

# **PROSPECTIVE SAFETY EFFECTIVENESS ASSESSMENT OF AUTOMATED DRIVING FUNCTIONS – FROM THE METHODS TO THE RESULTS**

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## **ABSTRACT**

The development in the areas of sensors and electronics has been bringing the automotive industry increasingly closer to automated driving in recent years. Automated functions that need to be continuously supervised by the driver are already on the market. Highly automated driving functions (HAD) will enter the market in the near future. The German Ethics Commission for automated and connected driving stated in its report that “the licensing of automated functions is not justifiable unless it promises to produce at least a diminution in harm compared with human driving, in other words a positive balance of risks” [1]. This leads to the question, how the traffic safety effect of automated driving functions can be assessed taking into account possible positive and negative aspects?

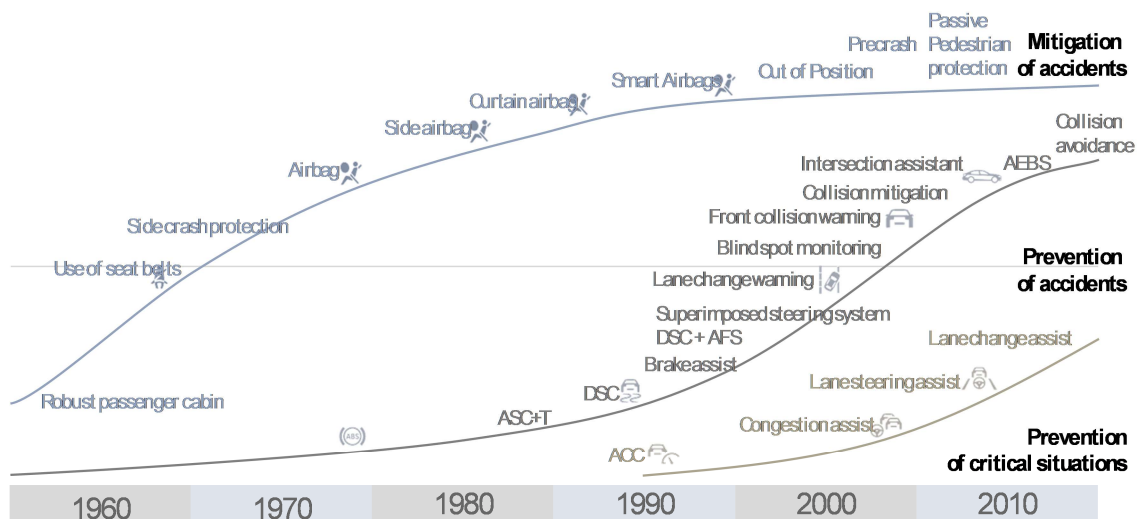
This paper introduces comprehensively a method that is used by BMW for the prospective safety assessment of HAD by means of virtual experiments. This method is besides others part of the evaluation and safety assurance activities for HAD. The method is described from the scenario selection via the simulation up to the validation and verification. In contrast to other simulation approaches in this area, which mainly use accident re-simulation, this approach uses Monte-Carlo techniques, in which the initial starting conditions of the simulated driving scenario as well as the parameters of the involved drivers are randomly selected from distributions. These distributions base on accident data as well as on naturalistic driving data. A core aspect of this approach is the stochastic cognitive driver behavior model to describe the behavior of individually different traffic participants in a scenario. In contrast to accident re-simulation based approaches, this approach allows to analyze time-wise larger driving scenarios, which are of importance for HAD, since these functions act throughout the driving within the operational design domain and not only in critical situations.

The method for assessing the safety performance is applied to exemplary HAD. The results cover the positive effects, which are mainly achieved in today known accident scenarios, as well as scenarios, in which potentially new

risks compared to manual traffic can occur. One example for this is the minimum risk maneuver, for which the consequences of different implementation is discussed. Like all other methods (accident analysis, studies in driving simulator or on test track, field operational test) the simulation based approach has advantages and disadvantages. The main criticism is that the assessment is done virtual, which poses the question on the validity of the simulation. In order to tackle this aspect the validation and verification of the method and tool is a key aspect. Therefore, our current conceptual considerations regarding validation and verification are described in this paper.

