of them are developed only for L2 vehicles, not for HADFs (L3, L4, and L5).

Scenario-based safety analysis is necessary for HADFs in respect of environmental, traffic situation consideration, and homologation purpose. It is widely understood that FuSa is not enough and SOTIF in the matter of functional inefficiencies including security need to be considered for assuring the overall safety of the HADF. Scenario-based safety analysis is not new and several research projects are investigating this area like (Galizia et al., 2018), (Mazzega, 2019), (Leither et al., 2020). But, none of them present a full set of scenarios for the safety analysis process for any specific HADF.

However, the challenge is to implement the FuSa and SOTIF process in a scenario-based HADF. The amount of scenarios is increasing together with the complexity of the system architecture if scenario-based safety analysis is considered. The existing scenario-based safety analysis method (e.g. HARA) with some modification to a complete HADF like Transverse Guidance Assist System (TGAS) is already examined(Khatun et al., 2020). The outcome of this investigation provides the great necessity of systematic approaches of scenario reduction for modeling and simulation of HADF scenarios.

A Functional scenario is a basis for any scenario-based analysis. According to author Menzel," *functional scenarios include operating scenarios on a semantic level including linguistic scenario notation. The description of functional scenarios is specific for the use case"* (Menzel et al., 2018). The definition for logical scenario is, *"it includes operating scenarios on a state space level can express with the help of parameter ranges in the state space. A logical scenario includes a formal notation of the scenario"* (Kalisvaart et al., 2019). Furthermore, concrete scenario- *"a concrete scenario is fully defined sequence. It describes a single instance from a logical scenario."* (Kalisvaart et al., 2019).

At the very beginning (Functional scenarios) of the safety development phase for HADF can be based on (a) risk analysis, (b) an accident database, and (c) virtual & long term vehicle test as described in (Galizia et al., 2018),(Damm et al., 2020) and (Fadhloun et al., 2020) but no scenario reduction approach is included explicitly. However, The parameter space explosion relates to factors like influence parameters, systematic test case. Based on Amersbach and Winner, choosing the correct discretization step is a challenge yet to be overcome (Amersbach and Winner, 2019).

The stochastic approach for scenario reduction, such as scenario tree reduction for multistage stochastic programs is proposed and developed with a sound theoretical basis with numerical experiences, keeping in mind the optimization model for electricity portfolios (Holger and Werner, 2009). Stochastic programming-based scenario reduction approach is used in electrical load in a power management model (Holger and Werner, 2003). But, these approaches are not formulated for an exemplary case of any HADF's scenario reduction.

The focus of our work is to implement the simple stochastic approach to reduce scenarios at the concept phase (left side of the V model) of a HADF.

3 GENERATING SCENARIO CATALOG

The scenario catalog provides a set of use cases for HADF safety analysis and is a base for further development. Based on the use cases, test runs can be generated. The scenario catalog provides support to define logical scenarios and concrete scenarios. The ODD is one of the characterization approaches to generate a scenario catalog. Society of Automotive Engineers (SAE), defines the ODD as *"operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics*" (SAEJ3016, 2018). It is obvious that defining the area outside ODD is difficult and less informative regarding the vast area that is out of the scope for HADF. It would rather make more sense to identify the area inside the ODD which reduces the observation area to analyze the functional boundaries of the system.

During scenario-based safety analysis, the number of functional scenarios is increasing tremendously and lead to the necessity of a scenario reduction approach for HADF. Moreover, finding new safety-relevant scenarios from virtual tests with parameter variation is in the scope of our research. By parameter variation, unknown-unsafe areas will be determined as simulation will be run considering optimization methods. Then, the unknown-unsafe area will be turned into a known-unsafe area as the area is found by simulation, hence, not unknown anymore. Author Georg graphically represented the reduction of unknown-unsafe area in his paper but didn't mentioned the evaluation process (Macher et al., 2019). If the area is known, safety measures can be implemented to make the area safe so it's turning into a known safe area based on optimization results. Thus, we can enlarge the ODD area for HADF gradually and the safety-relevant scenario catalog will keep growing and tools like CarMaker is used for scenario modeling and simulation. Therefore, the first key contribution of this paper is realized (modeled scenario catalog). Figure 1 gives a glimpse of the process as

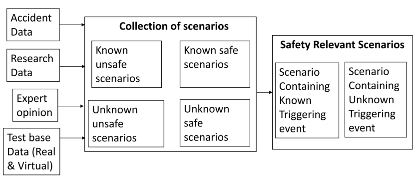

Figure 1: Safety relevant Scenario catalog-flow diagram.

