International Alliance for Mobility Testing and Standardization™
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Test Platform Assignment for Automated Driving System (ADS)

Rationale

Safety argumentation for vehicles equipped with automated driving systems (ADS)[1] must be fed not only by the release of the vehicle, but also its software and electronics. The "optimal" test strategy and composition and combination of test methods for these software-centric vehicles should be based on specific test practices and platforms. This remains a major challenge in the automated driving industry.

To address this challenge, the International Alliance for Mobility Testing and Standardization (IAMTS) works in collaboration with its industry partners[2], of which TÜV SÜD is a founding member, to establish a directory of dedicated test platforms and road systems (public or private) that can be used for AV testing and certification worldwide.

This article aims to address this challenge in particular to the underlying and preceding topic of test case assignment strategy in the context of ADS verification and validation. It takes a look at current proposals in the ADS-Industry (PEGASUS, VVM, ISO 35402, ASAM) while not disregarding presumed best practices from the related ADAS-Industry (ADAS "Code of practice").

The article is also meant to shed light on the big picture of ADS strategy in the context of ADS regulations and how the assignment of test cases and preceding processes fits into the overall regulatory landscape of autonomous driving.

Preface

IAMTS is a global, membership-based association of organizations that are stakeholders in the testing, standardization, and certification of advanced mobility systems and services. IAMTS brings together testing consumers and providers at a global scale to help develop a commonly accepted framework of test scenarios, validation and certification methods, and terminology.

Our mission is to develop and grow an international portfolio of advanced mobility testbeds that meet the highest quality implementation and operational standards.

Our vision is to create a global community of advanced mobility testing service providers with companies, organizations, and agencies in need of such services; to learn, develop, and share best practices to ensure consistent, replicable, and reliable testing; to maintain a global directory of physical, virtual, and cyber-physical testbeds and support and promote their audited capabilities; and to promote the rapid evolution of standards and certifications to ensure the safe deployment of advanced mobility systems and services.

[1] SAE Level 3 to 5 according to SAE J3016
[2] Founded in 2018 [2]

1. Introduction

The information in this contributory paper has been compiled by TÜV SÜD, a founding member of IAMTS, at the request of the Korean Automobile Testing Research Institute (KATRI)[3]. KATRI fully supports the International Alliance for Mobility Testing and Standardization (IAMTS) in its activities for establishing a directory of dedicated test platforms and road systems (public or private) that can be used for testing of automated driving functions (ADS) and certification worldwide.

There are five Working Groups at the IAMTS [2]:

- WG1 – Global Test Library (Scenario Database)
- WG2 – Global Directory
- WG3 – Correlation of Physical and Simulation Testing
- WG4 – Cybersecurity
- WG5 – Connected & Automated Vehicle Lifecycle Compliance

WG1 deals with test scenarios and the creation of the associated test cases. WG2 focuses primarily on the actual database. WG3 deals with simulation tests and the necessary test automation in view of correlating between the virtual and the real world.WG4 addresses the topic of cyber security. Finally, the newly formed work group WG5 deals with regulatory compliance for ADS vehicles considering the whole lifecycle.

This paper focuses on assigning test cases to test platforms, a topic that resides within IAMTS primarily in WG1 with their work on test scenarios and test case selection. The paper may also lead into other topics such as defining performance metrics and ensuring test coverage. It also seeks to place the subject of test platform assignment in the overall context of the approval process for ADS-equipped vehicles in regulated countries such as Germany.

For further information on IAMTS, please refer to the "Acknowledgements" section.

[3] https://www.kotsa.or.kr/eng/road/safetyResearch.do?menuCode=03020000

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2. Context and Assumptions

Testing of Automated Driving Functions (ADS)[4], as opposed to Advanced Driver Assistance System[5] (ADAS), focuses heavily on the Safety of the Intended Functions (SOTIF, [10]) in complex driving environments, as noted by [15], where the emphasis is not so much on the mechanical performance of the vehicle, but on the automated driving capability. A safety assessment regarding driving capabilities is usually validated by mileage-based tests on the road. This can be very time-consuming and complex due to the almost unlimited number of traffic scenarios and could potentially involve high safety risks.

This requires a change in strategy with a strong focus on scenario-based rather than mileage-based testing. Scenario-based testing is a test practice (or technique) that lets you transfer data (e.g., recordings from real test drives) into the simulation test platforms (or environments) and hence perform thousands of tests of safety-critical and realistic driving scenarios with dedicated hardware and software conveniently as a simulation. Scenario-based testing primarily involves test automation which is typically used to generate target scenarios.

Test automation is a software testing technique with the practice of running tests automatically, managing test data, and utilizing results using automated testing software tools to improve quality. As noted in [15] test automation is typically used to create target scenarios that serve as the basis for validating ADS functions. Validation will again use X-in-the-loop simulation test platforms in combination with proving ground and public road test platforms to demonstrate safety, as recommended by PEGASUS [13].

This strategy for ADS testing is well established and is already reflected in the UNECE framework for New Assessment and Testing Methods (NATM) for ADS [10], as shown in Figure 1. Scenario-based test cases are generated from a Scenario Library, which then uses Simulation, Test Track and Real-World test platforms for the final validation of ADS. These three test platforms are three of six pillars of safety certification for ADS within the NATM Framework (for details see the “UNECE’s GRVA” appendix).

[4] SAE Level 0 to 2 according to SAE J3016
[5] SAE Level 3 to 5 according to SAE J3016

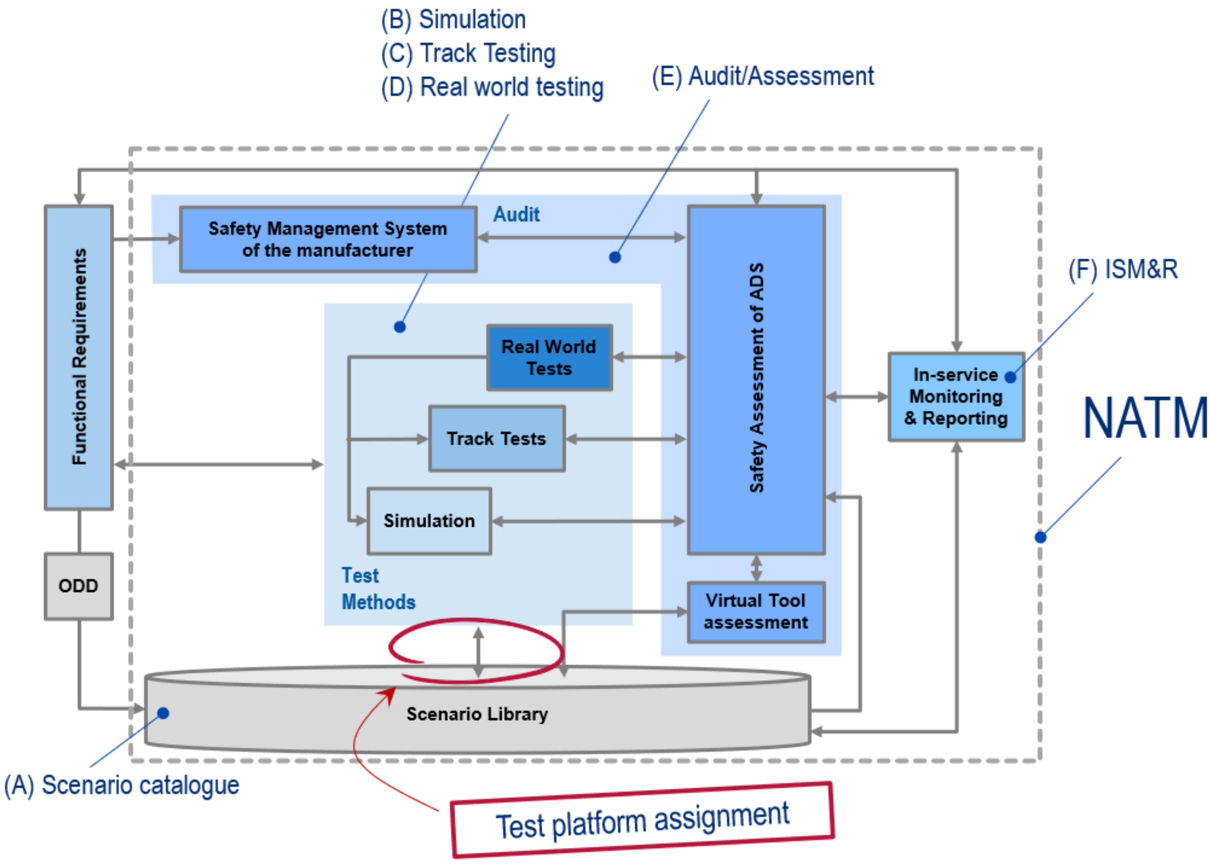

Figure 1: Test platform assignment in context of GRVA's NATM Six-Pillar approach [10]

Considering the framework, this paper will take a closer look at the interface between the Scenario and scenario generation Pillar (A) and the Test Methods block represented by the pillars (B), (C) and (D) as depicted in Figure 1. For scenario-based testing this interface specifies how a prioritized set of critical scenario-based test cases generated by (A) is assigned to the associated test platforms (B) and/or (C) and/or (D) based on a reasonable and traceable assignment strategy.

With respect to Pillar (A), this paper assumes an underlying state-of-the-art process for classifying and creating target scenarios. Each of these processes is explained in more detail in the next two chapters under "Assumption 1" and "Assumption 2".

Assumption 1: Classification of Target Scenario Test Cases

This contribution adopts the classification scheme for scenario-based test cases based on the proposal of the International Organization of Motor Vehicle Manufacturers (OICA) and the European Association of Automotive Suppliers (CLEPA) in their so-called ODD Framework [11] which has already been included in the EU Implementing Regulation for ADS [12] (Figure 2).

