ASAM SIM:Guide

STANDARDIZATION FOR HIGHLY AUTOMATED DRIVING

ASAM

Association for Standardization of
Automation and Measuring Systems

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IMPRINT

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Register of Associations:
Amtsgericht München,
VR: 16429

Publisher: ASAM e.V.
Art direction: Gina Ulses

ASAM

Dear Reader,

It was at the ASAM General Assembly 2016 – I had just started my assignment as ASAM Managing Director – when I heard of OpenDRIVE, OpenSCENARIO, OpenCRG and Open Simulation Interface (OSI) for the first time.

Our member AVL who managed the ENABLE-S3 project at the time, a large EU-wide research project on testing & validation of highly automated systems, contacted us with the remark to have a closer look at these standards as they might fit well into the ASAM portfolio.

Immediately, we recognized that highly automated driving (ADAS/AV) holds a huge potential for future standardization in ASAM. Only few weeks later, we started the first talks and discussions with the involved people. We learned about further activities, e.g. the German PEGASUS research project, where these standards also played a major role. The deeper we discussed these activities the more obvious this unique opportunity for ASAM became.

The number of ASAM members involved in these discussions became bigger and bigger and they all pushed us – ASAM is a membership driven organization! – to take over these standards, to develop them into industry standards (ASAM standards) and to guarantee their further development in the future.

After intensive negotiations with the IP owners (VIRES Simulationstechnologie, Daimler and the members of the PEGASUS Steering Committee), we had overcome all obstacles which came up during the negotiations. And finally, in September 2018, we were able to sign the transfer agreement for OpenDRIVE and one month later the agreements for OpenCRG and OpenSCENARIO. The transfer agreement for Open Simulation Interface with BMW followed in September 2019.

After some Kick-off workshops in the fourth quarter of 2018, we started the official project work at ASAM in early 2019 with the proposalworkshops for ASAM OpenDRIVE, ASAM OpenCRG and ASAM OpenSCENARIO. We were overwhelmed by the interest worldwide! Never before have so many people attended ASAM projects. And the good thing is that this interest did not decrease over time. In the last two years, more than 150 companies joined ASAM, most of them because of the ASAM OpenX (the name for the standards family in the new domain Simulation) activities.

One year later, in March 2020 we have released the first versions of ASAM OpenDRIVE V1.6.0 and ASAM OpenSCENARIO V1.0.0, followed by ASAM OpenCRG 1.2.0 in November 2020.

Meanwhile a lot of new ideas came up in the work groups and additional standardization activities could been started.

I invite you to read about all these activities and about the usage of the standards on the next pages of this ASAM Guide:SIMULATION.

My sincere thanks go to all those who made this success story in ASAM and for ASAM possible!

In a few days, my time as ASAM Managing Director is coming to an end – after five intensive and very successful years. Throughout my time, it was a great pleasure for me to be in contact with you!

Estenfeld

Dr. Klaus Estenfeld
Managing Director ASAM e.V.

For the past two years, from 2019 - 2021, I had the honor of chairing the ASAM Board of Directors. During this time, it has been a great pleasure to see how the field of „Simulation“ has developed at ASAM. And it was also exciting for me and my fellow board members to pave the way for its successful integration into the ASAM portfolio. With the „Simulation“ domain, ASAM has gained a new and highly relevant business branch.

The global market for autonomous vehicles reached a value of nearly US$ 820 billion in 2019, increasing at a compound annual growth rate of approximately 13% since 2015. It is forecasted to reach US $ 1,200 billion in 2023, rising to over US $ 3,000 billion by 2030. At the same time, car manufacturers are investing large sums in the development of autonomous driving functions and in the establishment of new cooperations in the areas of sensor technology, data acquisition and evaluation.

The ASAM OpenX standards precisely address these interfaces and form the essential basis for the integration of traffic infrastructure, sensor technology and simulation. The importance of the standardization activities is also underlined by the fact that the number of ASAM member companies has increased by 160 to a total of currently more than 350 in the last two years.

Parallel to the technical development of the OpenX standards, we have intensively engaged with other standardization organizations such as the International Alliance for Mobility Testing and Standardization (IAMTS) or the SAE and signed agreements on future cooperation.

We are particularly interested in the validation of the developed standards in real operations and the feedback of the results to the ASAM organization. To coordinate all relevant activities in the field of simulation, we have established the Coordination Group: Simulation, which supports both the Technical Steering Committee and the ASAM Board of Directors in upcoming decisions in the new domain. Currently, more than 100 member companies are working in 8 project groups on the development of the OpenX standards and have committed a development volume of well over 20 man-years. Many of the project groups are international and continue to work on the success of the standards in the usual way despite the global Corona impact. This was possible, because we created the necessary infrastructure to hold virtual meetings and exchange data very early during the pandemic crisis.

Some of the application areas and success stories are presented in this report and I hope you enjoy reading it. I would like to thank all the authors, and all the experts who contributed to the development of the standards. Of course, none of this would have been possible without the cooperation of our members, the commitment of our Managing Director, Dr. Klaus Estenfeld, and the staff in the ASAM office who strive every day to provide the best possible service to our members and working groups. I would also like to thank all the volunteers on the ASAM Technical Steering Committee, the Coordination Group: Simulation and my colleagues on the ASAM Board of Directors. They all contribute to our success.

As an ASAM member from the very beginning, I am convinced that we have already achieved a lot, but that much of the work still lies ahead of us and that standards will continue to play an essential role in vehicle development process in the future. I ensure you that ASAM is well prepared for this task.

Prof. Dr. Marcus Rieker
Chairman of the ASAM Board of Directors

About ASAM

ASAM e.V. (Association for Standardization of Automation and Measuring Systems) is a non-profit organization that actively promotes standardization within the automotive industry. ASAM provides a **neutral platform** that enables collaboration among all stakeholders: OEMs, suppliers, tool vendors, service providers and research institutes. The goal is to identify common, non-competitive challenges and to solve them together.

We pursue the vision that tools of a development process chain can be freely interconnected and data can be seamlessly exchanged.

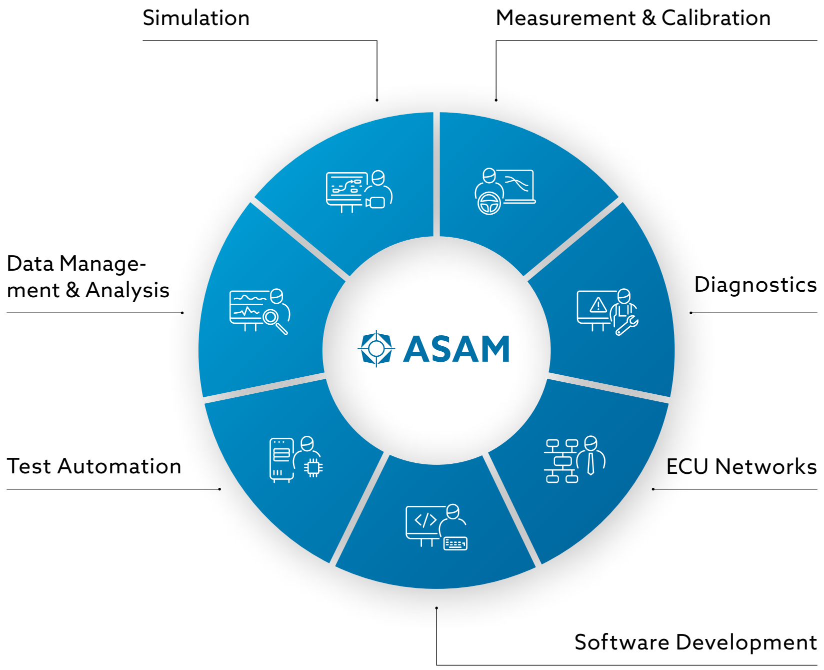
[ASAM Vision]

ASAM standards define interfaces, protocols, file formats and data models **for development and testing throughout the vehicle development pipeline.** Tools and products developed based on ASAM standards allow easy integration into existing value chains and seamless data exchange.

ASAM standards are developed in work groups, composed of experts from our **more than 350 member companies worldwide**. ASAM requests and encourages an open exchange within the work groups. However, the ASAM standardization process complies with EU competition law:

- ASAM work groups do not define products or take any business decisions preventing competition.
- ASAM standards are recommendations, they do not have an impact on regulatory framework.
- ASAM standards can be downloaded or purchased and are thus available for everyone.