## INTRODUCTION

Since the 1960's different technologies have been introduced in the automobile industry in order to improve the traffic safety, see **Figure 1**. The first type of technologies were passive safety systems (seat belt, airbag etc.). These technologies mainly aim to reduce the consequences of an accident. The next step were systems that actively try to prevent an accident or at least try to reduce – in case of unavoidable accidents – its consequences prior to the first contact. These systems are known as active safety technologies. Their development started with systems focusing mainly on the vehicle dynamics (e.g. ABS and ESC) in the 80's of the last century. From 2000 onwards further active safety systems entered the market. The systems use the information about environment and surrounding traffic in order to detect an imminent risk and to start countermeasures (e.g. AEB, blind spot detection). The third category of systems in the integrated traffic safety approach are systems that aim to prevent the occurrence of critical driving situations already beforehand. Systems of this category typically take over the control of the vehicle in longitudinal, lateral or both directions. These systems can be categorized by the SAE classification for automated driving [2]. The systems of this category range from advance driver assistance systems (ADAS), like ACC, up to highly automated driving functions (HAD). In particular the latter one is currently a major topic in the development of the automobile industry [3] [4].



**Figure 1. Integrated traffic safety approach [5].**

Highly automated driving functions are expected to bring major improvements in terms of traffic safety [6] by avoiding human error related accidents. However, it must be taken into account that accidents are very rare events. Altogether 20.928 accidents occurred on a German motorway in 2017, in which a human was slightly, severely or fatally injured [7]. Considering an annual driving distance of approx. 243 billion kilometers [8] an accident with injured persons occurs statistically on a German motorway only approx. every 11.6 million kilometers. An improvement of traffic safety due to automated driving would become reality once it is proven that accident frequency is less than for human driving. Therefore, the German Ethics Commission on automated and connected driving request in article 3 "...The guiding principle is the avoidance of accidents, although technologically unavoidable residual risks do not militate against the introduction of automated driving if the balance of risks is fundamentally positive" [1]. This poses the question, how a positive balance of risk for automated driving can be

investigated and proven already before real world accident data are available. One method to investigate this balance of risk for automated driving is the prospective safety effectiveness assessment approach.

In the paper different approaches for the prospective safety effectiveness assessment are presented including BMW's simulation based approach for automated driving. This approach is later exemplarily applied for different driving scenarios. Finally, the paper ends with a description of the taken validation and verification approach for this method.

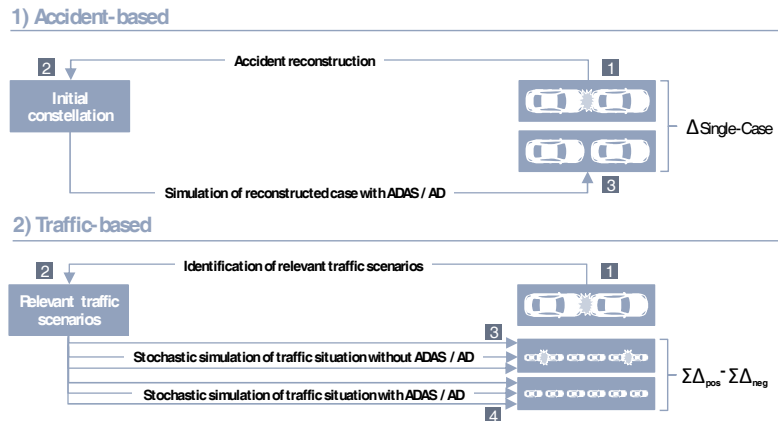
## **METHODS FOR PROSPECTIVE SAFETY EFFECTIVENESS ASSESSMENT**

There are different approaches and tools to determine the effectiveness of a technology on traffic safety. In general the safety effectiveness assessment conducts a comparison of the situation without the technology under assessment (baseline) with the situation with the technology presented in terms of traffic safety.

