**Credibility assessment framework**

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***Credibility assessment for using virtual toolchain in ADS validation***

* ***Introduction, motivation, and scope***. The use of Modelling & Simulation (M&S) is becoming widespread thanks to the increasing computational capabilities, accuracy, usability, and availability of M&S software packages. M&S can be beneficial for ADS safety validation because it allows to overcome some real testing limitations and to increase the number of testing scenarios. Nonetheless, M&S can also lead to erroneous/seemingly correct results, especially in relation to complex simulations not adequately supported by robust practices addressing all M&S aspects beyond pure validation. Therefore, higher confidence in M&S credibility is needed to apply virtual testing instead of/in conjunction with the other NATM pillars. In other words, M&S can be used for virtual testing if an assessor is able to consider the simulation results *credible* enough to make sound decisions taking into account the potential uncertainties of M&S. The validation of M&S can be considered the hallmark of simulation credibility. However, the validation has some limitations, which include the limited scope of the validation tests and the difficulty in retrieving data supporting the validation procedures. The use of M&S requires more attention towards all factors influencing the quality and validity of M&S with aim at:
	1. identifying a common framework to determine, justify, assess and report the overall credibility of the M&S,
	2. indicating the levels of confidence in results from the validation phase.

At the same time, this framework should be general enough to be used for different M&S types and applications. However, the goal is complicated by the broad differences across ADS features and the variety of M&S types and applications. These considerations lead to introduce a (risk-based/informed) credibility assessment framework relevant and appropriate to all M&S applications.

The proposed credibility assessment framework provides a general description of the main aspects considered for assessing the credibility of an M&S solution together with guidelines of the role played by 3rd parties assessors in the validation process with respect to credibility. Concerning the latter point, the assessor shall investigate the produced documentation supporting credibility at the audit phase, whereas the actual validation tests occur once the OEM has developed the integrated simulation systems.

Ultimately, the outcome of the current credibility assessment shall define the *envelope* in which the virtual tool can be used to support the ADS assessment.

* ***Components of the credibility assessment framework***. M&S can be used for virtual testing if its credibility is established by evaluating the fitness of M&S for the intended purpose. The credibility can be achieved by investigating and assessing five M&S properties:
	1. Capability – what the M&S can do, and what are the risks associated;
	2. Accuracy – how well M&S does reproduce the target data;
	3. Correctness – how sound & robust are M&S data and algorithms;
	4. Usability – what training and experience is needed and what quality of the process applied to it.
	5. Fit for Purpose – how suitable the M&S is for the ODD and ADS assessment.

Therefore, credibility requires a unified method to investigate these properties and get confidence in the M&S results. The Credibility Assessment framework introduces a way to assess and report the credibility of M&S based on quality assurance criteria that allow indicating the levels of confidence in results. In other words, the credibility is established by evaluating the following M&S influencing factors that are considered as main contributors for M&S properties and therefore for the overall M&S credibility: M&S management, team's experience and expertise, M&S analysis and description, data/input pedigree, verification, validation, uncertainty characterization. Each of these factors indicates the level of quality achieved by M&S, and the comparison between the obtained levels and the required levels leads to consider the M&S credible and fitness to use for virtual testing. A graphical representation of the relationship among the components of the credibility assessment framework is reported in Figure 1.



**Figure 1. Graphical representation of the relationships between the components of the credibility assessment framework**

* + ***M&S (Models and Simulation) Management***. The M&S lifecycle is a dynamic process with frequent releases that shall be monitored and documented. Management activities shall be established to support the M&S in a work product management fashion. Relevant information on the following aspects shall be included in this section:
		- **M&S management process:** shall:
			* describe the modifications within the releases,
			* designate the corresponding software (e.g., specific SW product and version) and hardware arrangement (e.g., XiL configuration),
			* record the internal review processes that accepted the new releases,
			* be supported throughout the full duration of the virtual model utilization
		- **Releases management:** Any M&S toolchain’s version used to release data for certification purposes shall be stored. The virtual models constituting the testing toolchain shall be documented in terms of the corresponding validation methods and acceptance thresholds to support the overall credibility of the toolchain. The developer shall enforce a method to trace generated data to the corresponding M&S version.
		- **Quality check of virtual data:** data completeness, accuracy, and consistency shall be ensured throughout the releases and lifetime of an M&S toolchain to support the verification and validation procedures.
* ***Team's Experience and Expertise***.