ASAM Standards Portfolio



ASAM DOMAINS

Since its foundation in 1998, ASAM has built up a reputation across multiple domains in the automotive sector. The current portfolio of standards is categorized into the following domains:

1. **Measurement & Calibration**
   Standards for working with ECU variables and parameters.
2. **Diagnostics**
   Standards for describing and testing the diagnostic subsystems of ECUs.
3. **ECU Networks**
   Standards for describing and testing ECU networks.
4. **Software Development**
   Standards supporting the ECU software development process.
5. **Test Automation**
   Standards for working with test systems.
6. **Data Management & Analysis**
   Standards for storing, retrieving and analyzing large amounts of data captured during simulation, testing, production and the operation of vehicles.
7. **Simulation**
   Standards that support the automotive industry in furthering the state of autonomous driving, especially with respect to (virtual) validation and verification.

GUIDING PRINCIPLES

ASAM's ultimate goal is to enable collaboration between all stakeholders in the automotive industry and thereby help drive automotive development. This requires an open exchange on a neutral, non-competitive basis. To ensure that these requirements are met, ASAM works by the following principles:

Member-Driven Organization

ASAM believes that the members know best, where and when standardization is useful. ASAM has therefore set up a process that makes it easy for its members to **contribute new proposals and ideas** for standardization. The Technical Steering Committee controls and regulates the projects.

Open Exchange

ASAM requests and encourages an open exchange among all stakeholders to discuss common needs and requirements and to develop standards. ASAM offers a **neutral, non-competitive setting** to support this exchange.

Domain Expertise

ASAM has built up a global network of companies that send their **domain experts** to contribute their knowledge to projects. Together, they work on a common vision while simultaneously extending their understanding on highly relevant industry topics.

Flexible Framework

ASAM is a lean and structured association, project groups can rely on proven processes. However, these processes allow great flexibility in terms of project content and time scope. This leads to **short development times of 16 months on average**. Additionally, short decision paths allow fast reaction to current needs and questions.

Project Support

Qualified and experienced **Technology Managers** support project groups with their technical expertise and their knowledge of the established ASAM processes to secure a successful and timely execution of projects.

STANDARDIZATION AT ASAM

To date, ASAM has 33 standards (with four more currently under way). Many of these standards are mature and have proven themselves many times in various development processes. A wide range of members ensures that our standards find their way into important tools that are used in the tool chains of OEMs and suppliers worldwide. Some of the standards have an estimated market adoption of more than 80 percent.

ASAM stands out as successful standardization organization for good reasons. One of these reasons is a development process that has been adapted over time to meet the requirements of both the membership and ASAM's stringent demands on quality.

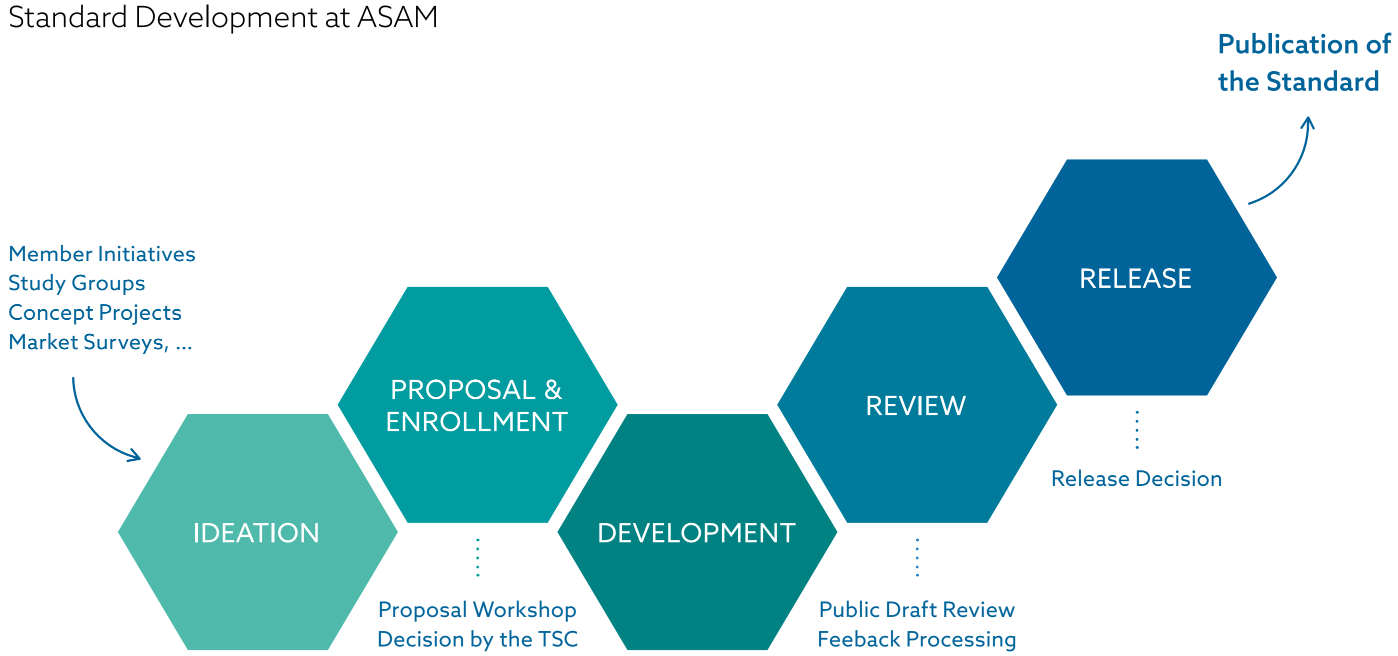
While allowing short development cycles, ASAM attaches importance to adhering to the **standardization process** consisting of an ideation phase (if required), a proposal phase, a development phase, a review phase and a release phase.

ASAM promotes a **collaborative, open development style:** While the standard development itself generally remains within the closed project group, there are plenty of opportunities to join the work group or bring in requirements or feedback at different stages of the process:

- **Ideation Phase:** Workshops and discussions are open for members and non-members alike.
- **Proposal Phase:** Proposal Workshops as well are open for both members and non-members. Additionally, members (for simulation standards also non-members) have the opportunity to comment on published proposals and to suggest further requirements for the standard development.
- **Development Phase:** If the industry momentum is so fast that not even the fast cadence of ASAM projects is sufficient, ASAM has recently introduced regular development updates on projects to keep the industry up to speed (e.g. OpenSCENARIO 2.0 Development Update).
- **Review Phase:** A public draft review process (applicable only for new standards and major versions releases) allows members to check for ambiguities and inconsistencies before release.

ASAM is not exclusively a place for standardization. It is a unique feature of ASAM to **also provide a platform for discussions** to develop ideas, identify further requirements and evaluate solutions. For that purpose, ASAM offers the possibility to start so called **"study projects"** or **"concept projects"**. These work groups can interact directly with related project groups at ASAM, ensuring that all ASAM activities are harmonized and follow one common goal. Usually, the results of study and concept projects will later serve as a basis for a standard development project.

Standard Development at ASAM



ASAM development process – From the first idea to the publication of a new standard

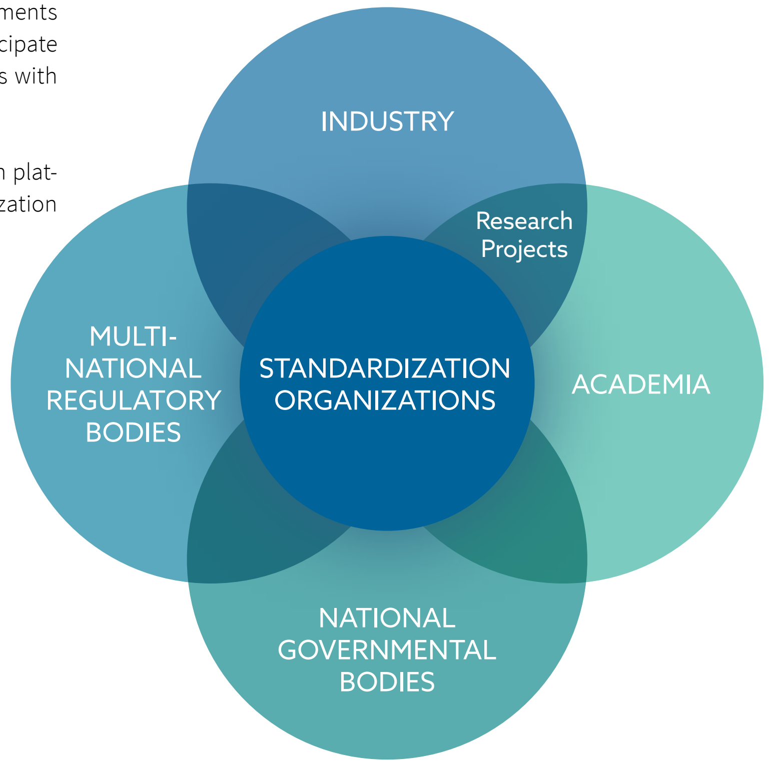
As an industrial standardization organization, ASAM **cooperates with many standardization organizations worldwide**. The goal is to prevent ASAM activities from competing or overlapping with existing or upcoming standards, and instead focusing on harmonizing the cross-organizational development activities. This helps to improve the acceptance of ASAM standards on the global market and to ensure an uncluttered and cooperative standardization landscape, directly benefiting all partners involved. Particularly close collaboration was established with ISO WG9, SAE (ORAD & AVSC), prostep IVIP and AUTOSAR to ensure alignment across activities.