At this point a distinction between the retrospective and prospective assessment approaches is necessary. The retrospective assessment is conducted after the market introduction of the technology. The assessment is typically done by means of real world accident data [9-11]. The advantage of this method is that it is capable to provide the real world impact of a technology. But there are two challenging aspects for this method. The first one is that confounding factors can hardly be controlled. The second aspect is that it requires a certain penetration rate of the technology, which means, that it cannot be used before a technology is introduced in the market or shortly after its introduction. However, the application of the method in the development is fundamental requirement, if the proof of a positive risk balance is prerequisite for the market introduction of automated driving.

The safety effectiveness assessment of the technology before its market introduction is aimed by the prospective assessment approaches. Basically, four different approaches are known. These are: field operational test (FOT), user studies in a controlled environment (driving simulator or test track), accident analysis and computer simulations. Each of these approaches has its advantages and disadvantages. The FOT approach, which has for instance applied in the euroFOT project [12], analyzes the effects of a technology in real world conditions. However, the approach requires quite high resources and can only be applied once a technology has reached maturity, which allows to test on public roads. Furthermore, due to the low likelihood of accidents, it is rather unlikely that a statistically relevant number of accidents is detected in a FOT. For this reason typically surrogate measures (e.g. critical driving situations) are applied in the assessment. Studies with users on test tracks or driving simulators provide detailed information about the interaction of the user with the technology under controlled conditions and without posing the users any risk. This approach has been used in different studies, e.g. by [13]. However, these studies require also a high effort – in particular if the effect of technology should be analyzed in a large number of driving scenarios. In contrast the prospective accident analysis, which for instance has been applied in [14-16], allows to investigate the potential field of application with relative low effort. The drawback is that the approach is limited in the way, how precise the effectiveness of technology can be calculated, since specific effects in driving scenarios cannot be taken in account.

The remaining approach is the computer simulation, which has been used in different studies (e.g. [17-19]). This approach is able to investigate the safety effect of a technology in various driving scenarios at a reasonable effort. The challenging aspect for this approach is that it is done entirely virtually, which poses high requirements for the in the simulation applied models. It is also clear that input data from other tools are required to set up the simulations [20], e.g. accident data, driving simulator data, FOT data or data from naturalistic driving studies (NDS). Within the prospective safety effectiveness assessment by simulation two different approaches are known, see **Figure 2**.



**Figure 2. Approaches for the simulation based prospective safety effectiveness assessment.**

The first approach is the accident-based approach. For this approach real-world accidents, which have been reconstructed, are simulated considering the technology to be assessed. The trajectory of the simulated traffic agents (combination of driver and vehicle) are derived from the original accident case. A prerequisite of this approach is that detailed reconstructed accidents are available. Examples for the application of this approach are [17] [18] [21-23]. Here, it must be noted that the uncertainty in the reconstruction increases the longer the accident case is reconstructed. Furthermore, this approach allows to investigate only critical situations. A modification of this approach in order to cover a wider range of situations can be accomplished by slightly altering the parameters of the original accident case in order to investigate, how a technology would react under the changed conditions [22] [24] [25].

The second approach is the traffic-based approach, which has been for example applied by [25-27]. Artificial driving scenarios are simulated within this approach. The starting conditions of the driving scenario are stochastically chosen from distributions that are derived from accident data or NDS/FOT data. Thus by means of the distribution the link between the simulated cases and the real world is ensured. In contrast to the accident-based approach no trajectories can be pre-calculated. Therefore, models are required that determine within the simulation the behavior of the traffic participants. For a valid simulation the quality of these models must be ensured. On the one hand there are no limitations in terms of duration and complexity (length of road, involved traffic participants, conducted maneuvers etc.) of the scenarios as for the accident-based approach. And by means of this approach also driving situations can be analyzed that are not critical in the first place, which allows to analyze, whether any false positive reactions of the technology are detected.