Even though Experience and Expertise (E&E) are already covered in a general sense within organization, it is important to get evidence on the specific experience and expertise for M&S activities.

In fact, the credibility of M&S depends not only on the quality of the simulation models but also on the E&E of the personnel involved in the validation and usage of the M&S. For instance, a proper understanding of the limitations and validation domain will prevent from possible misuse of M&S or from misinterpretation of its results.

In this perspective, it is important to provide evidence on the experience and expertise of:

* the Teams that will validate the simulation toolchain and,
* the Teams that will use the validated simulation for the execution of virtual testing with the purpose of validating the ADS

Thus, Team’s E&E increase the level of confidence on the credibility of M&S and its outcomes by ensuring that the human factors behind the M&S are taken into consideration and any possible human component risk is controlled as expected in any suitable Management System.

Team’s Experience and Expertise include two levels:

1. **Organizational level:**

The credibility is established by setting up processes and procedures to identify and maintain skills, knowledge, and experience to perform M&S activities. The following processes should be established, maintained and documented:

* 1. Process to identify and evaluate the individual’s competence and skills;
	2. Process for training competent personnel to perform M&S-related duties
1. **Team level:**

Once a M&S has been finalized, its credibility is mainly dictated by the skills and knowledge of the individual/team that will validate the M&S Toolchain and will use the M&S for the validation of ADS. The credibility is established by documenting that these Teams have received adequate training to fulfil their duties.

The OEM should then:

* Provide evidence on the Experience and Expertise of the individual/team that validates the M&S Toolchain
* Provide evidence on the Experience and Expertise of the individual/team that uses the simulation to execute virtual testing with the purpose of validating the ADS
	+ ***Data/Input pedigree***. The data/input pedigree contains a record of traceability from the OEM’s data used in the validation of the M&S.
		- Description of the data used for the M&S
			* The OEM shall document the data used to validate the model and note important quality characteristics
			* The OEM shall provide documentation showing that the data used to validate the models covers the intended functionalities the toolchain aims at virtualizing
			* The OEM shall document the calibration procedures employed to fit the virtual models’ parameters on the collected input data
		- Effect of the data quality on model parameters uncertainty
			* The quality of the data used to develop the model will have an impact on model parameters’ estimation and calibration. Uncertainty in model parameters will be another important aspect in the final uncertainty analysis.
	+ ***Data/Output pedigree***. The data/output pedigree contains a record of the signals selection that the M&S allows investigating.
		- Description of the data generated by the M&S
			* The OEM should provide [information on] any data and scenarios used for virtual testing toolchain validation.
			* The OEM shall document the exported data and note important quality characteristics
			* The OEM shall trace a M&S output to the corresponding simulation setup
		- Effect of the data quality M&S credibility
			* The M&S output data shall be sufficiently wide to ensure the correct execution of the validation computation
			* The output data shall allow consistency/sanity check of the virtual models via possibly exploiting redundant information
		- Managing stochastic models
			* Stochastic models shall be characterized in terms of their variance
			* Stochastic models shall be ensured the possibility of deterministic re-execution
	+ ***M&S Analysis and description***. The M&S analysis and description aim to define the whole M&S and identify the parameter space that can be assessed via virtual testing. It defines the scope and limitations of the models and toolchain and the uncertainty sources that can affect its results.
		- General description:
			* OEM should provide a description of the complete toolchain along with how the simulation data will be used to support the ADS validation strategy.
			* The OEM should provide a clear description of the test objective.
		- Assumptions, known limitations and uncertainty sources:
			* The OEM shall motivate the modelling assumptions which guided the design of the M&S toolchain
			* The manufacturer-defined assumptions play a major role in defining the limitations of the toolchain
			* Assumptions of road user behaviour may be used to support this
			* Different degrees of fidelity may be required for each of the model's
			* Simulation fidelity is dependent on the input data and how the data is used to support the ADS validation.
			* The OEM should provide justification that the tolerance for sim-real correlation is acceptable for the test objective
			* In addition to the assumptions used in developing the M&S, known limitations define conditions for which the virtual toolchain or one of its component is not valid and which the model cannot be used for
			* Finally, this section shall include information about the sources of uncertainty in the model. This will represent an important input to final uncertainty analysis, which will define how the model outputs can be affected by the different sources of uncertainty of the model used.
		- Scope (what is the model for?). It defines how the M&S is used in the ADS validation.
			* The credibility of virtual tool shall be enforced by a clearly defined scope of utilization the developed models.
			* The matured M&S shall allow a virtualization of the physical phenomena to a degree of accuracy which matches the fidelity level required for certification. Thus, the M&S will act as a “virtual proving ground” for ADS testing.
			* Simulation models need dedicated scenarios and metrics for validation. The scope includes the list of scenarios, among those needed in the ADS validation, that M&S will allow to execute together with the corresponding parameters’ limitation.
			* ODD analysis is a crucial input to derive requirements, scope, effects that the M&S must consider in order to support ADS validation.
			* Parameters generated for the scenarios will define extrinsic and intrinsic data for the toolchain and the simulation models.
		- **Criticality assessment:** the simulation models and the simulation tools used in the overall tool-chain shall be investigated in terms of their responsibility in case of a safety error in the final product. The proposed approach for criticality analysis is derived from ISO 26262, which requires qualification for some of the tools used in the development process. In order to derive how critical the simulated data is, the criticality assessment considers the following parameters:
* the consequences on human safety
* the degree in which the simulated results influence’s the ADS