Additionally, ASAM is currently **partnered with many national and international research initiatives and collaborative projects**. Such projects will lead to the standardization requirements of the future; hence ASAM feels it is crucial to be involved directly early on and provide support where possible. Not to mention that the strong membership network of ASAM can ensure further alignment between such initiatives. Some examples of partnerships include membership of the steering committee (TPX) for multiple German research Initiatives (SetLevel4to5, VV-Methoden, KI-DataTooling, etc., representation on the IAMTS Executive Board, IAMTS WG2, and collaboration with the European funded HEADSTART project.

Although ASAM standards have no impact on the development of regulations, they will have an **impact on the application and implementation on these regulations**. As an example, ASAM OpenSCENARIO is already being used to develop concrete scenarios for the recently released UNECE ALKS specification (ECE/TRANS/WP.29/2020/81 from June 23 – 25, 2020: https://undocs.org/ECE/TRANS/WP.29/2020/81). ASAM OpenSCENARIO 2.0 could be used for other upcoming scenarios (even functional scenarios) in future regulations. The significant benefits of using a standardized format in regulatory documentation would include ensuring a shared understanding of the requirements of these scenarios. For this reason, ASAM will also aim to participate in the UNECE IWG on VMAD and is involved in first discussions with the leadership.

ASAM feels that it is not only necessary to offer a collaboration platform for the membership but to also collaborate at an organization level in order to support the industry as a whole.

> *"Industry collaboration in automotive electronic engineering requires standards for shared understanding as well as a seamless communication and data exchange. ASAM provides a neutral platform to identify common, non-competitive issues and to solve them together."*
>
> DR. KLAUS ESTENFELD,
> Managing Director, ASAM e.V.



SIMU LATION

The importance of simulation in automotive development is also reflected in the strong participation of ASAM members in standardization: More than 100 member companies actively contribute to the development of the ASAM OpenX standards. For the current projects, these companies have committed more than 20 man-years. Never before in ASAM's history have so many companies worldwide participated in the development of ASAM standards.

The Role of Simulation in Automotive Development Today

In the past two decades, vehicle systems have substantialy grown more complex and driver assistance systems are becoming more common. With the capability to add more sensors and computational power to a vehicle at a reasonable price, more assistance functions can be realized. Advanced Driver Assistance Systems (ADAS) have been deployed to the consumer market and transitioned from optional to standard installations, mainly driven by the 5-star requirements from NCAP (New Car Assessment Program) or NHTSA (National Highway Traffic Safety Administration). Automated Driving (AD) systems have started to roll out and are estimated to have massive growth potential in the years to come.

The development and validation of these systems requires extensive testing with millions of test miles to cover all types of situations and scenarios that the system must handle. Therefore, it is not feasible to rely only on physical tests in the development process. There are several reasons for this. One reason is that at the beginning of development, the target hardware on which the software will run is not available as it is being developed in parallel. From the beginning, simulations play an important role in the development and validation of the software functions. By using simulations, the software can be tested at a very early stage and bugs and missing capabilities can be detected and fed back into the development. The use of simulations becomes even more important as the realism of the stimuli that simulations can provide for the target system under test increases.

Simulations can be used to challenge a virtual model (MiL) or software container (SiL), representing an ADAS or AD system. In the further development steps, simulations are used to interact with physical parts, single ECUs or collections of ECUs (HiL) of the final product. These physical elements of the car will already run the software on the intended target hardware. Once the ensemble of ECUs and software can be put together to represent the nervous system of the vehicle (ViL/DiL/proving ground), simulations can still interact with the system.

Virtual vs. Physical Testing

Virtual testing complements physical testing for the development and validation of ADAS and AD systems.

Being able to test and validate without any physical device under test (DuT), SiL and MiL testing have some major advantages: They accelerate the test process and save costs. One second in the simulation corresponds to about 20 seconds in real time. This means that more testcases can be executed and the system can be validated against all required scenarios.

But simulation has even more advantages:

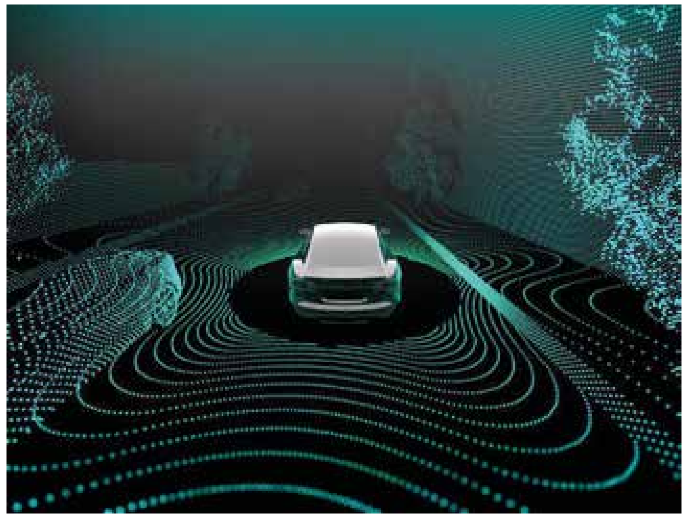
Physical testing on proving grounds

- needs test drivers
- needs test vehicles
- needs large areas dedicated as proving grounds
- relies on weather conditions for certain use cases
- is expensive

On the other hand, virtual testing in simulations

- enables parallel testing
- creates scenarios that focus on the test objectives
- enables to perform more tests in the same amount of time
- enables to replicate tests
- helps to define the test focus for physical test sites (HIL, VIL, proving ground)

Creating all necessary testcases for the validation of ADAS or AD systems is difficult and time consuming. It is impossible to cover all possible scenarios a vehicle can encounter in its lifetime. Developing a level 3 or level 4 vehicle is a huge challenge, even for big OEMs. **Collaboration is required** to avoid unnecessary costs, e.g. for format conversion, incompatible tooling, etc. The demand for exchange formats and description formats supporting the development of these systems is constantly growing. Standardized approaches are indispensable: Using common exchange formats will allow the industry to work together and ultimately make automated driving happen.



Achieving autonomous driving would not be feasible without simulation.

Simulation at ASAM

ESTABLISHMENT OF THE NEW ASAM DOMAIN SIMULATION

In 2018 and 2019, ASAM was entrusted with the further development of what was to become the new ASAM standards ASAM OpenDRIVE®, ASAM OpenCRG®, ASAM OpenSCENARIO® and ASAM OSI®. These standards constituted the new ASAM domain Simulation. The original owners made the decision to transfer these standards to ASAM to ensure the independent, long-term development and maintenance of these standards in a professional setting.

The first ASAM versions (ASAM OpenDRIVE V1.6.0, ASAM OpenCRG V.1.2.0, ASAM OpenSCENARIO V1.0.0) were released in 2020, followed by ASAM OSI V3.3.0 in Mar 2021. All of these new standards were released after around one year of development time. This was only possible due to the dedication of the work group members and the processes and framework provided by ASAM. Further extensions which were discussed in concept projects running in parallel to the transfer projects, are currently being developed.

ASAM OpenX Standards that Were Transferred to ASAM in Late 2018 and 2019

Static Road Network Desription

Static Road Surface Desription

Dynamic Scenario Desription

Interface for Simulation

NEW MEMBERS – NEW IDEAS

With the transfer of the OpenX standards to ASAM, a new business model was established: the newly released standards are free of charge and can be used by the whole community. With this approach, a lot more community engagement is possible. The user base of the ASAM OpenX standards has increased immensely which is also reflected in tremendous member growth at ASAM. Companies worldwide have joined the organization with the goal to use and contribute to the ASAM OpenX standards. With these new members also new perspectives and ideas came into the ASAM community and lead to new standardization initiatives:

ASAM OpenLABEL (new standard development): A concept has been developed and released in Nov 2020 with the goal to create the first object and scenario labelling standard. Currently a project group is developing ASAM OpenLABEL V1.0.0.