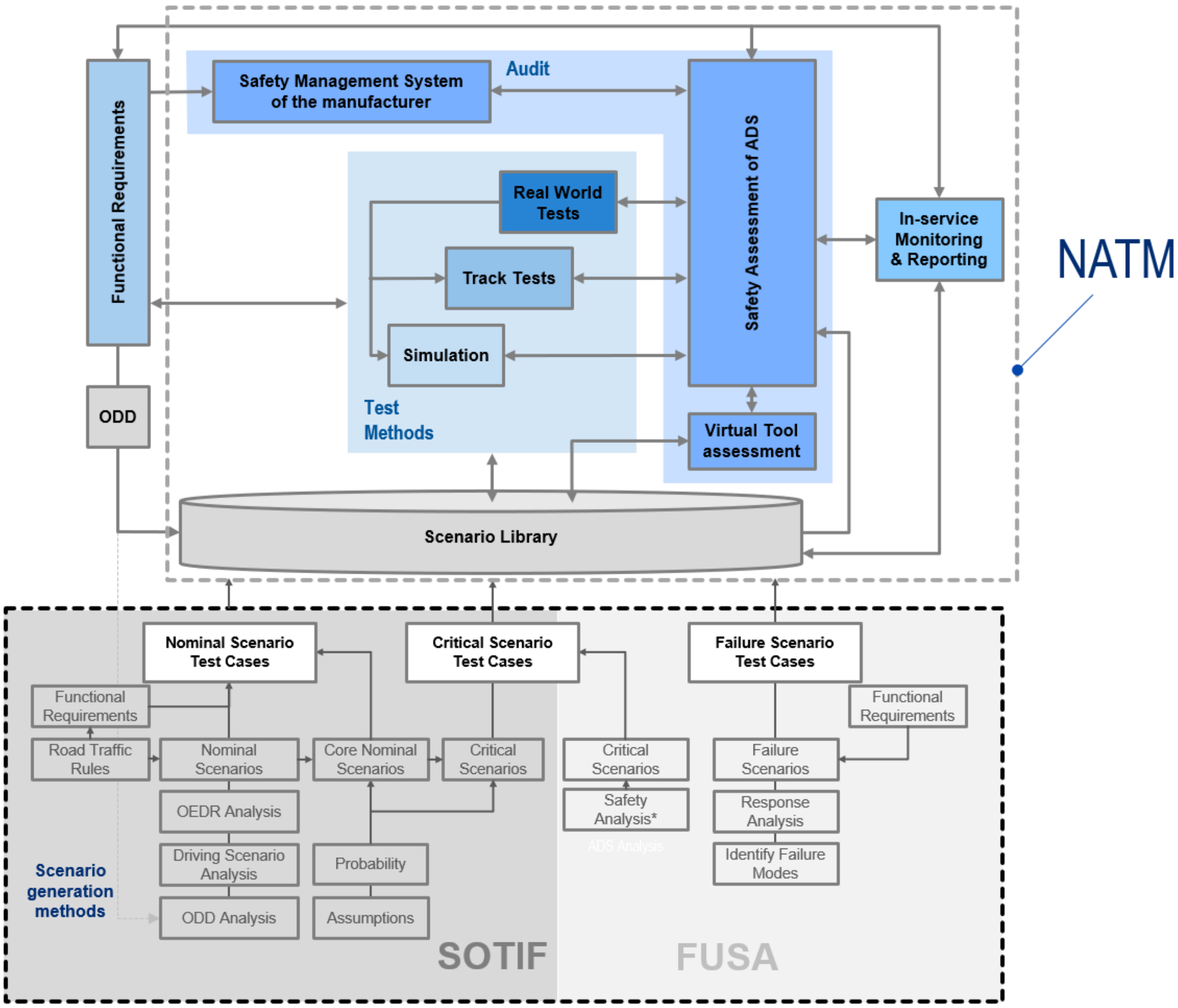

Figure 2: OICA/CLEPA "ODD-Framework" extension in NATM [11] [12]

The ODD-Framework distinguishes three types of scenario-based test cases:

- Nominal test case,
- Critical test case and
- Failure test case.

Nominal test case

Nominal scenario-based test cases are generated from the set of scenarios that are assumed to represent the intended domain of use or operation design domain (ODD) of the ADS feature, the so-called nominal traffic scenarios. Nominal traffic scenarios are reasonably foreseeable situations that the ADS encounters when operating within its ODD [12]. These scenarios represent the non-critical interactions of the ADS with other road users and result in normal operation of the ADS. Nominal scenarios are derived from the aforementioned ODD and the expected behavior competency[6] through analysis of a uniform categorization of driving code, ideally supplied by the EU's implementing regulation, and ADS Functional Requirements from Figure 2 [11].

Scenarios representing critical interactions of the ADS with other road users due to functional insufficiencies of the ADS or technical failure are covered by 'critical' and 'failure' scenario-based test cases respectively, which are discussed below.

[6] Behavior competencies may differ between highway, interurban, urban, and parking [11]

Critical test case

Critical scenario-based test cases are derived from critical scenarios that represent critical interactions of the ADS with other road users that are potentially ‘unsafe in use’ in terms of safety of intended function (SOTIF). These cases are not due to technical failure but are caused by functional inadequacy of the ADS feature[7]. Critical scenarios refer to the boundary conditions of the nominal traffic scenarios with unexpected conditions with exceptionally low probability of occurrence (edge cases) or unexpected conditions with two or more operational parameters that are at extreme values (corner cases).

Critical scenarios also refer to operational insufficiencies and are not limited to traffic conditions. They also include environmental conditions (e.g., heavy rain or low sunlight that blinds cameras), human factors, connectivity, and miscommunication that result in emergency operation of the ADS. Critical scenarios correspond to emergency operation of the ADS [12].

Failure test case

Failure scenario-based test cases are derived from failure scenarios. In contrast to critical scenarios, failure scenarios are due to technical failure, assuming that the intended function is safe in terms of SOTIF[8].

Scenarios can be data-based (DbS), such as accident data, or real driving data and/or knowledge-based (KbS) like knowledge from hazard analyses.

While nominal test cases provide evidence that the ADS performs the driving task independently within the respective operating range and complies with the traffic rules, critical and failure test cases serve to demonstrate that the ADS performs the required maneuvers with minimal risk to reach a minimal risk condition.

The ODD framework presented in Figure 2 also describes the elements (analyses and data) needed to create the three different classes of test cases. However, it does not show what a possible execution might look like. The next section provides some insight into this subject and assumes a best practice solution as second assumption.

Assumption 2: Process of Test Case Generation

This contribution assumes a current state of the art in generating prioritized scenario-based test cases for ADS as developed by PEGASUS [13] and VVM [14], considering best practice for test automation [15] and software engineering [8] (see Figure 3).

The result of this process is a prioritized set of test cases reflecting the target scenarios, which are assigned to test platforms for validation purposes.

[7] Example: using camera technology for foggy conditions.
[8] Example: camera shuts down due to internal power supply fault (in non-foggy conditions)

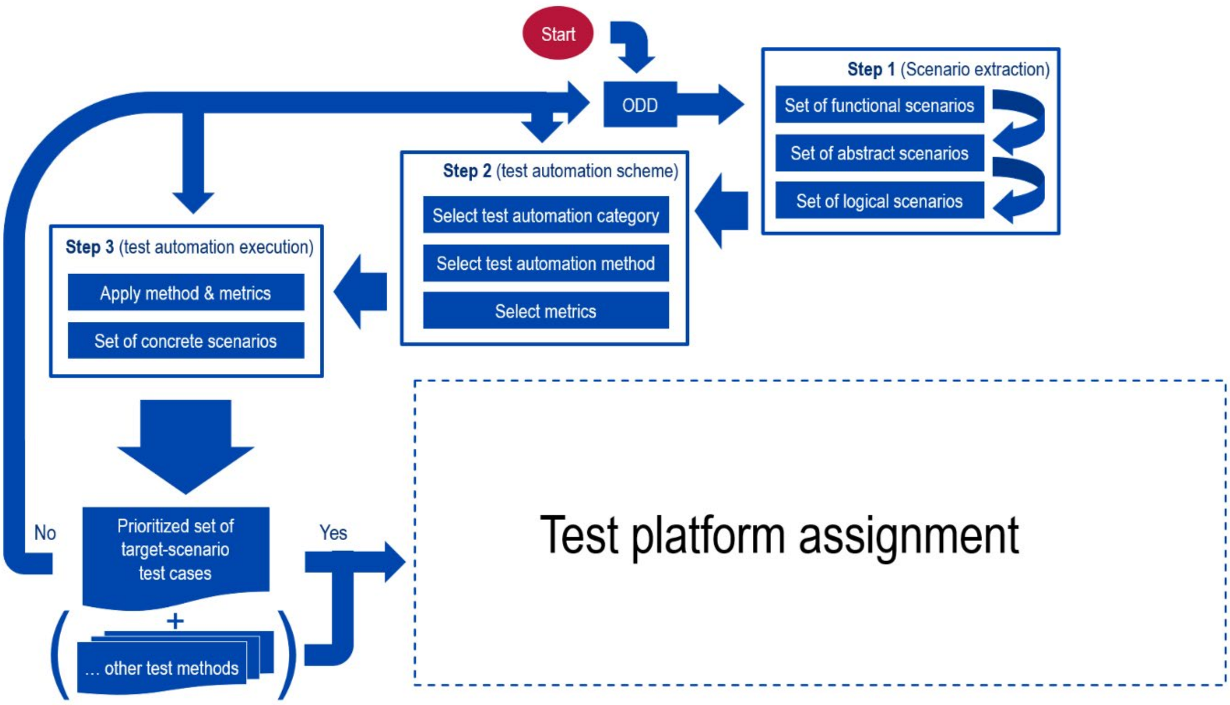

Figure 3: Process of scenario generation that precedes the test platform assignment

There are three steps in this process. In Step 1, the scenarios are extracted from the planned ODD (Start) and prepared for execution. In Step 2, the required automation methods and performance and criticality metrics are determined. In Step 3, test automation is executed based on the selected test automation scheme and metrics. The process ends with a prioritized set of test cases for the target scenario, as shown in Figure 3. Each of these steps is described in more detail below.

Scenario Extraction

This process starts by identifying the set of functional target scenarios related to the ADS feature that are representative of the ODD, in which the vehicle will be deployed.

Overall the following levels of abstraction for scenarios from [14] are considered, as shown in Figure 4.

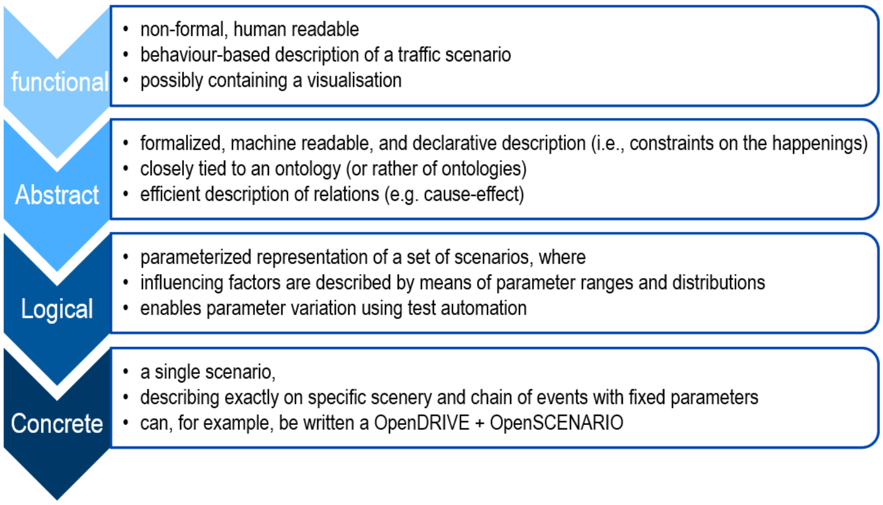

Figure 4: Overview of the different Scenario qualification levels [14]

Considering the ODD, the associated set of functional scenarios[9] is defined[10], which are then made machine-readable (aka abstract scenarios) and subsequently made testable by defining parameters for each abstract scenario[11]. The outcome is a set of logical scenarios (Step 1 in Figure 3).

If the manufacturer has limited resources or time to test all of the planned ADS features, the ODD can be limited at this stage to those feature that can be tested and deployed.

Test Automation Selection

In Step 2 of Figure 3, the test automation method is selected for finding the concrete target scenarios based on the test purpose, the test size of the ODD, the test resources, or the test stage using the workflow diagram in [15] as shown in figure below.