The table below provides a sample criticality assessment matrix to demonstrate this analysis. ADS manufacturers may adjust this matrix to their particular use case.

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| Influence on ADS | Significant | N/A | Perform degraded mode within reduced system constraints | Create a collision free and lawful driving plan | Correctly execute and actuate the driving plan |
| Moderate | Determine its location | Predict the future behaviour of other actors | Perceive relevant static and dynamic objects in the proximity of the ADS |
| Minor | Strategic control of the ADS by the User | Communicate and interact with other road users | Safe management of transitions of control | Determine if specified nominal performance is not achieved |
| Negligible | User interaction with HMI | User informed about operational status | N/A |
|  | Negligible | Minor  | Moderate | Significant |
| Decision consequence |

From the perspective of the criticality assessment, the three possible cases for assessment are:

* Those models or tools that fall within the red boxes are clear candidates for fully following the credibility assessment
* Those models or tools that fall within the yellow boxes may or may not be candidates for fully following the credibility assessment at the discretion of the assessor
* Those models or tools that fall within the green boxes are not required to follow the credibility assessment
	+ - ***Verification***. The verification of an M&S deals with the analysis of the correct implementation of the conceptual/mathematical models building up the M&S toolchain. The verification contributes to the M&S’s credibility via providing assurance that the M&S will not exhibit unrealistic behavior for a set of input which cannot be tested. The procedure is grounded on a multi-step approach which includes code verification, calculation verification and sensitivity analysis.
		- Code verification is concerned with the execution of test demonstrating that no numerical/logical flaws affect the virtual models
			* The OEM shall document the execution of proper code verification techniques
			* The OEM shall provide documentation showing that the exploration in the domain of the input parameters was sufficiently wide to identify parameters’ combination for which the M&S shows unstable or unrealistic behavior
			* The OEM shall adopt sanity/consistency checking procedures whenever data allows
		- Calculation verification deals with the estimation of numerical errors affecting the M&S
			* The OEM shall document numerical error estimates (e.g. discretization error, rounding error, iterative procedures convergence)
			* The numerical errors shall be kept sufficiently bounded to not affect validation
		- Sensitivity analysis aims at quantifying how model output values are affected by changes in the model input values and thus pointing out the parameters having the greatest impact on the simulation model results. The sensitivity study also affords determining the extent to which the simulation model satisfies the validation thresholds when it is subjected to small variations of the parameters, thus it plays a fundamental role to support the credibility of the simulation results.
			* The OEM shall provide supporting documentation demonstrating that the most critical parameters influencing the simulation output have been identified by means of sensitivity analysis techniques such as by applying a perturbation of the model’s parameters;
			* The OEM shall demonstrate that robust calibration procedures have been adopted while identifying and calibrating the most critical parameters to the end of increasing the credibility of the developed toolchain.
			* Ultimately, the sensitivity analysis results will also help defining the inputs and parameters whose uncertainty characterization needs particular attention in order to properly define the uncertainty of the simulation results.
	+ ***Validation***. The quantitative process of determining the degree to which a model or a simulation is an accurate representation of the real world from the perspective of the intended uses of the M&S.
		- Measures of Performance (metrics)
			* The performance metrics are defined during the M&S analysis.
			* Metrics for validation may include:
				+ Discrete value analysis e.g. detection rate, firing rate.
				+ Time evolution e.g. positions, speeds, acceleration.
				+ Flow of actions based analysis e.g. distance/speed calculations, TTC calculation, brake initiation.
		- Goodness of Fit measures