ASAM OpenXOntology (new standard development): During the the ASAM OpenSCENARIO concept project the need for an additional standard was identified to provide an ontology to harmonize all ASAM OpenX standards.

ASAM OpenODD (concept project): This concept which is intended to lead into a subsequent standard development, is an initiative to create a format for representing abstract ODDs (Operational Design Domain) which are currently being developed at other standardization organizations (ISO, BSI, SAE).

Scenario Based Testing (study project): This study project was started to research scenario-based testing and how this is supported by the existing standards in the industry. The project group is looking for approaches and architectures that can be used for scenario-based testing. The goal of the project is to determine whether it is necessary to standardize any gaps found in the research and to provide an overview to the industry on all the existing testing standards.

In addition to these new projects, the existing standards of the domain Simulation are further developed:

ASAM OpenSCENARIO: This standard is further developed in two parallel streams:

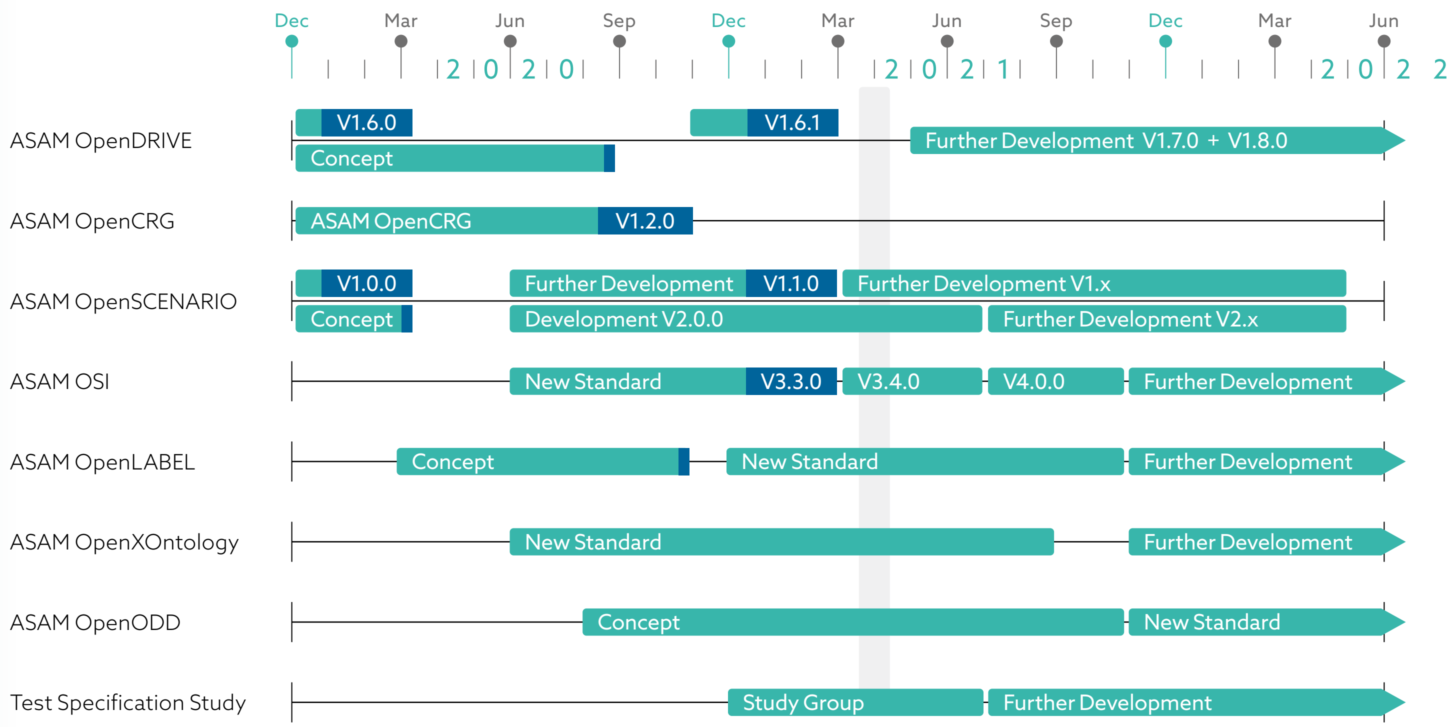
- ASAM OpenSCENARIO 1.x is the further development of V1.0.0.
- ASAM OpenSCENARIO 2.0 takes proven features and capabilities of ASAM OpenSCENARIO 1.0, like its event-based scenario execution model, and places them in a more general and expressive language framework, to serve as the foundation for both incremental improvements and more revolutionary enhancements.

ASAM OpenDRIVE: A concept has been released to prepare the further development of the standard.

ASAM OSI: This is the first standard that is developed as an open source project. Multible versions are being worked on in the scope of an ASAM project.

ASAM is proud to provide a platform for its member experts to work together to further advance highly automated driving.

ASAM Activities in the Domain Simulation (2020 – 2022)



WHERE IS ASAM HEADED?

The goal of the ASAM domain Simulation is to support the automotive industry in making level 4 and higher autonomous driving a reality. To get there, ASAM and its members are trying to support all steps in the testing workflow to validate autonomous driving. The figure below shows that ASAM's simulation standards, as well as standards currently in the pipeline, already support several steps of a scenario-based testing workflow.

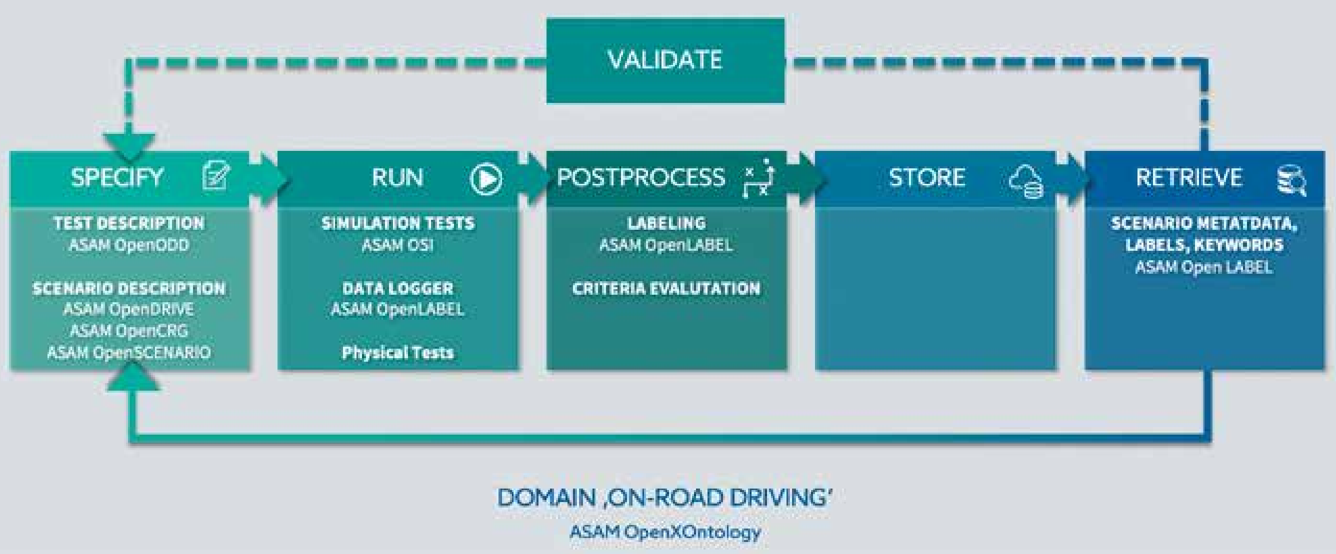
Additionally, ASAM is taking measures to identify further standardization needs at an early stage while taking existing solutions into account.

Currently, ASAM is following two strategy paths:

- **White spot analysis:** ASAM has initiated the study project "ASAM Test Specification" discuss the full scenario-based testing workflow and identify white spots or overlaps in standard development that need to be addressed. A work group has formed to deal with this task. The large number of participants makes sure that the results represent the industry practice and needs.
- **Taking advantage of existing standards:** Instead of developing new standards, ASAM aims to use existing standards where possible and – if necessary and feasible – adapt them to the new requirements. ASAM has several industry-proven standards that shall be evaluated for their usefulness for the validation of autonomous vehicles.