Due to the wide range of scenarios that can be analyzed at a reasonable effort BMW has used the traffic-based simulation approach for the prospective safety effectiveness in a wide range of different analyses [28-30] for ADAS. However, HAD poses new challenges for the prospective safety effectiveness assessment. The following sections discuss these challenges as well as the taken measures to solve them.

## **APPROACH FOR PROSPECTIVE SAFETY EFFECTIVENESS ASSESSMENT OF AUTOMATED DRIVING**

The required adaption to apply the method of prospective safety effectiveness assessment by simulation for automated driving functions can be derived from the difference to active safety functions. First, in general each technology can have positive as well as negative effects on traffic safety. The longer the technology is operating the more situations are affected by the technology. Active safety systems, such as AEB, only operate respectively intervene in the driving dynamics once a critical situation is detected. These situations are – of course depending on the individual driving style – rare and short driving situations. In addition, the situations, in which the system is active, are clearly defined. Thus, the situation space can be narrowed down to a few types of situations. Since intervention just starts seconds before the imminent collision, the simulated time frame can rather be short. Also when assessing potential negative consequences it can be focused on situations that are short in time.

For the HAD the nature of the technology leads to different requirement. Here, the function can constantly operate through driving as long as the vehicle is in the operation design domain (ODD). This longer operation time of the HAD means that the simulation needs to cover larger and longer driving scenarios. Since during the drive different

maneuvers occur, it is not enough to focus just on single maneuvers. It is rather required to simulate the entire range from normal driving via critical situations up to the moment of the collision.

Furthermore, challenging driving scenarios for HAD, which might lead to negative impacts on traffic safety, must be paid more attention compared to active safety system for two reasons. First, the longer operation of HAD and by this larger interference with the traffic raise risk of executing not for given situation appropriate actions. The second reason is that HAD leads to new driving scenarios that are not part of the manual driving today. The main example is a driving scenario in which the driver has to take over vehicle control from the function.

A last important aspect for assessment of automated driving is that the function does not only change the severity of a situation as mainly considered for active safety systems, but also can influence the frequency of certain driving scenarios. One example is the passive cut-in maneuver. First experiences on public roads already show an increase of occurrence frequency of this maneuver while driving automated compared to manual driving [30]. Since the safety effect of a technology is described by the change in the severity and the frequency in the relevant driving scenarios, such effects must also be taken into account when assessing automated driving.

These requirements lead to the conclusion for prospective safety effectiveness assessment, which is only one part of the entire test and safety assurances activities of HAD, that an assessment for automated driving is only feasible by means of the traffic-based simulation approach. The accident-based simulation approach is too limited in terms of scenario duration and selection of scenario to ensure a comprehensive assessment. Of course it must be noted that the simulation approach requires different input data. The input data must come from other sources, like accident data, driving simulator data for e.g. describing the overtaking abilities of human drivers as well as FOT and NDS data. In the following relevant aspects of the traffic-based simulation approach as it is applied at BMW are highlighted.

### Analyzed scenarios for automated driving

The assessment of automated driving requires consideration of driving situations, which might lead to positive as well as to negative effects in terms of traffic safety. In order to assess these effects the relevant driving scenarios must be identified. However, as stated earlier due the constant operation of HAD driving scenario does not mean that the scenario is limited in time to a few second and to a few involved traffic participants. Driving scenario here means that a larger road section – for instance two kilometers – with depending on the pre-defined traffic flow calculated number of traffic participant is simulated in which the certain driving maneuver or a kind of conflict occurs.

BMW's approach for identifying the scenario to be analyzed bases on three pillars, see **Figure 3**. The first pillar focuses on the driving scenarios for which positive effects of the HAD are expected. These can be derived from the driving scenarios, in which human drivers do not perform well. Typically these are accident situations. The major accident types that occur on German motorways are accidents related to (passive) cut-in, rear-end conflicts at the end of traffic jams, rear-end conflicts in general and single driving accidents, in which one vehicle leave the road not directly involving any other road users.