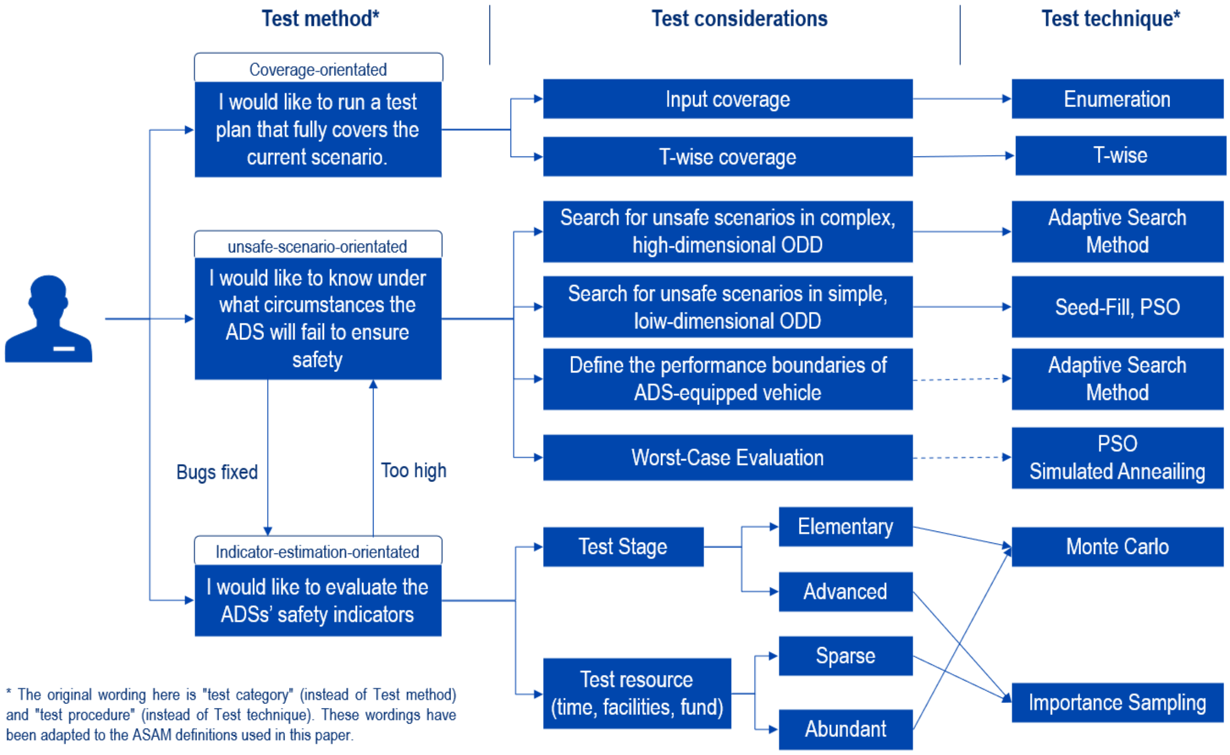

Figure 5: Choosing the most appropriate test automation methods [15]

The purpose of the test could be to create a test plan that fully covers the current scenario library of logical scenarios of the ADS-equipped vehicles (coverage-orientated test category), or to look for circumstances in which the ADS does not ensure safety (unsafe-scenario-orientated test category[12]), or to evaluate its safety indicators (indicator-estimation-oriented test category). The test ODD size can be 'simple, low-dimensional' or 'complex, high dimensional'. The test stage can be 'elementary' or 'advanced'. The test resources regarding time, facilities and or fund can be 'sparse' or 'abundant'. For further details, please refer to [15].

[9] VVM [14] designates four distinct categories of scenarios. These are the so-called functional, abstract, logical, and concrete scenarios. The level of detail increases, as described in [18], starting with a verbal description of the functional scenarios, further to the machine readability of abstract scenarios, then the logical scenarios which are described by parameter ranges and distributions, up to the concrete scenarios which are described by exact parameter values.

[10] e.g. cut-in on highway or left turn on intersection in urban area

[11] e.g. speed of ADS vehicle, V_{ADS} = {20 …. 60kph}

[12] also known as critical scenarios or hazardous scenarios. [15] defines four types of unsafe scenarios in this category: (1) high-risk scenarios which are scenarios that require emergency operations such as large decelerations and steering, or near-collision scenarios, (2) boundary scenarios which are scenarios between the safe and unsafe domains in an ODD, (3) collision scenarios, where the range between the vehicles is zero or negative and (4) worst-case scenarios, which are extremely unsafe scenarios for the ADS-equipped vehicle in a certain ODD. As a side note, it is for the high-risk type of unsafe scenarios where the risk metric (collision yes/no and possibly considering severity) and appropriate criticality metrics (TTC, WTTC, etc.) are applied.

Test Automation Execution

In Step 3 of Figure 3, the selected test automation method is applied to a virtual test platform according to the test consideration selected in Step 2. The parameter values of each logical scenario are varied and the metrics to obtain a prioritized set of target scenarios, for which associated test cases can be derived.

The above is the result of the scenario catalogue pillar (A). For the resulting target scenarios, the manufacturer must later demonstrate that its planned ADS function is capable of handling and controlling them in a safe manner. As mentioned at the beginning, the test platforms simulation, test track and real world are available for this purpose.

It should be noted, that the terminology “scenario class” in assumption 1 and “test category” in assumption 2 are related in a way that each scenario class (Figure 3) can be assigned to at least one test automation test category (Figure 5). Thus, nominal scenarios fall into the category of coverage-oriented tests, while critical and failure test cases would fall into the category of unsafe-scenario-orientated tests and presumably indicator-estimation-oriented tests.

3. Test Platform Assignment for ADS

Based on the assumptions of the scenario generation process and the scenario-based classification scheme of the target scenario test cases presented in the previous section, it becomes clear that the same test automation approach to deriving target scenarios is key to validating ADSs against meeting them.

Both PEGASUS’s “Test Concept” [13] and VVM’s "Test Orchestration to Distribute Scenario-Based Test Cases to Test Instances" [14] suggest validating the ADS function in simulation through parameter variation and, in turn, using test tracks to validate the simulation. (For more information, see the “PEGASUS” appendix in this document).

The ISO 3450x series of standards addresses the topic of test assignment with a corresponding set of requirements (Chapter 4.4.4.2, [19]), however, it does not provide best practice examples (for more information, see the “ISO 34502” appendix in this document).

The allocation of test platforms for conventional ADAS vehicles was also considered by reviewing the ACEA’s ADAS[13] Code of Practice (CoP, [17]). Unfortunately, the CoP is silent on the topic of assignment strategy and 'only' lists the advantages and disadvantages of individual test platforms (For more information, see the “ADAS Code of Practice” appendix in this document).

All three contributions agree on the subject of simulation integrity and the need for mandatory accompanying validation of the simulation environment (concept, tools and model). As a result, the concept of performing non-critical[14] scenario-based tests on the test platform of a test track with real vehicles for the purpose of validating the simulation has been proposed[15], as initially suggested by PEGASUS.

ASAM's "Test Specification Study Group Report 2022" [6] as another contribution also refers to this topic in its section “The Trustworthiness of Test Environments”. It even includes a breakdown of the different integrity measures namely Tool Qualification, Model Validation, Test Environment Adequacy and Fit-for-Purpose Checks.

It turns out that this report has proven to be very helpful with respect to the core topic of this document, the assignment of test platforms. First and foremost, it provides a holistic approach to the necessary test procedures for ADS. In addition to covering scenario-based testing, it also refers to various other test practices and platforms required for data-driven development of software-centric applications such as ADAS and ADS. The associated process flow is presented in Figure 6.

[13] SAE Level 0 to 2 according to SAE J3016, i.e., not ADS
[14] i.e., no critical or failure scenarios of unsafe scenario type “collision scenario” or “worst-case scenario” according to assumption 1 and 2
[15] as also quoted in [8], step 14 […] Scenario-based testing on proving grounds generates supporting points used to verify simulation results […].

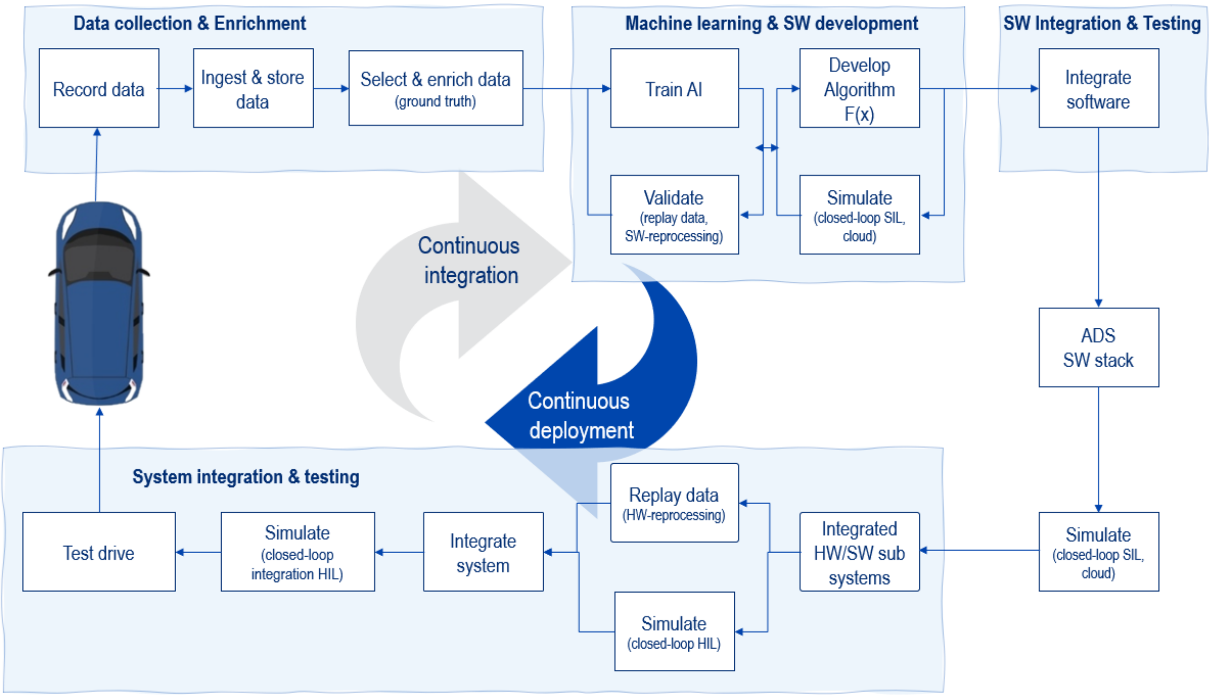

Figure 6: ASAM's generic data driven development process (such as for ADAS/AD) [6]

This process flow chart demonstrates how a safety argumentation for a software-centric vehicle such as ADAS/ADS must be supplied by both the release of the vehicle and also its software and electronics.

As a result, the group designed a new test strategy concept, the so called "test strategy blueprint", as shown in Figure 7, pointing out that it complies with safety standards, established best practices and important norms.