In carrying out all these measures, ASAM makes sure that the standards are harmonized with each other as well as with important standards from other organizations.

Scenario-Based Testing with ASAM OpenX



STANDARD DEVELOPMENT IN THE DOMAIN SIMULATION

ASAM OpenX – A Different Approach to Standards Development

A typical trade off in standardization is between development time, feature maturity and release cadence. Many organizations pursue a low release cadence with longer development pipelines driven primarily by finding consensus on more mature but maybe company-specific processes. While ASAM also applies this approach to some of its domains, many of the standardization activities, like those in the domain Simulation, have processes that are not as mature. Although these also require consensus among members, they are often more strongly driven by intensive joint development of processes that might not have existed in the first place. This poses particular challenges to the ASAM standard development process:

- **SPEED:** The need by the industry for standardization is high. ASAM has set up modern, agile development processes and tools that allow for projects, and thereby standards, to react much more rapidly to the momentum of the AD market.
- **HARMONIZATION:** Dynamic processes in AD development and multiple standardization efforts across multiple organizations require close collaboration of the industry and of the ASAM OpenX project groups in particular. ASAM helps bring the industry together to identify common ground and enables an easy exchange among work groups.
- **USABILITY:** The focus of the OpenX standardization efforts is to emphasize usability and readability to support fast adoption. They require close interaction with member companies to ensure the development of new features or changes does not lead to compatibility issues with existing tooling.

How ASAM Ensures Successful Standardization in Simulation

Over the past two years, many activities were started in the domain Simulation. To support the new work groups and to ensure their success, ASAM has taken several steps aimed at meeting the requirements above, while providing the best possible service to its members and users of the ASAM OpenX standards:

COORDINATION GROUP: SIMULATION: To coordinate all relevant activities in the field of simulation, ASAM has established the Coordination Group: Simulation (CG:Sim). This new body is tasked with identifying white spots in the standardization landscape, avoiding overlap of ASAM OpenX standards, and aligning ASAM with external activities. It also advises and supports the ASAM Technical Steering Committee (TSC) and the ASAM Board of Directors.

TECHNOLOGY MANAGERS: The number of new activities in the domain Simulation is enormous. To support the work groups in this particular domain, ASAM has hired three Technology Managers and a Technical Writer. They are responsible for the coordination and architectural support of simulation-based standards and ensure their compatibility with the rapidly growing demand for standards for highly autonomous vehicles.

NEW PLATFORM & WORK ENVIRONMENT: ASAM has adopted the "docs-as-code" approach for writing standards and accompanying deliverables. This refers to a philosophy that recommends writing documentation with the same tools as code. To support this, ASAM moved its standard development work to a modern versioning system and interface (GitLab/GitHub). This platform provides a Git-based repository with wiki, issue-tracking as well as continuous integration (CI).

To support a versionable collaborative workflow, all documentation deliverables were transferred to AsciiDoc, a markup, plain text authoring format. This format is integrated into a modern CI pipeline that provides easy to read, structured html with a shared look and feel across all standards as a final output.

OPEN SOURCE DEVELOPMENT: With ASAM OSI, ASAM is – for the first time - developing an open source standard. This is a significant change in the development of ASAM standards. ASAM has developed a concept that opens up a completely new opportunity for non-members to contribute to a standard while ensuring the content quality required by ASAM.

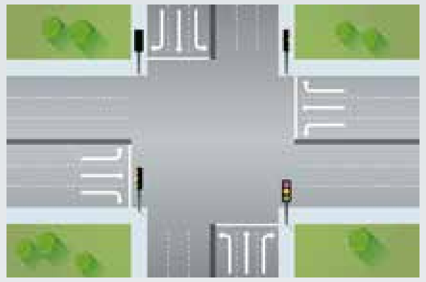
INTERNATIONAL WORK GROUPS: While the process steps remain the same, ASAM has moved towards a more open work group organization. The work groups are larger and more international. This places higher demands on the meeting organization. Meetings are mostly organized as virtual meetings with face-2-face meetings roughly every quarter to allow coordination and personal interaction among the members. It has also proven effective to delegate work packages to regional sub-work groups.

CONTRIBUTION BY NON-MEMBERS: The ASAM standard development process is already foreseeing many steps where members and non-members can bring in ideas or requests even if they are not part of the work group. For the domain simulation, this process is even more open. With the standards being publicly available free of charge, it is possible for non-members to contribute during ideation and proposal workshops and again during the public review phase. The project coordinators (Global Technology Managers) at ASAM are also available for feedback on standards and as an interface to project groups. This type of feedback is particularly welcomed as it is often the case that new organizations implementing the standards encounter bugs or issues that can be addressed or resolved in the scope of an ongoing project.

All these steps were taken to make sure that ASAM standardization in the domain Simulation is fast and open, while at the same time ensuring an orderly process that guarantees quality and market relevance of the standards.

ASAM SIMULATION PORTFOLIO

ASAM has developed a new business model for its domain Simulation: The standards are available free of charge and can be used by any industry player. This way, ASAM ensures that the standards are widely used and that the experience from their application directly feeds back into their further development.



ASAM OpenDRIVE®

Static Road Network Desription

The ASAM OpenDRIVE format provides a common base for describing road networks with extensible markup language (XML) syntax, using the file extension xodr. The data that is stored in an ASAM OpenDRIVE file describes the geometry of roads, lanes and objects, such as roadmarks on the road, as well as features along the roads, like signals. The road networks that are described in the ASAM OpenDRIVE file can either be synthetic or based on real data.

The main purpose of ASAM OpenDRIVE is to provide a road network description that can be fed into simulations to develop and validate ADAS and AD features. With the help of ASAM OpenDRIVE, these road network descriptions can be exchanged between different simulators. Providing a standardized format for road descriptions also enables the industry to reduce the cost of creating and converting these files for their development and testing purposes. Road data may be manually created from road network editors, conversion of map data, or originate from converted scans of real-world roads.

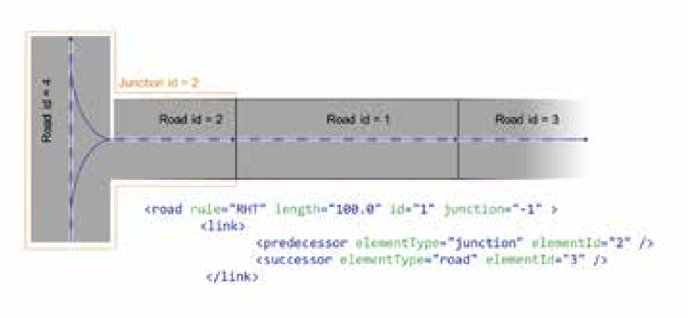
NODES

The format is organized in nodes that can be extended with user defined data. This facilitates a high degree of specialization for individual applications (usually simulations) while maintaining the interoperability that is required for the exchange of data between different applications.

REFERENCE LINE

The ASAM OpenDRIVE road network is modelled along the reference line, which is the core piece of every road. Roads, lanes, incl. their elevation profiles are all attached to the reference line [see Fig. 1] Objects representing features, such as signals, can be placed by using either the reference line or the global coordinate system, the road network is placed in. This can be seen in the above image. The reference line (blue line in the middle) is in the center of the road, the lanes (blue and light green) are attached to this reference line. The signs next to the road are placed in the s/t-coordinate system.

In ASAM OpenDRIVE several roads form a road network and can be connected. ASAM OpenDRIVE can be seen as a construction kit of different road sections. The overall road network is composed of individual sections interconnected with each other.



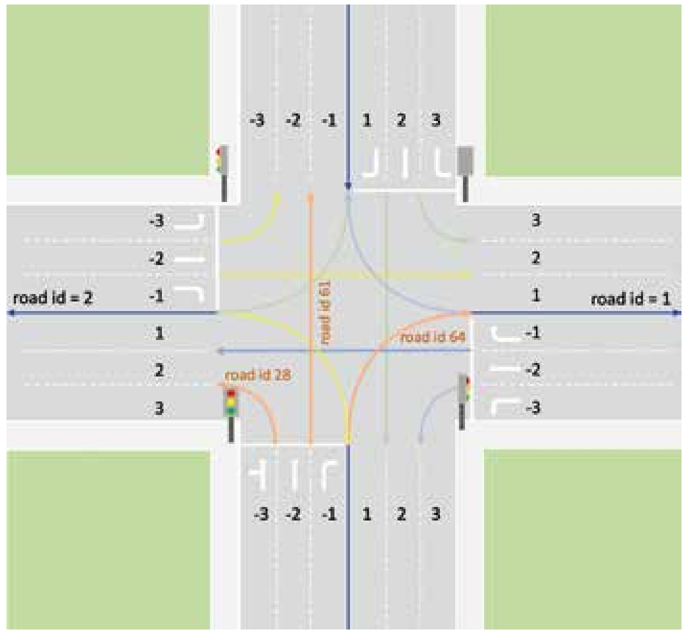
Example of a junction in ASAM OpenDRIVE

The above image shows how individual road segments interconnect e.g. with a junction. The shown XML snippet gives a short overview on how the linking of road segments can be used in ASAM OpenDRIVE. These links can support the driving logic of simulated traffic, especially for routing purposes, leaving more resources for the actual work of validating and developing AD driving features. In junctions, each possible connection between entry roads is connected via "connecting-roads". Due to this mechanism connecting roads are the only roads within ASAM OpenDRIVE with overlapping surfaces.