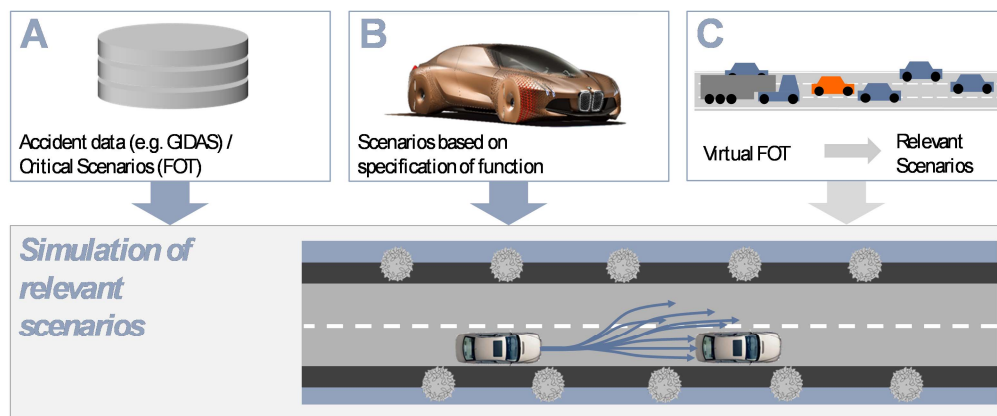


Figure 3. Identification of top scenarios for the assessment of HAD.

The second pillar considers the for the HAD challenging driving scenarios. The scenario can either have positive or negative effects. These driving scenarios are identified by means of analyzing the function itself. With respect to the accident frequency within manual driving, these scenarios are typically less relevant. Due to the uncertainty regarding the HAD behavior, they require more in-depth analysis. Examples are driving scenarios that require an interaction with other road users (e.g. highway entrance, end of driving lane), scenarios in which the HAD needs to take complex decisions (e.g. obstacle in the driving lane) and the already mentioned transition of control scenarios, in which the driver (suddenly) has to take-over the vehicle control from the function.

The last pillar addresses the issue of detecting changes in the frequency of driving scenarios. This is hardly possible by simulating driving scenarios. This requires even larger traffic simulations, in which longer and representative road sections are simulated. Therefore, BMW considers for this purpose a “virtual”-FOT approach, in which traffic scenarios with the HAD are simulated. In a second step relevant driving scenarios are identified in the output data of the simulations. This approach allows to get an understanding how the frequency of certain driving scenarios changes.

### **Simulation tool openPASS**

Naturally, the simulation based approach for the prospective safety assessment requires a simulation tool, in which the simulation are carried out. There are several commercial tools available on the market. However, most of these tools are proprietary software tools that lead to limitations in terms of the required adaptations. Therefore, BMW does use for its approach the open source simulation tool openPASS [31], which is currently jointly developed under the eclipse foundation developed by BMW, Daimler, Volkswagen, Toyota, Bosch, TÜV Süd and ITK-Engineering. openPASS offers the opportunity to simulate both simulation bases approaches in the prospective safety assessment, namely the accident-based and the traffic-based approaches. The modular framework of openPASS allows to include different models for the different modules, while the open source approach offers a certain transparency. Furthermore, it is possible to use within openPASS the open source interfaces such as openDRIVE, openSCENARIO, OSI and FMI. For the used approach of the HAD assessment the most important aspect of openPASS is that scenario can be simulated with several stochastic variations that could affect the environment, the vehicle, the sensors parameters and the traffic. A last important aspect is the driver behavior model that is addressed in the next section in more detail. Here, the flexibility of openPASS is used by integrating the BMW’s driver behavior model in the simulation framework.