Test platform/-environment / Test practice/ -technique	MODEL IN-THE-LOOP (MIL)	SOFTWARE REPROCESSING (SW-DR)	CLOSED-LOOP SW IN-THE-LOOP (SIL)	HARDWARE REPROCESSING (HW- DR)	CLOSED-LOOP HW IN-THE-LOOP (HIL)	VEHICLE-IN-THE-LOOP (VIL)	DRIVER-IN-THE-LOOP (DIL)	PROVING GROUND	OPEN ROAD TESTING FIELD MONITORING
REQUIREMENTS-BASED TEST (RBT)	RBT for verification of functionality (Model only)	RBT for verification of functionality via open loop	RBT for verification of functionality (SW only)		RBT for verification of SW-/HW integration (closed loop)	RBT for verification of vehicle integration		Testing in a controlled proving ground environment	Testing of the ADAS/ADS functions under real-life use cases in the field
INTERFACE TEST (INT)			INT for verification of Software integration	INT for verification of functionality (incl. HW)	INT for verification of Higher-level integration	Testing of complete ADAS/ADS effect chain on system level			
FAULT INJECTION (FIT)	FIT for verification of safety mechanisms (Model only)	FIT for Evaluation of robustness	FIT for verification of safety mechanisms, (SW only)	FIT for verification of safety mechanisms (incl. HW)	FIT for verification of safety mechanisms (with integrated systems)		FIT for Validation of the overall system behaviour	FIT for Verification of the overall system performance	
RESOURCE USAGE PERFORMANCE TEST					Testing of the vehicle network performance				
SCENARIO-BASED TEST (SBT)	SBT for Validation of control components		SBT for validation of SW (closed loop)		SBT for validation of electronics integration	SBT for validation of SW on system level	SBT for validation of driver / system interaction (HMI)	SBT for validation of ADS on vehicle level (controlled environment)	SBT for validation of ADS on vehicle level (non-controlled environment)

Figure 7: ASAMs test data management concentric test strategy concept for software-centric development [6]

The blueprint is a testing matrix that provides an overview of generic test methods for software-centric vehicles such as ADAS/ADS, which are essentially a combination of test practices (or techniques) and test platforms (or environments). The blueprint points out that these test methods are an acceptable combination to meet the test coverage for a software-centric vehicle, claiming to be sufficient for release and approval [6].

The term test method is used here following the American Society for Testing and Materials and refers to “a procedure”, defining it as […] *any procedure that fulfils test goals and defines, for example, applicable test techniques or practices as a part of this specific method […].*

Following this idea, requirements-based testing, for example, is a test practice but not an actual test method.

Accordingly, a test method (or test procedure) is considered to be an interaction of a dedicated test practice, test platform, test level and applicable procedure as presented in [6] and summarized in Table 1.

Table 1: Components of a test method according to ASAM [6]

Test Method “Ingredients”	**Description**
Test Practice	▪ requirements-based testing ▪ scenario-based testing ▪ model-based testing ▪ equivalence partitioning ▪ state-based testing ▪ fault injection testing
Test Platform[16]	▪ HIL ▪ SIL ▪ MIL ▪ VIL ▪ DIL ▪ Proving ground ▪ Open road
Test Level	▪ system test level ▪ integration test level
Applicable procedures/processes	▪ post-processing ▪ risk assessment

A test method always requires a specific test goal. The test goal can be achieved with a single test method, i.e., a combination of test practices/platforms/integration levels/applicable procedures whereas a different test goal may require multiple test methods, i.e., a combination of combinations of test practices/platforms/integration levels/applicable procedures. This is exemplified in Figure 8 using “coverage-orientated target scenario-based test cases” test method from Figure 5[17].

[16] “Test environment” in ASAM
[17] is provided "as is", with no guarantee of completeness or accuracy

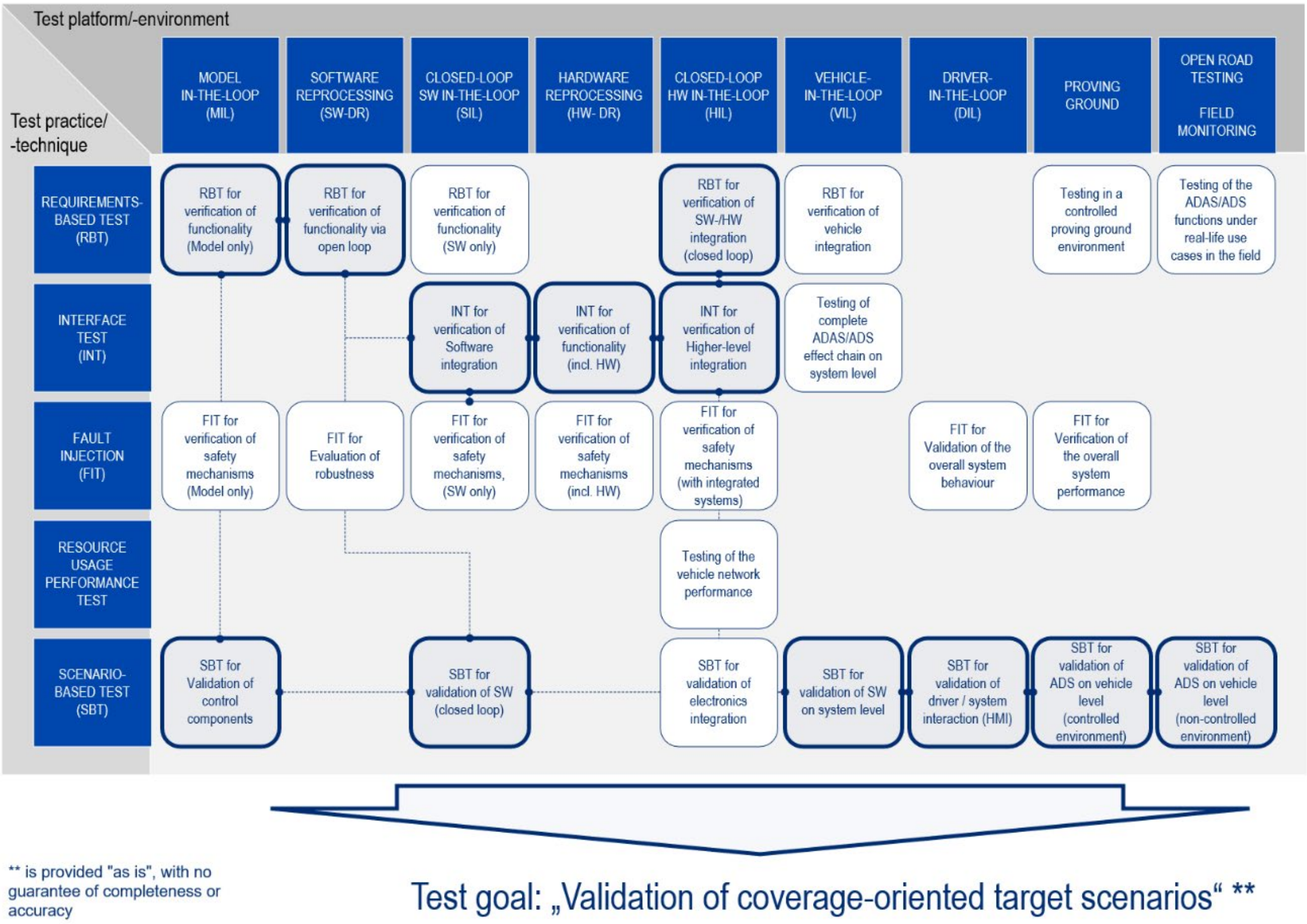

Figure 8: Test goal vs. Test method(s) (exemplary)

The test methods of the blueprint are mapped to the ADAS/ADS development process from Figure 6 (blue boxes), taking into account the industry-accepted Software Process Improvement and Capability dEtermination Assessment Framework (ASPICE[18], grey boxes). This mapping indeed seems to confirm the above claim that its blueprint meets state of the art.

[18] also known as ISO/IEC 15504 or SPICE, is a software process assessment framework developed in 1993 by ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission). Its goal is to evaluate development factors that enable assessors to determine an organization's ability to deliver software products effectively and reliably. ASPICE, or Automotive SPICE, applies this framework to the automotive industry, which has its own critical requirements.

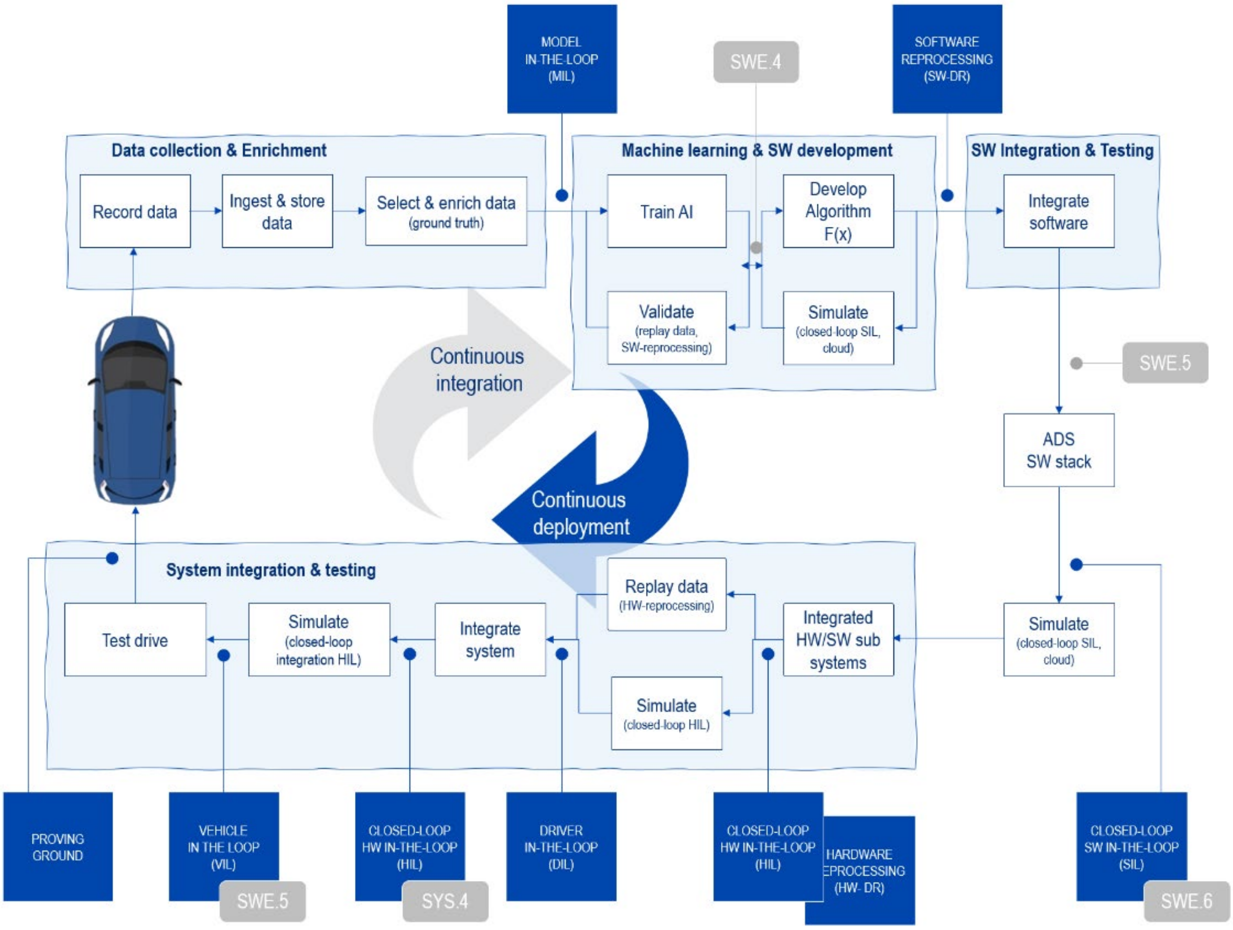

Figure 9: ASAM's mapping of the test strategy blueprint to the generic development process for ADAS/ADS considering ASPICE [6]

Based on research application examples of test methods[19] and associated artifacts[20] and taking into account the aspect of test data management the group then developed a potential ADAS/ADS specific use case called "ADAS/ADS domain" model as shown in Figure 10. It is the abstract model for proper test data management for the ADAS/ADS domain.