In ASAM OpenDRIVE not only roads are linked but also the lanes between roads. These lane links can again support simulated traffic. They are also important for the visualization of the road network when the reference line of connecting roads and roads that enter the junction are not necessarily aligned (this is the case e.g. in junctions).

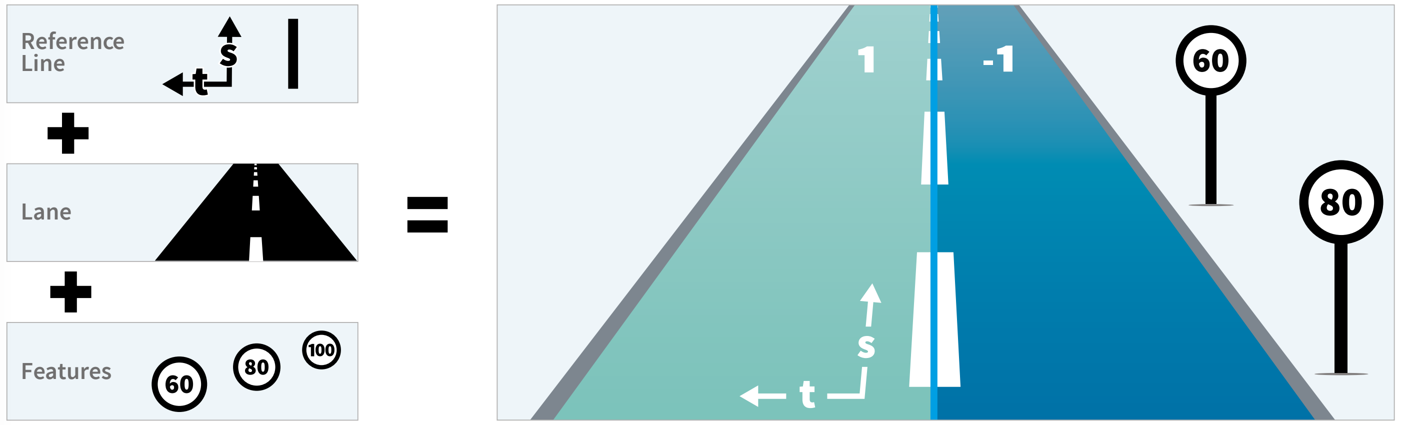
The ASAM OpenDRIVE description format contains all static objects of a road network that allow realistic simulation of vehicles driving on roads. In order to render the complete environment, additional description formats for static 3D roadside objects, such as trees and buildings, are needed. Road surface profiles are included from the ASAM OpenCRG file format. The dynamic content of driving simulations, such as vehicle maneuvers, can be described with ASAM OpenSCENARIO. The three standards complement each other and cover the static and dynamic content of in-the-loop vehicle simulation applications.

ASAM OpenDRIVE is a well established standard for the description of road networks. It is already in use by many well-known manufacturers and companies developing ADAS and AD functions or performing high-accuracy kinematic surveying worldwide. It is being used for road and rail networks.



Example of a junction

ASAM OpenDRIVE Elements (Figure 1)



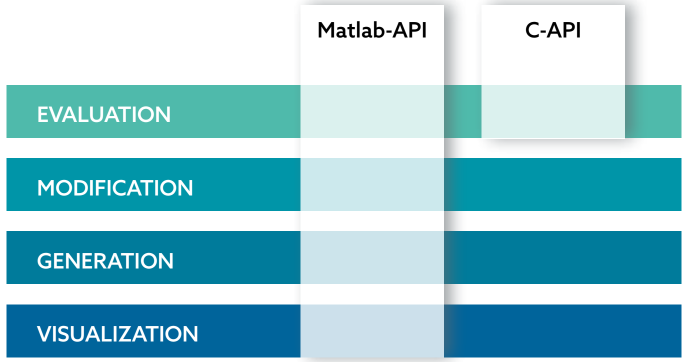
ASAM OpenCRG®

Static Road Surface Desription

The ASAM OpenCRG format provides a common base for describing high fidelity road surfaces. With ASAM OpenCRG, the road surface is described using a curved regular grid, with the ability to be represented in any customizable resolution. ASAM OpenCRG was originally developed to model detailed road surfaces for vehicle dynamics tests. These tests require a precise and highly performant road surface format to simulate the surface accurately for the intended test, thus providing valid test results.

MATLAB/OCTAVE API AND C-API

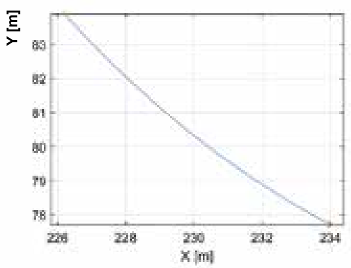
ASAM OpenCRG is a binary file format and comes with a Matlab/Octave API as well as with a C-API. The Matlab/Octave API offers features to create, manipulate, visualize and check ASAM OpenCRG files. The C-API only allows to check and process ASAM OpenCRG files.



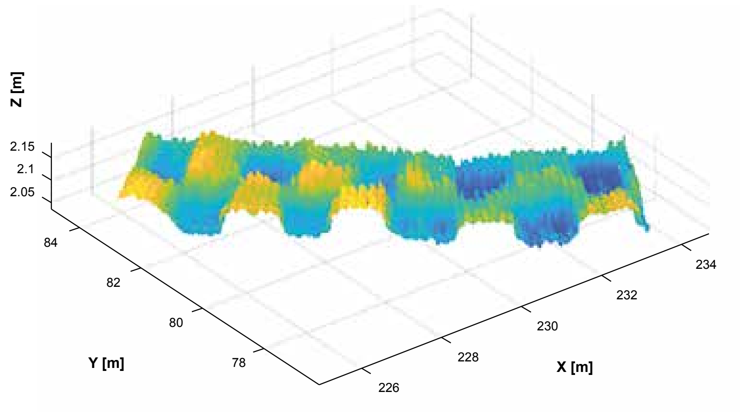
ASAM OpenCRG API overview

CURVED REGULAR GRID

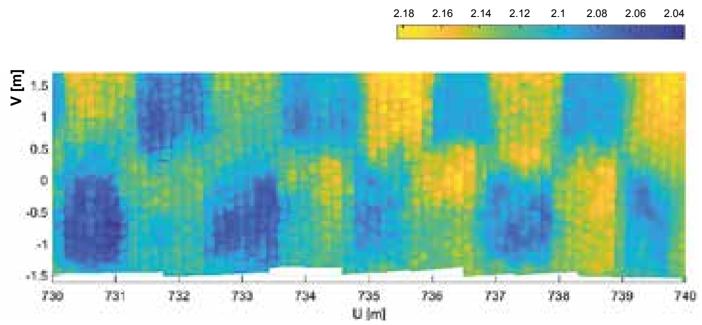
A curved regular grid represents road surface data in proximity of an arbitrary road centerline. The road surface is tiled into a curved grid. Longitudinal cuts are parallel to the road centerline. Lateral cuts are orthogonal to the road centerline. One road data value is assigned to each tile. Road surface data usually represents road elevation but may also be used for other data, for example friction coefficients.