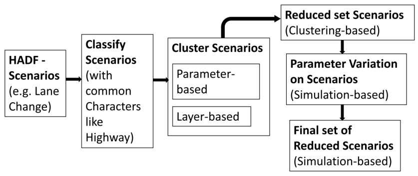

Figure 2: Proposed Scenario Clustering Approach.

described above in a simple block diagram.

For the implementation of Scenario-based HARA in a specific HADF such as TGAS can be used (Khatun et al., 2020). We realized that restriction of ODD is necessary to deal with the huge number of scenarios focusing on vehicle malfunction (FuSa) and SOTIF (functional insufficiency) at function level for a complete HADF. To show the completeness of a scenario-based HARA, restricted ODD for the TGAS of the HADF is examined (like a logical scenario, lane change in the highway). Hence, a targeted use case is analyzed, assessed, and a scenario catalog is proposed. In detail, the ODD is restricted by considering highly automated lane change function in the highway with other road users (3 road users) in a good environmental condition. The basic scenario is based on two vehicle functions (like turning left and turning right) with functional units of ego vehicle (such as solid object detection, moving object detection, etc).

4 SCENARIO REDUCTION METHOD

The combination of different parameters (e.g road type, environment, ego vehicle breaking) for a single functional scenario leads to a high number of logical scenarios. From the investigation of scenario-based hazard analysis (Khatun et al., 2020), the functional scenario "lane change" around 537,602 possible scenarios were derived by full factorial combination of parameters based on the 6 layer model (as described in section 5) without applying parameter discretization steps. The clustering of scenarios at the top level is possible in connection with the context and similarity of the assessment. Safety-relevant parameters are grouped based on the scenario classification to implement the clustering approach for scenario reduction. After that, for a specific safety-relevant parameter, variation is applied and collision result is analyzed to establish a reduced set for concrete scenarios. The proposal is illustrated in Figure 2. In the simulation, the selection of the correct discretization width step for parameter variation is an observation oriented (experiment and/or study based) approach at the logical scenario. The overall range is compromised by ODD.

Computation time for large number of parameters of scenario-based analysis is a challenge yet to be solved. To support the scenario reduction, the stochastic approach is estimated to optimize the critical scenarios at the early stage of development. Based on the research (Dupačová and Kozmík, 2015), the random parameters in stage t= 2, ...T as ξ_t, where T is a given horizon, and ξ is a situation (parameter set) are assumed. The random elements are estimated based on simulation, distribution, or from known field tests. The parameters of the first stage, $\xi_1 = (c_1, A_1, b_1)$, are assumed to be known based on decision x_1 (like lane change function will activate when collision free lane change is possible otherwise not). The random parameters at stage t, ξ_t contain cost coefficients c_t, constraint matrix A_t, the recourse matrix B_t and constraints coefficient b_t. For example, the cost for performing a lane change differing from different (desire) velocity, recourse matrix reflect the safety parameters (e.g. safe distance) and weather condition and/or road type (highway) can be considered as constraints parameters. For first stage, the probability distribution is known for simulation.

The components of ξ and the decisions x are assumed to be random vectors and defined on some probability triple (Ω, $\mathcal{F}$, P). Here, Ω is a set of all possible outcomes (possible lane change situation from safety analysis) and $\mathcal{F}$ is a set of events (collision with the vehicle in-front or side or behind). An event is being a set of outcomes in the sample space (only consider the collision with the vehicle in-front). Let, $\mathcal{F}_t \subseteq \mathcal{F}$ be the σ-field generated by the projection of the stochastic data process ξ. The sequence of decisions and observations is

$$x_1, \xi_2, x_2(x_1, \xi_2), ..., x_T(x_{T-1}, \xi_2, ...\xi_T) \quad (1)$$

In scenario reduction assumptions, P is the discrete probability distribution carried by a finite number of scenarios ($\xi^1, \xi^2, ..., \xi^N$) with probability $p^i > 0$, i = 1,....,N ($\sum_i p^i = 1$) and Q is the discrete probability distribution with a lower number of atoms (scenarios). Generally, atoms of the reduced distribution do not need to correspond with atoms of the original distribution (Dupačová and Kozmík, 2015).