### **Driver Behavior Model**

For the traffic-based simulation approach a driver behavior model is an essential building block. A driver behavior for the assessment of HAD is required for two purposes. The first purpose is to simulate the behavior of driver in the automated vehicle in situations, in which the driver must take over the driving task from the function. The second purpose is to describe the behavior of different traffic participants during situations considering the interaction among all relevant traffic participants. In the baseline simulation all traffic participants are controlled by the driver behavior model. In the treatment simulation the model is only relevant for the non-automated agents. Due to the fact that in the assessment a comparison between the baseline and treatment simulation is done, the risks in the baseline simulation should be comparable to the real world. Hence, the driver behavior model should cover the driving ability of a wide range of drivers including accident prevention strategies as well as faulty behavior of human drivers.

The requirement led to the development of Stochastic Cognitive Driver model (SCM) at BMW from 2014 onwards. This driver behavior model is mainly designed for highway traffic. The functional concept of the SCM combines human cognitive processes with stochastic process modeling. The SCM consists of five different sub-modules to represent the behavior of different drivers (information acquisition, mental model, decision making process, action patterns, action implementation). By means of these models it is possible to represent the process from the information acquisition up to steering, braking or acceleration actions by the agent. Due to the stochastic characteristics of the SCM it is guaranteed that agents behave differently in certain driving situations. And it is even possible that the same agent in the same situations reacts differently. By this it is ensured that a wide range of driver behavior is covered by the assessment.

Further developments of the SCM in the recent years covered two aspect. The first aspect is that the model’s prediction and anticipated capabilities have been improved in order to ensure a better traffic flow and to reduce the accident rate in passive cut-in maneuvers [32]. The second aspect is the driver characteristics module. This sub-module links driver parameters (age, driven mileage) and states, such as fatigue and stress [33], with the driver parameters of the SCM. It covers individual and inter-individual driver differences and their impact on driver

behavior. In a one-way stochastic process, traffic agents are provided with a set of individual driver characteristics that shift, widen or narrow baseline distributions of stochastic parameters in all sub-modules of the SCM. By this, a broader spectrum of the over-all driver population can be modelled and virtual traffic simulations can be run as realistic as possible. For filling this sub-module with valid data, a driving simulator study has been conducted. After the general background has been discussed, the next chapter shows exemplarily the application of the method for HAD.

## APPLICATION OF METHOD FOR AUTOMATED DRIVING

After presenting the approach this chapter focuses on its exemplary application. For this purpose the effect of an exemplary HAD is analyzed in eight different driving scenarios. The eight different driving scenarios are: 1. Cut-In, 2. Traffic jam, 3. Rear-end accident, 4. Single driving accident, 5. End of Lane, 6. Obstacle in the lane, 7. Highway entrance and 8. Minimum risk maneuver after transition of control. The analysis have been conducted in the context of the European funded research project AdaptIVe [34] and the German funded research project Ko-HAF [35]. The first four scenarios are reported in the section for the accident scenarios, whereas the remaining four are reported in the section for the challenging scenarios.

It must be noted that analyzed HAD is an example function that does not represent BMW's actual implementation.

### Analyzed highly automated driving function

The exemplary HAD that is simulated in the following has been implemented according to the **Table 1**. For the minimum risk maneuver that is activated in case the driver does not take over from the function two implementations are analyzed. For the first implementation a moderate deceleration (approx. 2 m/s<sup>2</sup>) and for the second implementation a strong deceleration (approx. 5 m/s<sup>2</sup>) is considered.