[19] these are the so called "use cases" in the report, some of which are sumarized in the "ASAM" appendix)
[20] e.g. necessary input, output, information to assist the test preperation

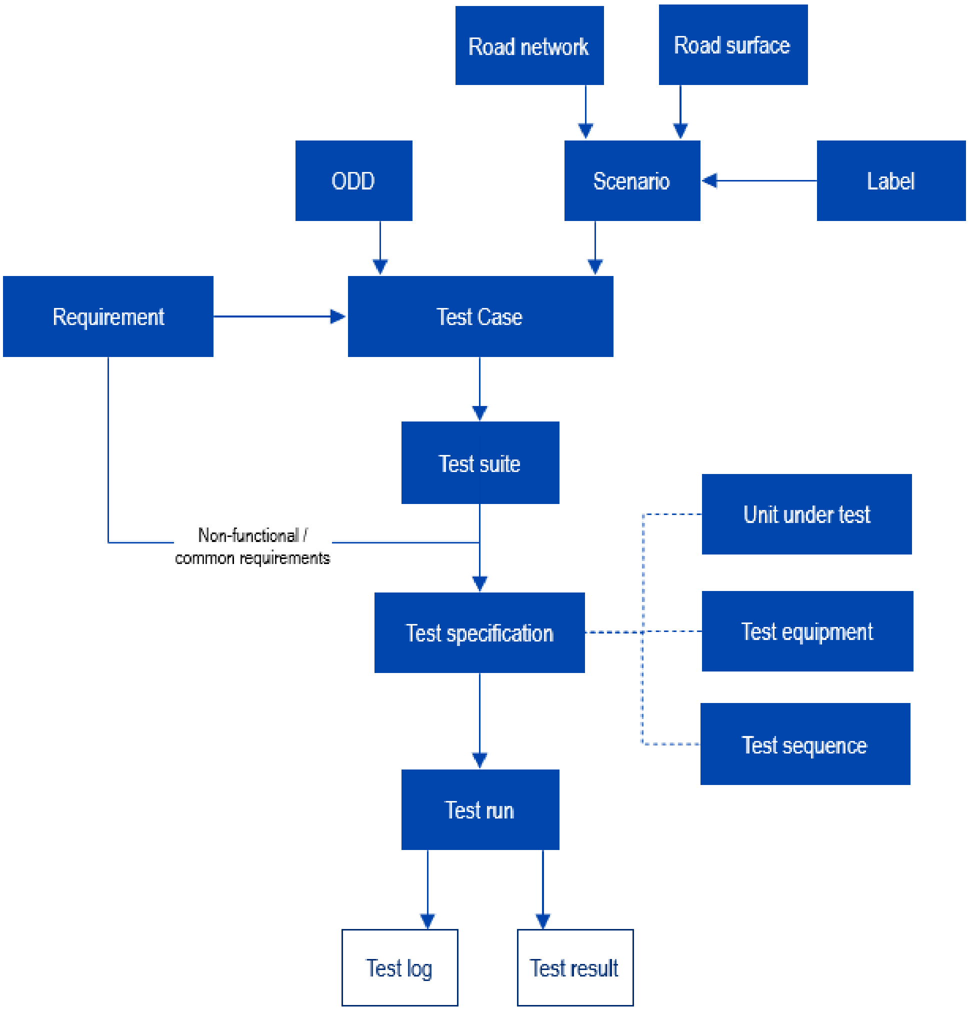

Figure 10: Graphical Display of ASAM's abstract test data management model for the ADAS/ADS domain [6]

The model represents a concrete testing workflow for a uniform test and data management with related artifacts specifically related to the ADAS/ADS domain use case. It also assumes that the test specifications are derived from the requirements.

The terms in this workflow are grouped according to their relation to one another. Artifacts of the workflow are marked as blue boxes, while the information needed to (re)perform a test run is shown as white boxes (see [6] for more details).

Although the ASAM report [6] generally focuses on the test data management and data modelling aspects of ADAS/ADS function development, they intend that the above proposed test strategy outline[21] serve as an overarching domain model and a basis for more advanced modelling in future standardization efforts.

The author highly recommends using this test strategy as a basis for assigning test cases to test platforms. No other contribution is as holistic as this one when it comes to the required test procedures, especially for ADAS/ADS, considering early phases of testing through to the open road. Furthermore, the outline was not randomly conceived, but was carefully, systematically and comprehensively derived from classic state of the art methods. It was already quite feasible given the fact that data-driven management was at the forefront of this outline, one of the biggest challenges of such software-centric developments.

[21] consisting of the generic test strategy blueprint, the generic ADS development process and generic ADS-domain data management model

4. Relevance for IAMTS

The main objective of IAMTS is to establish a database where test facilities are registered and their capabilities are described in a standardized way, including quality criteria for test benches, which could then form the basis for an audit and certification process [1].

As already mentioned in the introduction, there are five groups (WG) at the IAMTS:

- WG1 – Global Test Scenario Library
- WG2 – Global Advanced Mobility Testbeds
- WG3 – Correlation of Physical and Simulation Testing
- WG4 – Cybersecurity Testing
- WG5 – CAV Lifecycle Compliance

As a reminder, WG1 deals with test scenarios, WG2 includes the database for global testbeds and open test areas, WG3 incorporates simulation testing and associated correlation with physical testing, WG4 incorporates cyber security considerations and WG5 involves regulatory compliance for ADS vehicles considering the whole lifecycle (for more information, see the "IAMTS" acknowledgements).

The author believes that this contribution is primarily relevant to three IAMTS groups, namely WG1, WG2 and WG5. There are, however, also aspects that are applicable in general to IAMTS as a whole. All aspects that contribute are presented in the following.

Contribution in general

- The term differentiations of test method (or -procedure) vs. test practice (or -technique) vs. test platform (or -environment) from ASAM and adopted here may help IAMTS challenge its own glossary.
- Create general awareness and transparency:
    - Potentially help IAMTS place the groups in the context of the overall regulatory framework for ADS using Figure 2.
    - Placing the IAMTS groups in the context of an ADS test strategy with the ASAM outline containing the generic ADS test strategy blueprint, the generic ADS development process and generic working model for testing in the ADS-domain.
    - Understanding the relationship between the regulatory framework for ADS and the implementation of this framework in relation to test case creation and assignment.

Possible Contribution for WG1

- In its effort to develop scenarios for vehicle testing, WG1 must start from a predefined scenario generation process that corresponds to the state of the art. Here, it can draw on the described three step test case generation process in Assumption 2, described earlier and reflected by the dashed frame in Figure 11.

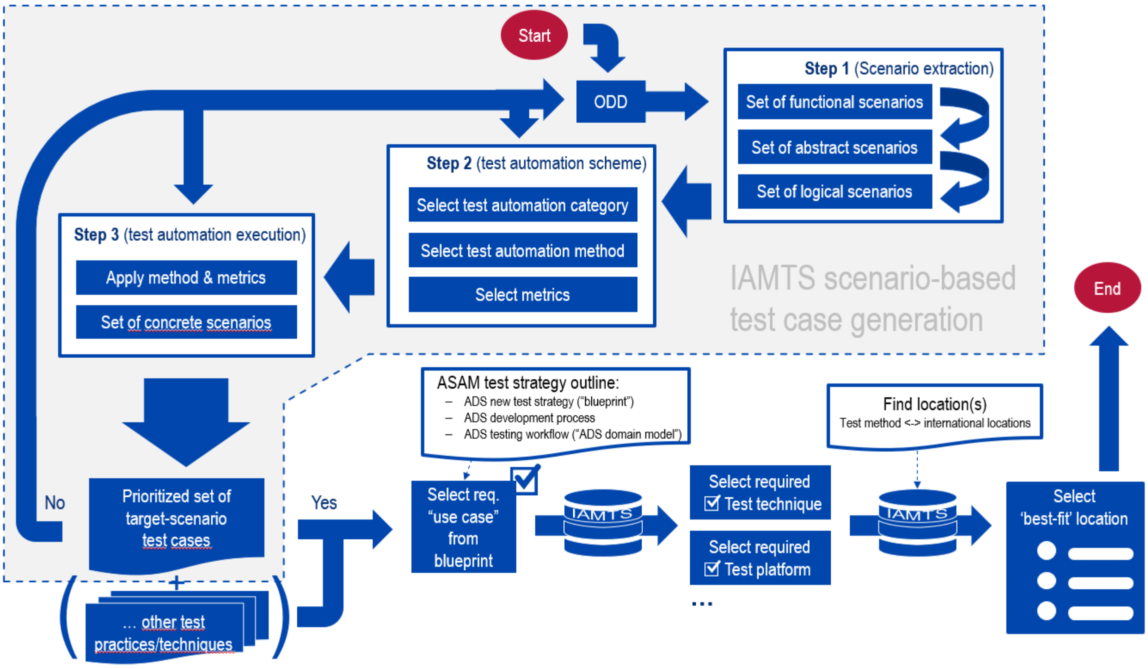

Figure 11: Test practice of scenario-based test case generation and test platform assignment

- The goal of IAMTS is to have its results used by both the automotive industry but also by regulatory authorities, therefore, its proposals and results should ideally be in line with the underlying homologation process for ADS. Here, the NATM classification proposal for target scenarios (assumption 1) and its correlation with the test automation scheme for the scenario-based testing technique (assumption 2, step 2) and the context to "all" other testing techniques (ASAM test strategy outline[22]) can be useful.
- The use of the ASAM test strategy outline places the scenario-based test technique, which is a strong focus of WG1, in the context of the overall test strategy, but at the same time reminds the user of the need for holism[23]. This means that the required safety argument may involve more than "just" the scenario-based test technique. Even if one were to argue with only one test technique, one would still have to justify why all other test techniques and combined test platforms are not relevant to one's use case. The associated argumentation based on this outline could strengthen the argument of completeness.

Possible Contribution for WG2

- In working to create a database for global test sites and open test areas in WG2, expanding the DB to include more or even the "full" set of test techniques and test platforms could lead to better visibility of IAMTS in the ADS industry utilizing the ASAM test strategy blueprint as shown in Figure 12.