			* The analytical frameworks used to compare real world and simulation metrics. They are generally KPIs indicating the statistical comparability between two sets of data.
			* The validation should show that these KPIs are met.
		- Validation methodology
			* The OEM should define the concrete scenarios used for virtual testing toolchain validation. They should be able to cover to the maximum possible extent the domain of usage of virtual testing for ADS validation.
			* The exact methodology depends on the structure and purpose of the toolchain. The validation may consist of one or more of the following:
				+ Validate Subsystem models e.g. environment model (road network, weather conditions, road user interaction), sensor models (RADAR, Camera, LIDAR), vehicle model (steering, braking, powertrain)
				+ Validate vehicle system (vehicle dynamics model together with the environment model)
				+ Validate sensor system (sensor model together with the environment model)
				+ Validate integrated system (sensor model + environment model with influences form vehicle model)
		- Accuracy requirement
			* Accuracy requirement is defined during the M&S analysis. The validation should show that these KPIs are met.
		- Validation scope (what part of the toolchain to be validated)
			* A toolchain consists of multiple tools, and each tool will use a number of models. The validation scope includes all tools and their relevant models.
		- Internal validation results
			* The documentation should not only provide evidence of the simulation model validation but also used to obtain sufficient information related to the processes and products that provide overall credibility of the toolchain used.
			* Documentation/results may be carried over from previous credibility assessments.
		- Independent Validation of Results
			* The assessor shall audit the documentation provided by the manufacturer and may carrying out physical tests of the complete integrated tool
	+ ***Uncertainty characterisation***. This section is concerned with characterizing the expected variability of the virtual toolchain results. The assessment shall be made up of two phases. In a first phase the information collected the M&S Analysis and Description section and the Data/Input Pedigree are used to characterise the uncertainty in the input data, in the model parameters and in the modelling structure. Then, by propagating all the uncertainties through the virtual tool-chain, the uncertainty in the model results is quantified. Depending on the uncertainty in the model results, proper safety margins will need to be introduced in the use of virtual testing of ADS validation.
		- Characterisation of the uncertainty in the input data
			* The OEM shall demonstrate to have opportunely estimated critical model’s inputs by means of robust techniques such as providing multiple repetitions for the assessment of the quantity;
		- Characterisation of the uncertainty in the model parameters (following calibration)
			* The OEM shall demonstrate that critical model’s parameters that cannot be estimated identically are characterized by means of a distribution and/or confidence intervals;
		- Characterisation of the uncertainty in the M&S structure
			* The OEM shall provide evidence that the modeling assumptions are given a quantitative characterization of the generated uncertainty (e.g. comparing the output of different modeling approaches whenever possible);
		- Characterisation of aleatory vs. epistemic uncertainty:
			* The OEM shall aim to distinguish between the aleatory component of the uncertainty (which can only be estimated but not reduced) and the epistemic uncertainty deriving from the lack of knowledge in the virtualization of the process.
	+ ***Documentation structure***. This section will define how the aforementioned information will be collected and organised in the documentation provided by the OEM to the relevant authority.
		- The OEM shall produce a document (a “simulation handbook”) structured after the present outline providing evidence for the topics presented
		- The documentation shall be delivered together with the corresponding release of the M&S and related produced data
		- The OEM shall provide clear reference that allows tracing the documentation to the corresponding M&S/data.
		- The documentation shall be maintained throughout the whole lifecycle of the M&S utilization
	+ ***Interdependences with VMAD SG1 and SG3.***
		- VMAD SG1’s developed scenarios are the input of the M&S toolchain
		- The credibility analysis can be exploited to support industry audit’s procedures established in VMAD SG3