CRG references line XY overview map



CRG road XYZ map (in curved XY grid)

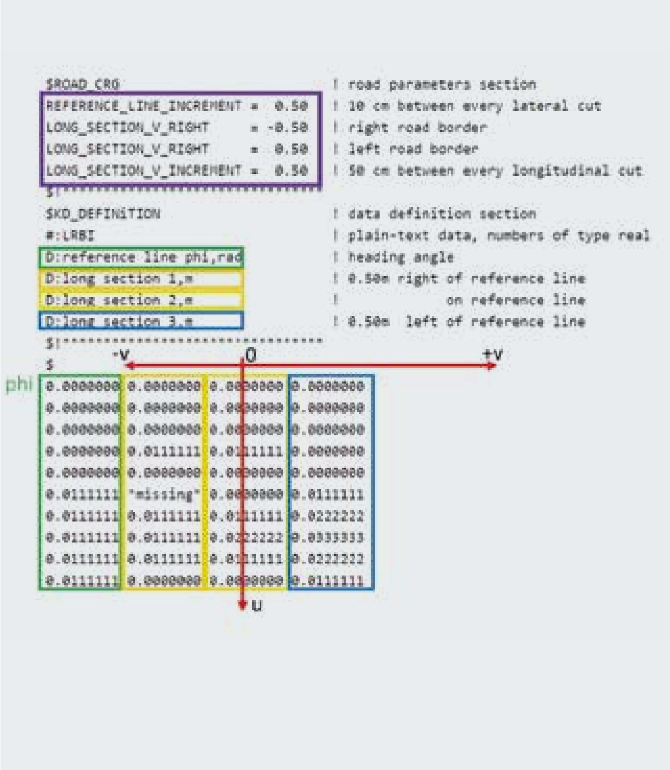


CRG road UVZ map (in uncurved UV grid)

Curved regular grids use a reference line coordinate system. The road centerline is given by a curved reference line. A curved reference line is defined by series of low-precision heading angles. The u-direction follows the tangent of the reference line. The v-direction is orthogonal to the u-direction. Road surface data is given in z-direction orthogonal to the u/v-plane.

A curved regular grid may be placed in an inertial x/y-coordinate system by providing a high-precision start position in x/y-coordinates. To avoid drift when integrating along the reference line, an optional high-precision end position in x/y-coordinates may be provided.

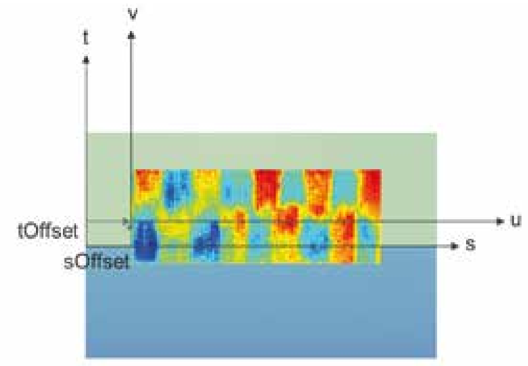
An OpenCRG file consists of several data sections that represent different aspects of the road surface data described in that file. OpenCRG files are written in plain text using ISO 8859-1 encoding. The actual road data may be provided in a binary format. Each line in a data section is considered a record. Except for the road data section, a record shall have a maximum length of 72 byte for a maximum of 72 characters per record. In the road data section, a record shall have a maximum length of 80 byte.



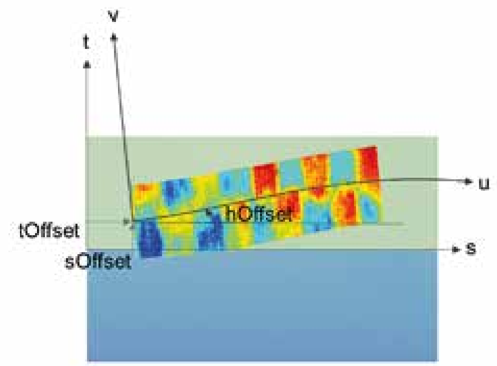
ASAM OpenCRG in text form

The dimensions of the grid are defined at the top of the file, followed by the modifiers. In the green box it is possible to define heading and banking of the reference line used in the ASAM OpenCRG file.

ASAM OpenCRG can be combined with ASAM OpenDRIVE to enhance the road network with detailed surface patches, e.g., for pot-holes, speedbumps and manhole covers. There are different attachement modes for ASAM OpenCRG files in ASAM OpenDRIVE, e.g. attached or genuine. When combining ASAM OpenCRG and ASAM OpenDRIVE files, the ASAM OpenCRG file can be used as surface layer or as friction layer. As ASAM OpenCRG provides only the grid of values, the interpretation of those values is up to the simulator, the purpose (friction or elevation) for those values is provi-ded by ASAM OpenDRIVE. The ASAM OpenCRG patches, in combination with ASAM OpenDRIVE, then only cover the desired parts of the road within the road network.

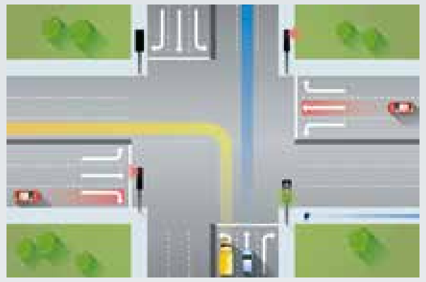


„ATTACHED"



„GENUINE"

ASAm OpenDRIVE attachment modes for ASAM OpenCRG files.



ASAM OpenSCENARIO®

Dynamic Scenario Desription

ASAM OpenSCENARIO defines the dynamic content of the world, for example, behavior of traffic participants and how these are expected to interact with each other and the environment. Static components, such as the road network, are not part of ASAM OpenSCENARIO but can be referenced by the format.

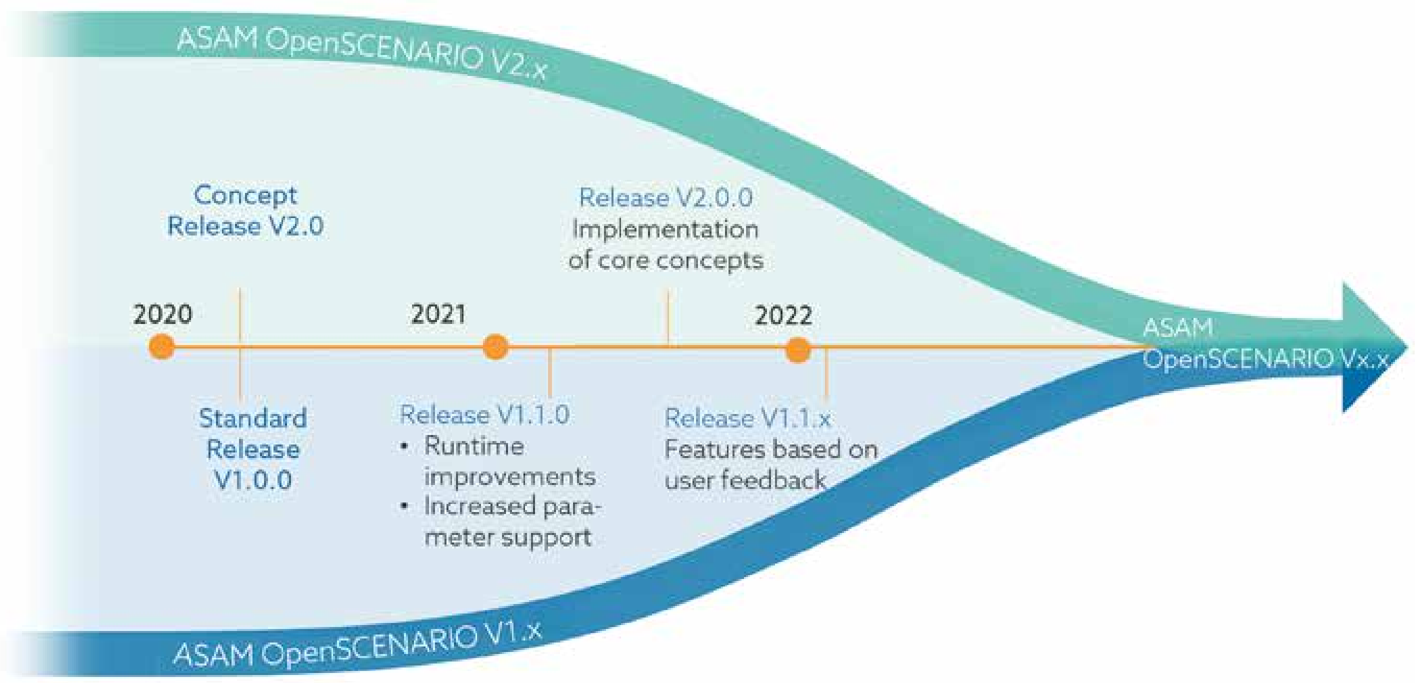
The ASAM OpenSCENARIO standard occupies a unique position among the ASAM OpenX standards in that ASAM currently actively develops two parallel versions of it. The so called 1.x pipeline, (V1.0.0 released March 2020, V1.1.0 released March 2021) and the 2.0 pipeline (first version to release fall 2021).