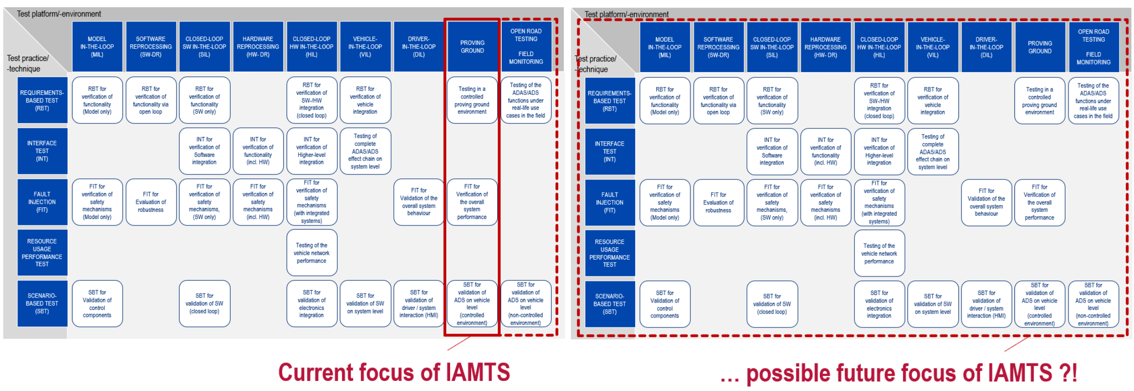

Figure 12: Conceivable IAMTS scope expansion

[22] consisting of (a) the generic ADS test strategy design ("blueprint"), (b) the generic ADS development process and (c) the generic ADS domain model ("workflow")
[23] As pointed out in the report [6] current test strategies are often heterogeneous and have grown over several vehicle generations. For ADS development, these must be considered holistically and also used for vehicle approval.

- The main goal is that the IAMTS DB would not only provide test site test platforms to DB users but would also incorporate all other types of test platforms and test techniques, and would output the most appropriate site(s) to the user based on the selected test methods and/or use cases using the ASAM test strategy design for ADS to meet their needs as depicted in Figure 13.

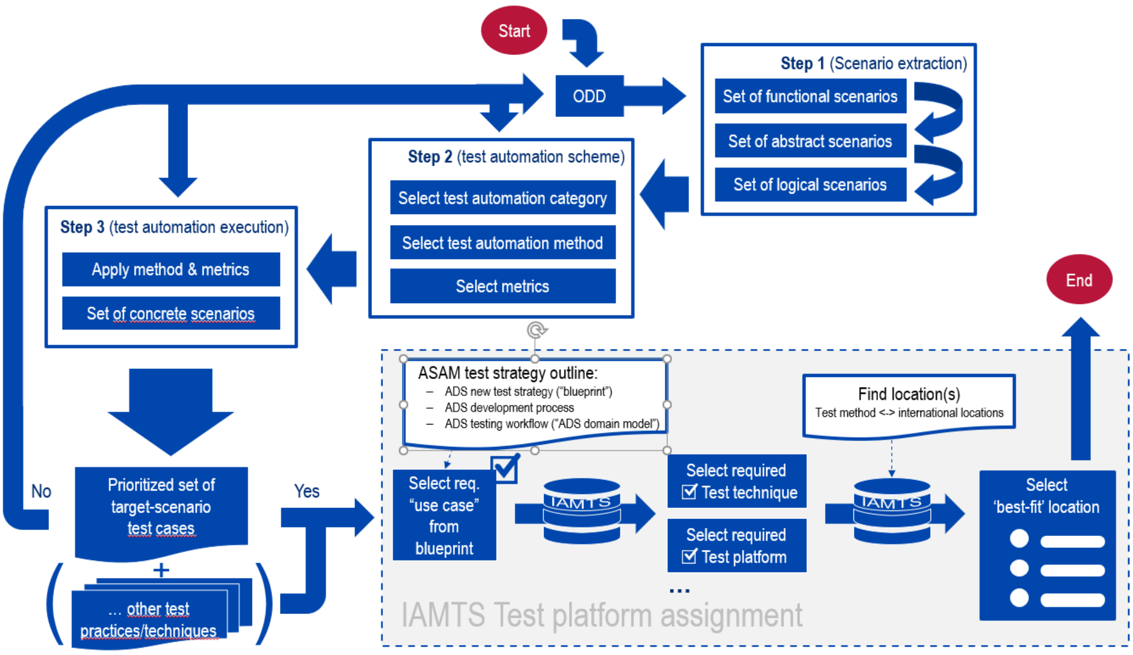

Figure 13: Extending the scope of the IAMTS DB to other test methods and test platforms.

Possible Contribution for WG5

- Since WG5 focuses primarily on the topic of regulatory compliance for ADS vehicles considering the whole lifecycle, the relationships presented between ADS regulations, ADS test strategy with its key elements of a generic test strategy design (ASAM "blueprint") containing in particular details on the test technique of scenario-based testing required for ADS and a generic ADS development process and a generic ADS testing workflow ("ADS domain model") could be helpful. The relationships are shown again graphically in Figure 14.

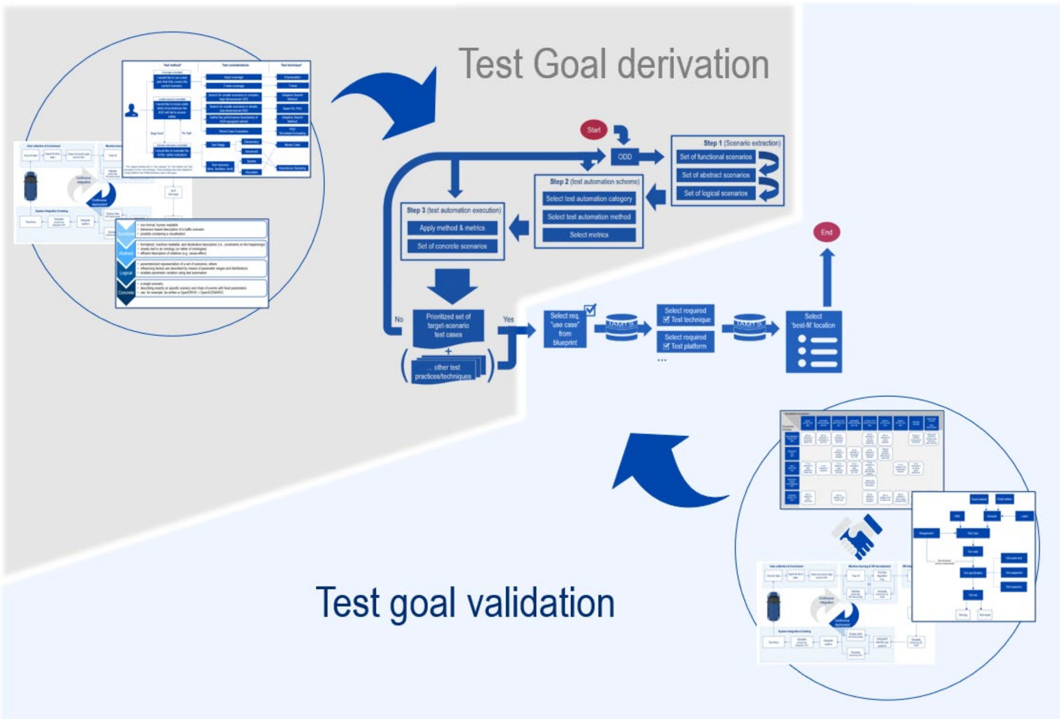

Figure 14: Attempt to show the overall relationship

- In the long term, WG5 could consider certification of other or even all other test platforms as well as the associated test practices, e.g. in the context of tool qualification.

5. Conclusion

This article presents an overall and long-term view of ADS strategy in the context of ADS regulations and, in particular, how the assignment of test cases fits into the overall regulatory landscape of automated driving.

Assumptions about the preceding process of test case creation based on the state of the art were also presented, with a particular focus on the state of the art of test automation for the creation of target scenarios in scenario-based testing practice.

The contribution also provided some insight into the composition and combination of test procedures/methods for ADS vehicles based on state of the art. By harvesting the content of the ASAM Test Specification Study Group, it processed results relevant to the topic of test platform assignment in a way that may be useful to IAMTS, particularly the WG1, WG2 and WG5, and their efforts to standardize mobility testing.

6. Appendix

ADAS "Code of Practice" ... about test platform assignment

In its section "Final proof of controllability by a test with naïve subjects" in chapter 4.2 of [17], the ADAS Code of Practice (CoP) argues, based on practical testing experience, that tests with naïve subjects with a number of 20 valid records per scenario can provide a basic indication of validity of the test. Naïve in this context means that the test subjects have no more experience or prior knowledge of the system than a subsequent customer.

The test scenario is "passed" if the subject responds as expected beforehand, or in a reasonable way to control the situation. A controllability level of C2[24] for a scenario can be claimed, if all 20 out of 20 valid data sets meet the pass criteria.

At this point it is stated that a decision must be made about the test platform: test on public roads, test on a test site or test in a simulator. Unfortunately, there is no indication of an assignment strategy.

The advantages and disadvantages of the different test platforms are provided and compared as demonstrated in Figure 15 (Annex B and D of [17])

	Advantages	Disadvantages
On-the-road-trials	• realistic environment • normal driving behaviour • high validity of results	• difficult to create and instrument • costly and time consuming • not fully controlled • potentially less safe, provoking of risk situations and failure states (fault injection) is often too unsafe
Test track trials	• allows testing of (simulated) potentially hazardous • situations • fault injection possible • control of influencing variables (Reliability) • safer than on-the-road trials, although an • element of risk is still involved	• artificial situation • no routine driving behaviour • difficult to create and instrument • expensive particularly if traffic conditions are to be simulated

Figure 15: ADAS "Code of Practice", Annex B.2 [17]

PEGASUS ... about test platform assignment

According to PEGASUS [8], in the test platform assignment strategy for validating the ADS feature, the identified critical test cases from the scenario generation process[25] mentioned in the introduction are first all assigned to a single, virtual test platform.

Here these critical concrete scenarios are evaluated according to a pass/fail criteria[26]. So called "interesting" or critical cases (i.e. not fulfilled or close fulfilled pass-criteria in simulation) are additionally validated on another test platform of a test track with real vehicles. For the not fulfilled critical cases the need for soft crash targets is pointed out. Unfortunately, it is not clear why these are necessary and how they come about.

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[24] which means that more than 85% of the average drivers or other traffic participants are generally able to control the damage

[25] In PEGASUS, the technique to vary the parameters values to determine critical concrete scenarios is called automated/stochastic variation of the logical scenarios' parameters.

[26] Note: the project has not established pass/fail thresholds as such, only the need to have them.

In addition, manually selected concrete test cases are also evaluated on the test platform of a test track with real vehicles (i.e. test according to ECE R79 [20] or evaluation tests).

PEGASUS points out the challenge of modelling, i.e., validating the simulation environment, and that this challenge must be overcome. For this purpose, PEGASUS proposed the concept of performing non-critical scenario-based tests[27] on the testing platform of a test track with real vehicles for the purpose of validating the simulation[28].

Other than the above, the author is not aware of any other PEGASUS decision processes for assigning and dedicating test cases to test platforms.