For the first run, the statistical data approximation of P and a subset of the atom of P is carried by Q. The number of reduced scenarios are denoted as $j \in J \subset \{1,....,N\}$. In statistical distance d (P, Q) variation, the distance between two probabilities is measured from the first simulation result. This approach can be applied with multiple stages (multistage stochastic) for HADF in light of the functional scenarios to logical scenarios regarding the influences of parameters like distance with realtive speed of two vehicles. The optimization of parameter's range at the first stage (functional scenario) is the focus of this paper which can support limiting the logical scenarios.

The accident samples and testing phase are limited(Kopestinsky, 2021). The simulation-based optimization considering the available accident statistics of L2 vehicle's are taken as distributed input parameters. To overcome the discretization step (correct range) of parameters from functional scenario to logical scenario, normal distribution of the parameters (e.g. distance between vehicles) is assumed using mean, median, and standard deviation of discrete parameter distribution for the first probability experiment (MC) and verified by CarMaker simulation. Hence, a possible precise range of parameter boundaries can be achieved by two steps: first, by probability estimation and second, by parameter variation based on the outcomes of the first step.

This section contributes to the functional scenarios reduction regarding parameter variation and clustering. One functional scenario can be described with different safety-critical levels caused by a different range of one parameter and/or combination of parameters. Parameters can be selected by vehicle parameters (e.g. Speed), road type (e.g. highway, urban), safety measures (e.g. distance), etc. To trace the meaningful reduced functional scenarios utilizing relation between function units (camera, radar, etc) and vehicle's functions are realized by pre-selection of the triggering events. The combination of FuSa and SOTIF safety analysis is done by developing a generic HARA focus on both FuSa and SOTIF aspect (Khatun et al., 2020). During the investigation, based on a HADF (TGAS) in an ODD, around 786 scenarios are observed for HARA analysis for the use case (as described in section 3). The pre-selection approach is able to reduce the total number of scenarios to around 444 which is about 43% achieved from hazard analysis. But, the number is still huge and an additional reduction process is required. The pre-selection approach is, each possible triggering events has been estimated with vehicle malfunction and the vehicle's functional insufficiencies for a specific function to support validation. For example, function like detection of a moving object is only possible if a camera is providing the correct signal to the the functionally safe vehicle. Consequently, clustering and grouping are applied to reduce the scenarios as well. Additionally, a simple scenario reduction approach is described to confirm the second and the third key contribution of the paper. This paper does not focus on a further reduction approach for particular test cases and test criteria but investigates the simulation results to collect a reduced set of reduced logical scenarios only.

5 SCENARIO MODELING AND ANALYSIS

Modeling the scenario in HADF has great benefit by means of:

- visualizing the scenario
- parameter variation
- identifying the possible unknown-unsafe area
- optimizing discretization step

To start with the scenario modeling, a systematic description of the scenario (lane change) is layered as proposed in the Pegasus project (Mazzega, 2019). But, only five layers (from layer 1 to Layer 5) are considered for modeling scenarios in this paper. The last Layer (Layer 6- digital information) is out of scope for the scenario modeling. All layered information is combined and a list of scenarios is estimated using simple simulations as described: For each scenario, layers L_i (Layer1 = L1, Layer2 = L2, Layer3 = L3, Layer4= L4, Layer5 = L5), where i = {1, 2, ...5}; as only 5 layers are assumed. So, the total functional scenario set is:

$$Functional\ Scenario = \prod_{i=1}^{5} L_i \qquad (2)$$

where each layer assign with a different cardinality set in terms of different categories and/or types. Assumed, L1={$1l_1$, $1l_2$...$1l_a$}; L2={$2l_1$, $2l_2$...$2l_b$}; L3={$3l_1$, $3l_2$...$3l_c$}; L4={$4l_1$, $4l_2$...$4l_d$}; L5={$5l_1$, $5l_2$...$5l_e$}. The symbols *a*, *b*, *c*, *d*, *e* define the finite cardinality number of each layer. A simple representation is shown in Table 1.