**Table 1.**  
**Specification of analyzed artificial automated driving function.**

Category	Operation conditions
Road Type	Motorway
Conditions, when function is deactivated	Invalid environment conditions, end of motorway, defect in vehicle, loss of sensor data, loss of software module(s), construction sites
Covered environmental conditions	Dry condition and light rain in day and night
Speed range	0-130 km/h
Sensor range (front / side left / side right / rear)	200 m / 40 m / 40 m / 200 m
Covered driving maneuvers	Vehicle following in lane, obstacle or VRU on the road, lane change, stop & go driving, speed / time gap adaptation, enter and exit of motorway, minimum risk maneuver
Max. / Min. long. acceleration (normal operations)	4,0 m/s <sup>2</sup> / -4,0 m/s <sup>2</sup>
Max. / Min. lateral acceleration (normal operations)	3,0 m/s <sup>2</sup> / -3,0 m/s <sup>2</sup>

### Safety performance of HAD in accident related traffic scenarios

First the driving scenarios are simulated according to the described method for which a positive effect of the HAD is expected. The change in the accident risk for the automated vehicle compared to the manual driven vehicle are given in **Table 2**. As expected all scenarios show potential to reduce the accident risk.

**Table 2.**  
**Results of the simulated accident related traffic scenarios [34].**

Driving scenario	Expected mean change of accident rate [Confidence interval]	Accidents within ODD in GIDAS (including accident at speeds outside the operation conditions)
1. Cut-In	-83% [-76%; -90%]	72% (92%)

2. Traffic jam	-40% [-25%; -55%]	80% (89%)
3. Rear-end accident	-73% [-56%; -91%]	69% (96%)
4. Single driving accident	-100%* [-;-]	67% (93%)

The only scenario that has not been covered by the simulation approach is the “single driving accident”. In this scenario the vehicle leaves unintendedly the lane or the road. It is expected that as long as a curve is in the ODD and no functional issues occur the function will be able to keep the vehicle in the lane and prevent by this the related accidents.

However, the effect in the driving scenario is only one part of the potential safety effect, since it implies the function can operate under all conditions and is always active. This of course does not meet the truth, since HAD is as described in Table 1 limited in terms of the ODD. In order to consider this limitation the third column in table 3 provides information about the proportion of the GIDAS accident [36] for which the ODD have been fulfilled. Regarding the proportion of the in the ODD included accident there is an uncertainty regarding accident that occur outside the operation speed of the HAD. For these cases either the function is switched on and drivers benefit as calculated or drivers intend to drive faster, which means that he/she switches the function off. This would result in no benefit at all. To a certain extent this is a country specific aspect, which is more relevant in Germany than other countries due to the in terms of speed limit unlimited German motorway. However, the principle question applies to all accidents above the operation speed of the HAD. Regarding the usage of the HAD any statement before market introduction is hardly possible, since the actual usage will depend on the HMI design and user’s attitude towards the function.

#### Safety performance of HAD in challenging traffic scenarios

After the driving scenario with expected positive effect the challenging scenarios are evaluated. Table 3 provides the results of expected mean change of accident rate in the driving scenarios as well as the proportion of accidents in the ODD.

**Table 3.**  
**Results of the simulated challenging traffic scenarios [34][35].**

Driving scenario	Expected mean change of accident rate [Confidence interval]	Accidents within ODD in GIDAS (including accident at speeds outside the operation conditions)
5. End of Lane	-14% [-8%; -20%]	67% (83%)
6. Obstacle in the lane	-40% [-34%; -47%]	78% (97%)
7. Highway entrance	-49% [-45%; -53%]	95% (95%)
8. Minimum risk maneuver (moderate deceleration)	+2.6% [+0.2%;+5.0%]	No reference data available
9. Minimum risk maneuver (strong deceleration)	+48.4% [+36.4%;+60.4%]	No reference data available

Simulations show a high variation in the results for the challenging scenarios. For obstacle in lane and highway entrance driving scenario a high potential for the reduction of accident risk is detected compared to the baseline scenario. For the minimum risk maneuver the situation differs. This does not surprise, since compared to normal driving an additional and properly for other traffic participant surprising braking maneuver is induced. For the moderate minimum risk maneuver the accident risk is approximately in the range of manual driving. The minimum risk maneuver with strong deceleration shows a significant increase of the accident risk compared to manual driving. Thus, from traffic safety perspective the deceleration in the minimum risk maneuver should be rather low. However, it is important to note in this context that the technical feasibility of applying a minimum risk maneuver has not been considered in this study. It is obvious that the implementation effort for moderate deceleration is significantly higher than for stronger deceleration, since the time that need to be covered by the maneuver is higher.