The focus of PEGASUS is on the test platform of virtual testing (simulation) and the associated derivation of the critical scenarios that represent the ODD of the ADS (representative scenarios). The use of a test platform within a test track to validate the simulation is introduced for the first time in PEGASUS. However, it is not explained in detail.

VVM … about test platform assignment

In the Verification and Validation Methods (VVM) project, the distribution of scenario-based test cases to the test platforms[29] is performed as part of the so-called test orchestration [9].

VVM test defines three classes of test platforms, “Simulation”, “Bench” and “Vehicle” (proving ground and/or in-field), as shown in Figure 16.

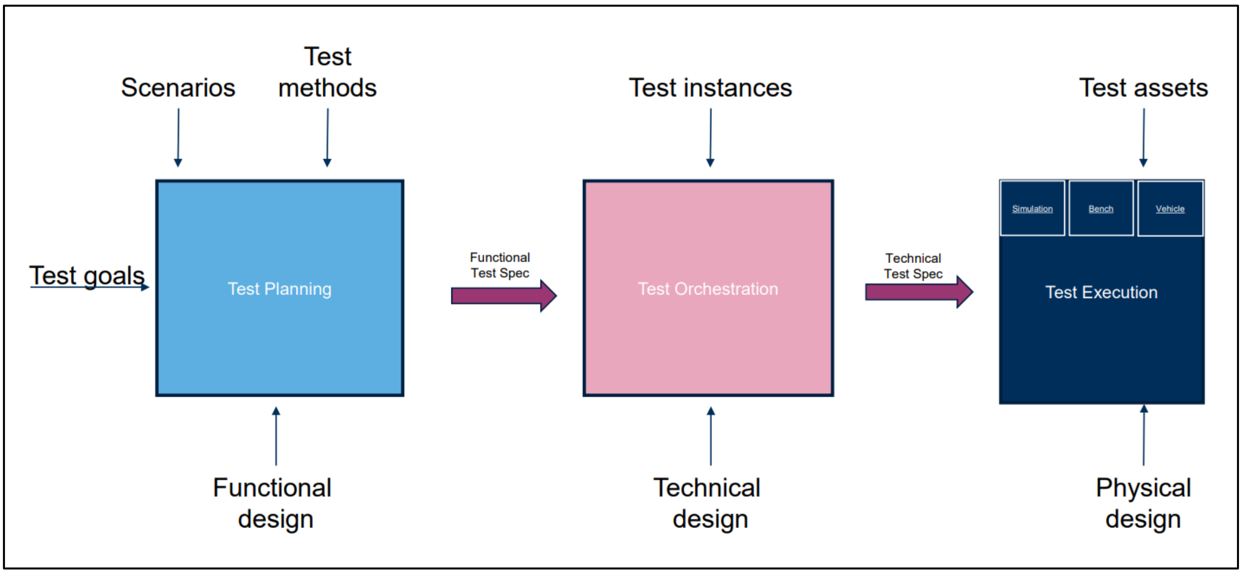

Figure 16: VVM test orchestration in the context of V&V [9]

A key issue in test orchestration, in addition to defining quality criteria and metrics for the individual subsystems and components and ensuring evidence for the safety argument, is to select test platforms.

The following points are considered when selecting the test platforms:

- Test coverage
- Suitability of the test instances
- Validity of the test instances
- Efficiency

Unfortunately, no further details on this topic are available yet, such as which test to prioritize, what the pass/fail criteria are, or what the decision process is for retakes, etc. However, VVM works on the concept of creating test platforms in

[27] test that does not lead to a crash according to simulation results
[28] as quoted in [8], step 14 […] Scenario-based testing on proving grounds generates supporting points used to verify simulation results […].
[29] referred to as ‘test instances’ in VVM

“Simulation” and “Vehicle” that complement each other ("seamless tests"), which requires the generation and development of comparable and mergeable (aggregable) test results.

Figure 17 shows the associated process where the same test cases are performed both on the “Vehicle” and the “Simulation” test platform using the same parametrization and test description for both test platform, where the scenario is subsequently evaluated by comparing the results.

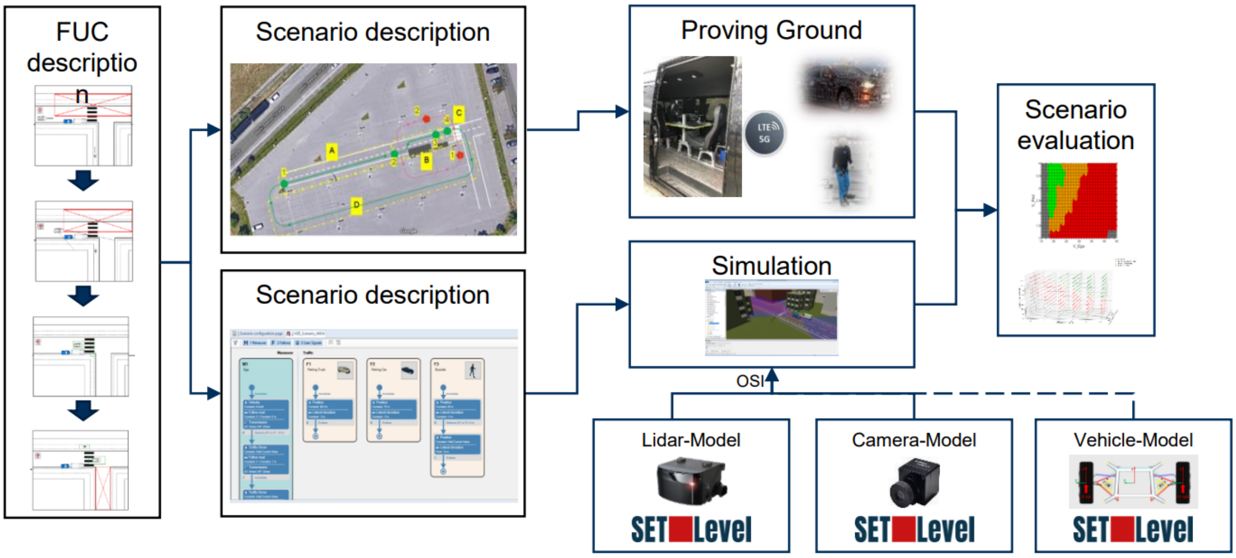

Figure 17: VVM towards seamless testing [9]

VVM is currently working on criteria for the evaluation of test platforms, which will certainly be helpful in the decision-making process for assigning test cases to test platforms as shown in Figure 18. VVM is still under development. It is expected that by completion of the project (end of 2023) more details about the decision-making process accompanied by examples will be developed and made available.

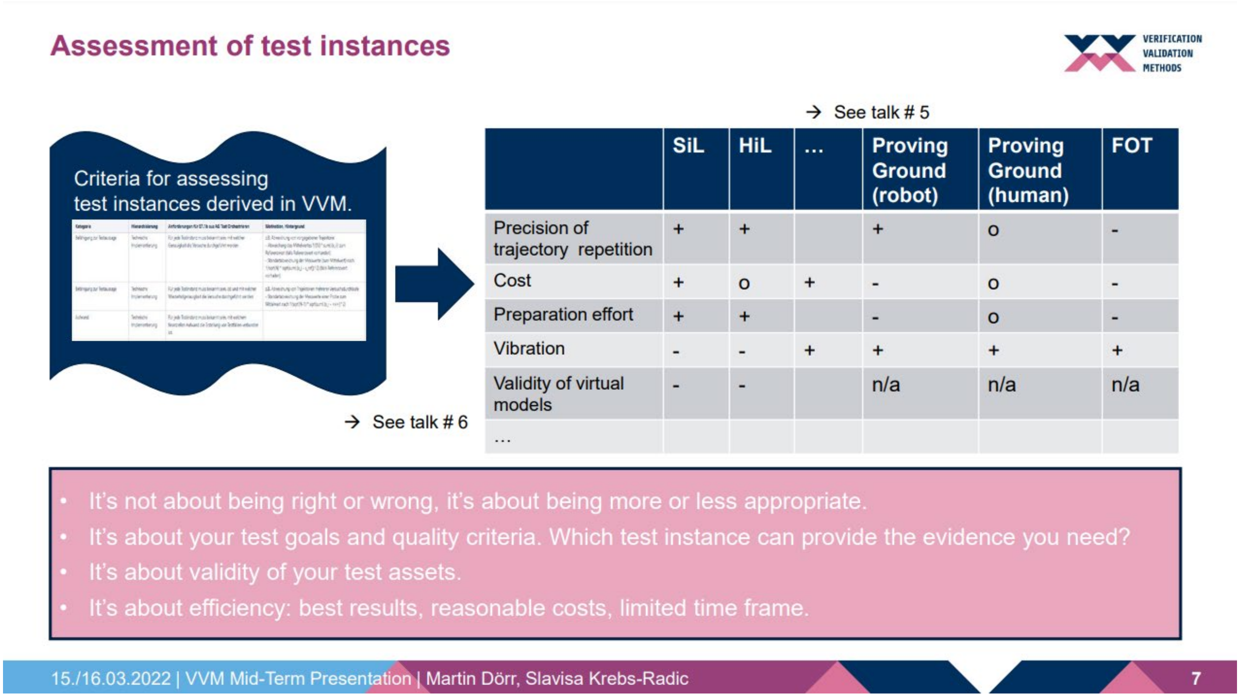

Figure 18: VVM’s Assessment of test instances

ISO 34502 … about test platform assignment

As with PEGASUS referenced in sections above, ISO 34502 also points out in its Annex G of the standard [10] the challenge of the trustworthiness of the test platform of virtual testing (abbreviated VTP) and that this must be validated accordingly.

One of the contributors (among others[30]) is the test platform of a test track with real vehicles. The validity of the applied VTP modelling and simulation tool is verified by means of comparisons with Real World Test Platforms (RWTP) for certain concrete scenarios.

The VTP is considered as valid for the evaluated scenarios only when the results deviation from RWTP is limited. One way is measuring the deviation between results of a certain scenario evaluated on a VTP and a reference from RWTPs. Thus, the error between a VTP compared to a reference can be statistically determined (=validation result).

Unfortunately, neither examples[31] nor associated threshold values are specified (which is not uncommon for a standard).

Otherwise, the ISO 3450x series of standards only addresses the topic of assigning tests to test platforms in the requirements section of chapter 4.4.4.2 of ISO 34502.

The following requirements are specified:

- Relevant test cases shall be allocated to at least one test platform.
- The selected test platform shall be suitable for the assigned concrete scenarios.
- VTP should be used to execute tests that would be too dangerous or too complicated to execute in real life.
- The allocation of tests to RWTP such as test tracks can/or should be based on pre-selected tests, e.g.,
- certification tests or
- tests with high relevance to vehicle dynamics and real-world sensor performance or
- rare events that rarely occur in real-world tests or
- events on public roads with low repeatability.
- Assignment of tests to real word test platforms (RWTP) such as test benches and test tracks can and/or should be based on high relevance to real system performance. Depending on the ability to control each parameter, environmental conditions may vary more or less randomly.

Section 4.5.3.2 establishes some requirements specifically for the test platform of a test track which need to be considered in the manufacturer's test platform assignment procedure:

- The selected test platform shall be suitable for the assigned concrete scenarios.
- Virtual test platforms (VTP) should be used to execute test that would be too dangerous or too complicated to execute in real life.