Table 1: Layer-based Scenario modeling.

Layer	Description of Layer with elements
Layer1 (L1)	Road level (straight,cruved,uphill...)
Layer2 (L2)	Traffic Infrastructure (construction site, road sign,...)
Layer3 (L3)	Combination of L1 and L2 (single lane same direction, ...)
Layer4 (L4)	Objects (Other traffic, solid object, ...)
Layer5 (L5)	Environment (Sunny, cloudy, rainy, snow,...)

The total possible set of functional scenarios can be constructed by associating every element of one set with each element of another set by using the cartesian product.Thus, the Equation 2 can be expressed for a single functional scenario as $(1l_1, 2l_1, 3l_1, 4l_1, 5l_1) \mid 1l_1 \in$ L1; $2l_1 \in$ L2; $3l_1 \in$ L3; $4l_1 \in$ l4; $5l_1 \in$ L5.

Layer information is used as a basis for the modeling of any HADF functional scenario. The layer-based approach is easy to understand, but challenging to model because the layer-based approach describes the scenario as semantics. Therefore, for efficiently modeling the scenario (re-usability) parameter-based clustering is assumed. Four major steps, to insert the parameters in a scenario are:

- Ego vehicle parameters
- Road type parameters
- Road traffic and Environment Parameters

For modeling the scenarios, tools like CarMaker are used. Figure 3 overlays the scenario modeling approach with four steps.

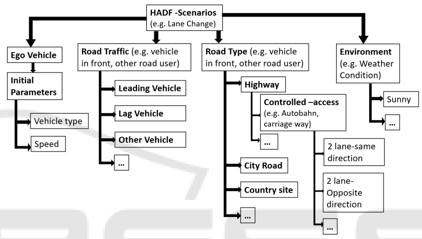

Figure 3: Scenario Modeling steps (in CarMaker).

One of the goals for parameter-based modeling is to reuse the modeled scenario (partly or fully) in the next level of analysis like analyzing the logical scenario for the selection of the discretization step. Although, modeling scenario consumes some amount of time, but it is necessary to simulate the scenario at concept phase to identify the safety-relevant parameters. The re-usability of the scenario model will provide great help and make the process faster for further (new) scenario generation.

To reduce the effort of modeling scenarios in tools (e.g. CarMaker) and to optimize the possible boundary of parameters from a probability distribution, a simple Monte-Carlo (MC) experiment is applied in a HADF's lane change use case scenario. The optimization technique is chosen for HADF analysis as concrete field test data are not available for research. However, a high-performance computing system is demanded for such type of experiment (to minimize the computing time), but it's still possible to get the result of collision probability with the leading vehicle by varying a specific parameter (speed) over a certain boundary in the use case.

Initial parameters are assumed based on research, field experiment results like probability distribution ((Gyllenhammar et al., 2020), (Hassan et al., 2014),

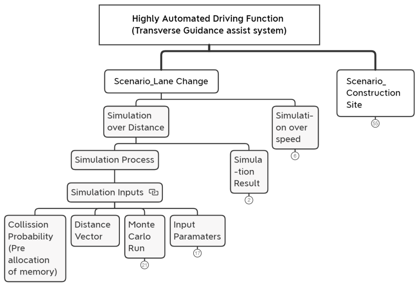

Figure 4: Monte Carlo Simulation for Parameter Optimization.

(Cana et al., 2008), etc). So, a finite number of scenarios are weighed as reflects (ξ^1, ...,ξ^N) and discrete probability distribution with a lower number of atoms (Q) is optimized in the MC experiment. Based on the first run (1st simulation) result, parameter adjustment has been done in the later revisions of the MC experiment. The goal for this experiment is to get the collision probability concerning parameters (distance between vehicles, speed). A model-based approach of the experiment process is represented in Figure 4.