#### VALIDATION AND VERIFICATION PROCESS



Since the present approach for the prospective effectiveness assessment relies on virtual computer simulations, validation and verification is essential to ensure that the simulation provides trustable and reliable results. Within the validation and verification it is checked whether the results of a single model or the entire simulation meet the results of a reference within a pre-defined range. The challenge within the validation and verification for simulation is ensuring correctness of the simulation while keeping the effort for this activity at reasonable level.

Since BMW considers validation and verification as an important aspect for the method of the prospective safety effectiveness assessment, a validation and verification process has been defined for its simulation. The main requirements of BMW's validation and verification process are:

- This process must cover the entire method and all relevant (sub-)modules within the simulation method.
- The process shall be conducted at least once for each model and the entire method.
- It needs to be repeated depending on the changes on the method or on the simulation tool. For this purpose it is distinguished between minor and major changes depending on the impact of a change.
- In case already validated models are used, a further validation or verification of this model is not required.
- The reference shall be selected in accordance with to be validated model and the quality of the reference data.

An overview on models that can be validated and verified by means of different reference is given in the **Table 4**. Independent of the taken approach, it must be decided in the end whether the output of the validated model is close enough to the reference. For the definition of the criteria the purpose of assessment as well as the quality of the reference data are of relevance. In case explicit criteria (e.g. max. error) are available, it shall be shown that these thresholds are met. This applies also if a certain target range is defined. Here, it can be necessary to break down into permitted inaccuracies per model. In case no explicit criteria is available the quality of a module can be quantified by one of the following approaches:

- 1) Calculation of a quality indicator (max. error).
- 2) Quantification of technical deviations between distributions (e.g. effect size).
- 3) Sensitivity analysis.
- 4) Explicit declaration of confidence intervals.

**Table 4.**  
**Reference data for different models in the validation and verification of simulation models.**

<b>Reference</b>	<b>To be validated simulation model</b>
Real world effectiveness based on accident data	Entire method, collision model
FOT or NDS	Traffic module, driver behavior module
Test on test tracks	Vehicle module, technology module, driver behavior module
Driving simulator	Driver behavior module
Sensitivity analyses	Vehicle module, technology module
Review against the specification	Technology module
External database / literature	Environment module, driver behavior module, traffic module
Inspection	Collision module
Software tests incl. module, unit, integration and system tests	Simulation control

## CONCLUSIONS AND DISCUSSION

This paper presented a comprehensive overview on the prospective safety assessment approach for HAD. The introduction of HAD leads to different challenges for the prospective safety assessment of this technology. In principle, different tools can be applied for the safety assessment. However, considering the advantages and disadvantages the simulation based assessment approach is the most promising approach for this purpose, since it is capable of covering a high variety of driving and traffic scenarios at reasonable effort. Nevertheless, the input of the other tools can and should be used for the correct definition of the in the simulation applied models. In this sense the simulation is a synthesis of knowledge that is gained by the assessment tools.

The key challenges of the simulation approach for the prospective safety assessment approach for HAD are besides the implementation of the function the identification of the relevant driving scenarios, the simulation tool and the driver behavior model. In the paper it has been reported how BMW addresses each of the issues.

Finally, the described method has been applied for an exemplary HAD. The results indicate that HAD can lead to a significant reduction of the accident risk in the specific scenarios within the ODD. For the challenging scenario the situation is not that clear. Here, also new risk in terms of traffic safety can occur. However, the differences in the outcome in terms of accident risk for the two minimum risk maneuvers emphasize the demand for detailed analysis considering the exact technology behavior as well as detailed simulations in this area.

The last challenge in the context is to prove that the derived results are reliable and trustable. Therefore, validation and verification of the method as well as the simulation tool including all models is essential. The paper reported on the taken validation and verification approach for the prospective safety assessment at BMW.

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