In summary, the ISO 3450x series of standards addresses the topic of test assignment with a number of requirements. It unfortunately does not (yet!) provide any best practice examples.

ASAM Classical use cases (exemplary)

ASAM addresses the subject of test platform assignment in the context of a so-called holistic test strategy [6]. Holistic test strategy is driven by a product's safety argument/case and combines test platforms[32] and test methods in a meaningful and efficient way to supply the necessary arguments and evidence for its required holistic assurance case.

Based on the classical approach to test strategy development, it defines typical use cases for testing, considering the required test platform and test method as shown in Table 2.

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[30] Other contributors can be tool qualification including accompanying documentation and validation of the suitability of the VTP models incl. documentation regarding model capabilities, ODD, boundary conditions, assumptions, and assignments.
[31] It can be expected that examples will be worked out and published in the next versions of the ISO standards, FDIS (draft international standard) and/or IS (international standard, final).
[32] ASAM calls it test environment

Table 2: ASAM's findings of classical test method use cases, exemplary

	Testing Use case	**Test Idea**	**Required Hardware / Tools**
5.2.3	Fault Injection Testing MiL	Fault injection testing[33] at the Model-in-the-Loop level[34]	
5.2.4	Scenario-based Open Road Testing	Validation testing of ADS functions in an open environment on public roads.	▪ Test vehicle ▪ Tools for analyzing recorded data
5.2.5	Proving Ground Scenario-based testing	Validation testing of ADS functions in the area of the proving ground test platform.	▪ Robotic platforms ▪ Steering Robots ▪ Measurement systems ▪ Periphery devices[35]
5.2.6	Hardware Re-Processing / Data Replay (DR)	Verify, that an ADS component performs correctly within its defined ODDs under different traffic conditions using DR[36],[37]	▪ SW-DR test station[38] ▪ HW-DR test station[39] ▪ Replay Data Management Tool ▪ Test-Management Tool ▪ Coordination Management Tool

According to its [6] the main goals of the ASAM Test Specification Study Group are:

- Provide overview of test methods in the field of ADAS/AD
- Develop a potential basis for future testing, the Test Strategy Blueprint
- Detailed use cases for the implementation of a test strategy
- Alignment with current standardizations
- Provide recommendations for stakeholders and proposals for further standardization activities

[33] Fault-injection testing serves mainly two purposes: First, it checks whether functionalities that are intended to be implemented in a fault-tolerant manner indeed sustain the fault. Second, it analyzes the behavior of not-fault-tolerant functionalities in case of failure due to a specific fault [6].
[34] To supplement the classic fault injection testing activities performed at the hardware level [6].
[35] e.g., weather stations, traffic lights, lane markings
[36] DR is an open loop testing method based on playing recorded data sets at the interfaces of a system under test (SUT) and evaluating the responses of this SUT against reference or ground truth (GT) data [6]
[37] Depending on the type of component, the test platform can take the form of a software-only test platform (SW-DR) or a hardware test platform (HW-DR) once the SUT is deployed on the target system on chip (SoC):
[38] For functional testing, especially at the beginning of the software development, SW-DR is preferable for the ease of scalability and parallelism.
[39] HW-DR is preferred in later development cycles for function testing, as well as for robustness testing in different traffic scenarios. Both test platforms are usable for failure insertion on bus/network as well as sensor data streams

7. Contact Information

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8. Contributors

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KATRI

KATRI (Korea Automobile Testing & Research Institute) was established for the purpose of reducing human casualties and/or injuries due to traffic accidents, protecting rights and interests by protecting consumers, providing technical information support for domestic automobile-related industries, and providing government automobile-related policies and technical support.

As a research institute affiliated with the Korea Transportation Safety Authority, it performs effective quality investigations to determine defects in product and manufacturing which can cause safety flaws in automobiles. The KNCAP (Korean New Car Assessment Program) evaluates how safe a vehicle is and informs the public. It is a standardization process that establishes global standards for automobile safety standards, a future vehicle safety research and development for safer and smarter vehicles, government contracting-out projects that lay the foundation for vehicle safety, and automobile parts management projects that secure vehicle performance and safety through efficient vehicle management.

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IAMTS

The International Alliance for Mobility Testing and Standardization (IAMTS) as collaboration of industry partners[40] is working to establish a directory of dedicated test platforms and road systems (public or private) that can be used for AV testing and certification worldwide. It has established a database registering these facilities and describing their capabilities in a standardized way, including quality criteria for test benches, which could then form the basis for an audit and certification process [1].

There are five groups (WG)[41] at the IAMTS:

- WG1 – Global Test Scenario Library
- WG2 – Global Advanced Mobility Testbeds
- WG3 – Correlation of Physical and Simulation testing
- WG4 – Cybersecurity Testing
- WG5 – Connected & Automated Vehicle Lifecycle Compliance

Figure 19: Working Groups of IAMTS [5]

Working Group 1 – Global Test Scenario Library – is focused on test scenarios. A test scenario is defined as any functionality that can be tested. It is also called a test condition or test possibility. As a tester one should take the view of the end user and figure out the real-world scenarios and use cases of the application under test. Modern vehicles can drive semi-autonomously or autonomously. The challenge here is to develop scenarios to test the vehicle under predefined conditions. Scenarios facilitate testing and evaluation of complicated end-to-end problems. Creating good test scenarios ensures complete test coverage. [5]

Current next steps for Working Group 1 are

- to agree on a globally harmonized scenario library and the process for selecting a subset of scenarios for a particular AV deployment based on the scenario libraries created in different regions,
- to define the methods for selecting test cases for all scenarios, and
- to define performance metrics that cover both safety and road safety.

Working Group 2 – Global Testbed Database – concentrates on test beds and addresses the establishment of a database for global testbeds and open test areas, including the necessary provisions for the registration, qualification, and digitization of testbeds for automated driving systems. Its focus is on test equipment, test software, interfaces, and the unit under test. The unit under test is the vehicle. A well-designed testbed can ensure test stability and repeatability. Complicated vehicles can have extremely complicated and expensive test setups (testbeds). [5]

[40] founded in 2018 [2]
[41] formation in 2019 [4]

Working Group 3 – Correlation of Physical and Virtual Testing – is focused on simulation testing. Testing vehicles for Level 4 and 5 requires a novel approach, as the responsibility for controlling the vehicle is primarily in the hands of a computer. In order to simulate a specific virtual environment, it is important to make the virtual image of a real environment such as roads or buildings sufficiently accurate. The testing of the vehicle subsequently takes place in a 3D virtual world.

Since it is impossible to accumulate enough test miles on a real road with a prototype vehicle, the virtual system should demonstrate that the failure rate is statistically on the order of or lower than the human failure rate (which is equivalent to 1.06 per 100 million miles). In the virtual world, it is possible to repeat the test as many times as necessary. This is fast and cost effective. [5]

This Working Group is developing and defining methods and processes to enable virtual testing methods for ADAS/AD validation focusing on the correlation process between the virtual and real world. The methodology, set of general rules and best practices and recommendations is the output of the group. That output should than be used by the industry and regulatory bodies.[4]

Working Group 4 – Cybersecurity Testing – IAMTS working group is concentrated on developing the rules and regulations to protect the vehicle from cyber-attacks. The work group recently published an Automotive Cybersecurity Practice Report to provide an overview about tools, procedures, testing methods and regulations. [4]

The latest development within IAMTS is the Working Group 5 which focuses on the topic of regulatory compliance for ADS vehicles considering the whole lifecycle. This working group recently emerged from the Study Group 5 after completing the task of creating a whitepaper in cooperation with CITA (the world's only association of vehicle inspection organizations) which will be published soon. [4]

IAMTS has a strong focus on test facilities for physical testing and helps manufacturers to find the appropriate location for their AV use case. It can therefore to be placed in the Test Methods section of the NATM framework due to its strong emphasis on Track Testing Pillar (C) as depicted in Figure 20.

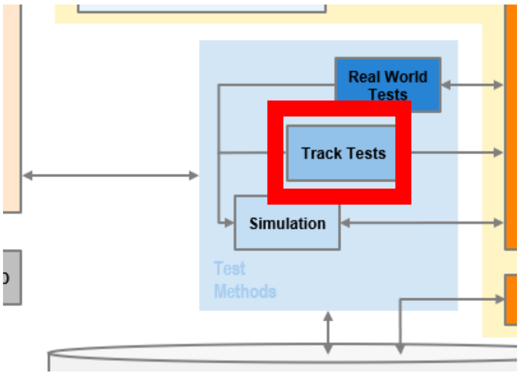

Figure 20: IAMTS in context of NATM

UNECE's GRVA

GRVA is the Working Party within the UNECE that prepares draft regulations, guidance documents and interpretation documents for adoption by the parent body, the World Forum for Harmonization of Vehicle Regulations (WP.29).

GRVA deals with safety provisions related to the dynamics of vehicles (braking, steering), Advanced Driver Assistance Systems, Automated Driving Systems and well as Cyber Security provisions. The group supervises around eight informal work groups (IWGs) and tasks forces [7].

Four Informal Working Groups (IWG) deal with the safety of automated vehicles and its framework document (FDAV):

- Functional Requirements for Automated Vehicles (FRAV)
- Validation Method for Automated Driving (VMAD)
- Event Data Recorder and Data Storage System for Automated Driving (EDR/DSSAD)
- Cyber Security and Over-The-Air issues (CS/OTA)

The NATM framework was drafted by VMAD and is a current state of the art guideline that serves as an orientation method for manufacturers. It recommends a procedure for validating the safety of automated driving systems (ADS).

NATM is newly prescribed by the UNECE for the use of ADS vehicles on public roads in Europe. It is approved by the UNECE Working Party on Automated/Autonomous and Connected Vehicles (GRVA).

NATM consists of the following 6 Pillars, shown in the figure below:

A) Scenario catalogue (incl. creation of scenarios)
B) Simulation / Virtual testing
C) Track testing
D) Real world testing
E) Audit and Assessment and
F) In-service Monitoring & Reporting

The first Pillar (A) contains the necessary legal requirements for the manufacturer to systematically derive and define its scenarios for scenario-based testing that represent the real world in its operational domain (also known as Operational Design Domain ODD). As mentioned, the focus here is on the use case of scenario-based testing[42], the new "ingredient" for ADS. All other, more classic use cases (e.g., requirements-based testing, interface testing, etc.) are not considered in this paper.

The Simulation Pillar (B), Track testing Pillar (C) and Real-world testing Pillar (D) belong to NATM’s overarching block of scenario-based testing methods. This block addresses the associated requirements for the manufacturer for testing AVs on the various test platforms for scenario-based testing.

The Audit and Assessment Pillar (E) provides guidance on the necessary requirements and for manufacturers' ADS process development and evaluation.

The In-Service Monitoring & Reporting Pillar (F) contains the requirements for the necessary post-deployment and field operations activities.

[42] Providing a safety rating for automated vehicles is very time-consuming and complex due to the almost limitless number of traffic scenarios. Scenario-based testing lets you transfer recordings from real test drives into the simulation and hence perform thousands of tests of safety-critical and realistic driving scenarios with dedicated hardware and software conveniently as a simulation.

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