6 SCENARIO SIMULATION

The goal is to find the critical parameters to realize the HADF by simulation. No longer a vehicle with HADF can be validated and verified for a limited set of use cases. Unusual situations can arise while driving and test case numbers are increasing drastically. So, to confirm vehicle's performance and finding the key parameters and/or combination of parameters, scenario-based simulation with optimization is performed. The key concept of our investigation is to reduce the area for modeling scenarios in an efficient way.

This section divides the scenario simulation into two parts to explain the fourth key contribution of this paper. The first part demonstrates the optimization of a parameter by MC simulation. The second part provides the modeled scenario with parameter variation to optimize the boundary range for a Logical scenario. The complex stochastic approach will be applied to the logical scenario to reduce the scenarios. Each logical scenario can exponentially increase the number of concrete scenarios with respect to parameter variation (x_j with j = {1,2,...,N}) which can be shown in the equation:

$$Logical\ Scenario = \prod_{i=1}^{5}\prod_{j=1}^{N} L_i * x_j \tag{3}$$

The process of the modeling scenarios and experiment of scenarios is highlighted by a flow diagram in Figure 5.

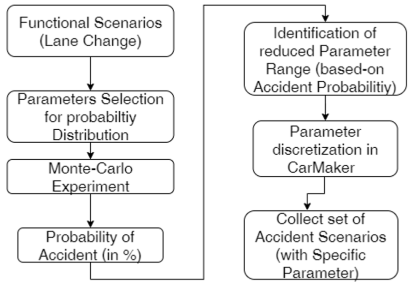

Figure 5: Scenario Simulation Flow Diagram.

As described in section 3, probability triple (Ω, $\mathcal{F}$, P) is described where Ω is a set of all possible outcomes. The functional scenario image is created in 2D which is enough for MC simulation as represented in Figure 6 where a straight highway with three other road users are considered for the experiment. The ego vehicle is marked as yellow color (V1) and other road vehicles are marked with different light colors like carolina blue (V1), dusty blue (V2), and aqua (V3). The scenario is that the ego vehicle is turning from the right lane to the left lane of the road and overtaking vehicle V3 and then back to the previous lane again.

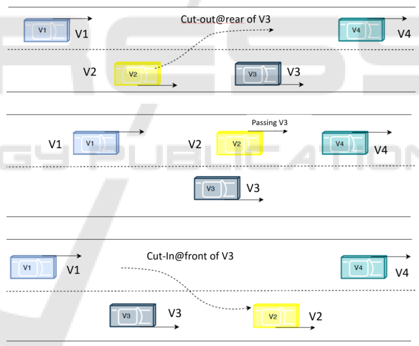

Figure 6: Functional Scenario (Lane Change of HADF Level 3 automation).

Based on the described scenario the MC experiment is done for HADF. It is well known that statistical data for HADF is not well established and limited up to L2 for certain cases. The discrete probability of parameter distribution is found for L2 vehicles which are assumed to be the same for L3 vehicles at the beginning of the experiment to optimize the parameter range ((Gyllenhammar et al., 2020), (Hassan et al., 2014), (Cana et al., 2008), etc). For simplicity of the simulation, a continuity correlation (Normal approximation) is used by a given mean and standard deviation to approximate the discrete distribution by continuous distribution. The result of the simulation is a discrete probability distribution of the occurrence of an accident over parameters (like distance with other vehicles). The approximation of the input parameters is shown in Figure 7. The probability distribution describes the possible values and likelihood that a random variable can be taken within a given range. The ranges can be bounded as a minimum and maximum possible values. To identify the precise possible value, the distribution factor needs to be plotted. These factors include the mean, median, and standard deviation. So, probability distribution is considered as input for parameters like vehicle's in-between distance (V1 and V2, V2 and V3 and V3 and V4).

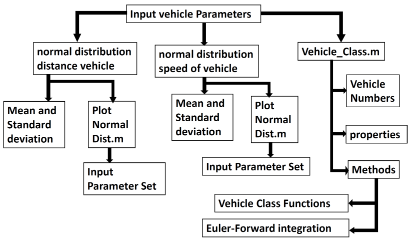

Figure 7: Input parameters approximation for Monte-Carlo Simulation.

The output of the experiment provides the probability of an accident in percent over the distance between the ego vehicle (V2) and leading vehicle (V3) as exhibited in Figure 8. To build confidence and getting an acceptable optimization value, several thousand Monte-Carlo runs are examined. To utilize MC, several sets of MC run (Like, 800 MC runs, 1000 MC runs and 30000 MC runs) has been computed and optimize the probability of the accident. Although, the computational costs are high for the MC scenario simulation and improvement can be possible. However, MC helps to assess the safety and to estimate reduced boundary of the safety critical parameters. Furthermore, the paper tries to propose a concept that supports reducing the scenarios up to a level and provide evidence by probability assumption not enforcing the accuracy of the performance of the experiment. Although, a future research aspect is to compare the result with completely different tools like CarMaker for optimizing the acceptable result. Based on the accident probability result, the distance range and speed of the vehicles are considered for parameter variation with discretization steps in CarMaker simulation.

From the MC experiment, optimized boundary parameters are used in CarMaker scenario modeling and simulation. To build the confidence of the optimized result and determining the accuracy from the MC experiment, the same scenario is modeled in CarMaker, and results are compared.

The discretized steps are considered as a variation of parameter in CarMaker as variation as illustrated in Figure 9. Ego vehicle's speed is considered as a parameter for variation and the simulation result is observed. CarMaker simulation is a repetitive approach to finding possible collision scenarios with specific parameters. Undoubtedly, the simulation results support the scenario catalog (by listing a possible group of use cases) and the concrete scenario generation. The concrete scenario set can be used for further test case application.

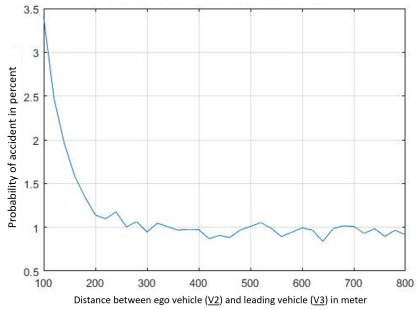

Figure 8: Monte-Carlo Simulation output (Probability of accident).

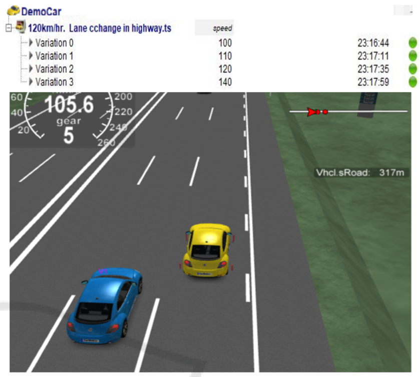

Figure 9: Parameter Variation in a Logical scenario.

7 CONCLUSIONS

The reason for applying the same optimization method to two different tools is to compare the outcomes with no redundancy which supports safety validation and verification. Our scenario-reduction approach will downsize the modeling effort by optimized parameter's boundary. Further reduction in logical scneario is possible by implementing MC in logical scenarios modeled in CarMaker (using tool interference like Matlab). It is ssumed that by observing the simulation with parameter variation, unknown-unsafe scenarios can be realized which are carried in the scenario catalog and provides support to complete the scenario catalog for a HADF.

The proposed pre-selection approach for an ODD of TGAS shows the functional scenario reduced about

43% during scenario-based hazard analysis (at the early stage by clustering and grouping) is counted as an outcome of this paper for supporting a complete HADF scenario set. Furthermore, using a stochastic program to optimize the safety-relevant parameter's boundary reduces the number of logical scenarios which reduce the effort of modeling scenarios. A simple stochastic program is advantageous at the function level to deal with a large number of scenarios and uphold to sustain a systematic approach that supports the safety aspect of HADF. This approach supports in general to build confidence in simulation-based scenario investigation in HADF development which can be cost-effective and time-efficient. Although, a further scenario reduction approach is required from a logical scenario to concrete scenario determination.

In our future research, we would like to focus on the complete scenario database for a complete HADF and propose a reduced set of concrete scenarios based on simulation results that can support to provide evidence for safety approval (homologation). Approximation techniques that reduce more scenarios in each step of clustering and/or grouping at function level may be improved by other types of stochastic programs like a multistage program. Interesting is to observe the accuracy rate of the experiment and simulation result by studying a huge number of scenarios which has to be investigated.

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