The two versions occupy different positions in the application tool chain. V1.0.0 is a low-level and concrete specification format, primarily designed to be read by simulation tools whereas V2.0 allows those users that create maneuver descriptions and tests, to define scenarios at a higher level of abstraction, providing alternative expression methods than the current detailed XML-format of ASAM OpenSCENARIO 1.0.0.

Due to the strongly coupled development activity, ASAM expects (and encourages) both parallel versions of ASAM OpenSCENARIO to converge in the mid- to long-term.

ASAM is taking early measures to ensure that convergence and compatibility between the two standards is given.

OpenSCENARIO V2.0.0 is intended to be a full superset of the features of ASAM OpenSCENARIO V1.0.0. Conversion of a subset of ASAM OpenSCENARIO 2.0 that maps to the feature set of ASAM OpenSCENARIO 1.x will be possible. All future ASAM OpenSCENARIO releases will be accompanied by an up-to-date ruleset for a migration path from 1.x to 2.x. The run time behavior of any scenario converted from the latest ASAM OpenSCENARIO 1.x to ASAM OpenSCENARIO 2.0 shall also be the same.



The convergence roadmap for ASAM OpenSCENARIO.

ASAM OpenSCENARIO 1.x

ASAM OpenSCENARIO defines a data model and a derived file format for the description of scenarios used in driving and traffic simulators, as well as in automotive virtual development, testing and validation. The primary use-case of ASAM OpenSCENARIO is to describe complex, synchronized `Maneuvers` that involve multiple instances of `Entity`, like `Vehicles`, `Pedestrians` and other traffic participants. The description of a scenario may be based on driver `Actions`, for example, performing a lane change, or on instances of `Trajectory`, for example, derived from a recorded driving `Maneuver`. The standard provides the description methodology for scenarios by defining hierarchical elements from which scenarios, their attributes and relations are constructed. This methodology comprises:

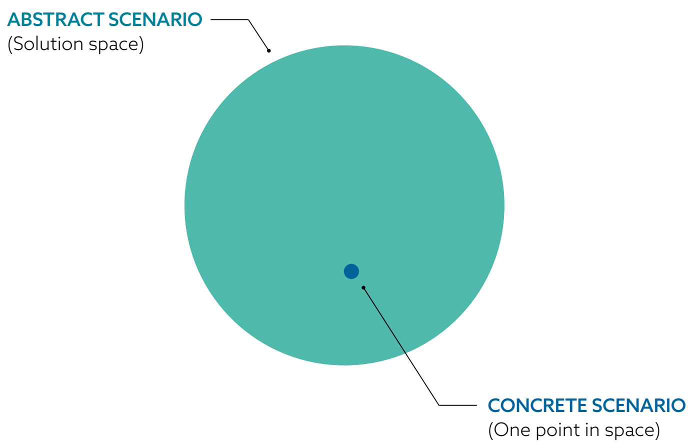
- Storyboarding, that is usage of a `Storyboard`, `Story` instances, `Acts`, `ManeuverGroups` and `Maneuvers`
- Usage of `Events` triggered by `Triggers`, defined by `Conditions`. `Events` cause Actions executions
- References to logical road network descriptions
- Instantiation of instances of `Entity`, such as `Vehicles`, or `Pedestrians`, acting on and off the road
- Utilization of re-use mechanisms, that is `Catalogs` and `ParameterDeclaration`
- Other content, such as the description of the Ego Vehicle, driver appearance, `Pedestrians`, traffic and environment conditions, is included in the standard as well.

The data for scenario descriptions in ASAM OpenSCENARIO is organized in a hierarchical structure and serialized in an XML file format with the extension xosc.

The standard is based on an UML data model which is used to derive XML schema files for XML file validation. Moreover, the standard is comprised of a reference guide and a user guide.

ASAM OpenSCENARIO 2.x

ASAM OpenSCENARIO 2.0 is founded on the concept of a domain-specific language (DSL), that should support all levels of scenario description, from the very abstract to the very concrete in a suitable way. A central aspect of consideration is the ability for domain experts to directly author and review scenarios without specific tooling, while retaining the ability to have a fully formalized description amenable to precise interpretation and execution by machines as well as humans.



Resolution of a solution space with abstract and concrete scenarios

Example of a Simple Scenario in Both Abstract and Concrete Forms

This is an early example from the concept paper (available on asam.net) and the syntax is subject to change significantly prior to release.

```
Concrete overtake scenario
scenario overtake_concrete:
  v1: car with(category: sedan, color: black)
  p: path
  path_explicit(p,[point("15",30m),
                 point("95",1.5m), ...])

  do parallel():
    dut.car.drive(p) with:
      lane(2)
      speed(50kph)
    serial:
        A: v1.drive(p, duration:3s) with:
          speed(70kph)
          lane(2, at: start)
          lane(1, at: end)
          position(15m, behind: dut.car, at: start)
          position(1m, ahead_of:dut.car, at:end)
        B: v1.drive(p, duration: 4s) with:
          position(5m, ahead_of: dut.car, at: end)
        C: v1.drive(p, duration: 3s) with:
          speed(80kph)
          lane(2, at: end)
          position(10m, ahead_of: dut.car, at: end)
```

```
Abstract overtake scenario
scenario overtake:
  v1: car # the first car
  v2: car # the second car
  p: path


  do parallel(duration: [3..20]s):
    v2.drive(p)
    serial:
      A: v1.drive(p) with:
        lane(same_as: v2, at: start)
        lane(left_of: v2, at: end)
        position([10..20]m, behind: v2, at: start)
      B: v1.drive(p)
      C: v1.drive(p) with:
        lane(same_as: v2, at: end)
        position([5..10]m, ahead_of: v2, at: end)
```

In comparison to ASAM OpenSCENARIO V1.0.0, a more detailed set of actions and attributes for the relevant simulation models shall be defined to allow a more comprehensive scenario description and to improve exchangeability. It should cover use cases at varying levels of autonomy. Hence, the language should represent an adequate level of complexity including maneuvers and ODD features that are not accounted for otherwise. An example is an AV driving on a complex road with road features such as roundabouts, bus stops, highway ramps, entries and exits or in dense traffic where various maneuvers like cut-ins, lane reductions and cross traffic with other agents on the road.

Beyond such improvements, the proposed domain-specific language supports the creation of more complex scenarios through flexible composition and parametrization of component scenarios in ways that allow realistic, emergent behavior to occur. This is expected to enable massive testing and verification of new, complex hardware and software systems, and their interaction with the complex environment of driving.

The first release of the 2.0 pipeline is expected in fall of 2021.

ASAM OpenSCENARIO 2.0 Implementers Forum

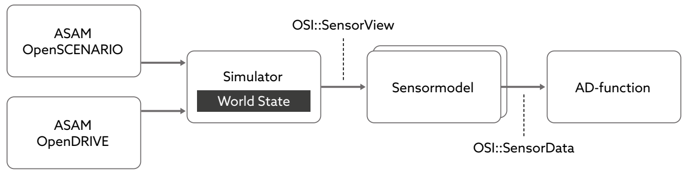
To support the implementation and adoption of a new standard like ASAM OpenSCENARIO 2.0 ASAM has also initiated a so-called "Implementers Forum". This forum brings implementers from different companies, open source projects and stakeholders together in order to discuss and work on implementation specific issues or questions. A core focus is to ensure there is no ambiguity in language features and constructs to prevent problems in exchange of scenarios across different implementations. The expected output of this forum is a shared understanding for implementation in both proprietary and open source tooling as well as demonstrative partial implementations or extensions for future implementers of the standard.

ASAM OSI®

Interface for Simulation

To achieve a widespread use of driving simulators for function developers, the connection between the function development framework and the simulation environment has to rely on generic interfaces. ASAM OSI provides easy and straightforward compatibility between automated driving functions and the variety of driving simulation frameworks available. It allows users to connect any sensor, via a standardized interface, to any automated driving function and to any driving simulator tooling. It simplifies integration and thus significantly strengthens the accessibility and usefulness of virtual testing.

ASAM OSI (Open Simulation Interface) started as a generic data exchange interface compliant with the ISO 23150 logic interface for the environmental perception of automated driving functions in virtual scenarios. In tandem with packaging specifications, such as the ASAM OSI Sensor Model Packaging (OSMP) specification, ASAM OSI provides solutions for simulation model data exchange across different implementations.

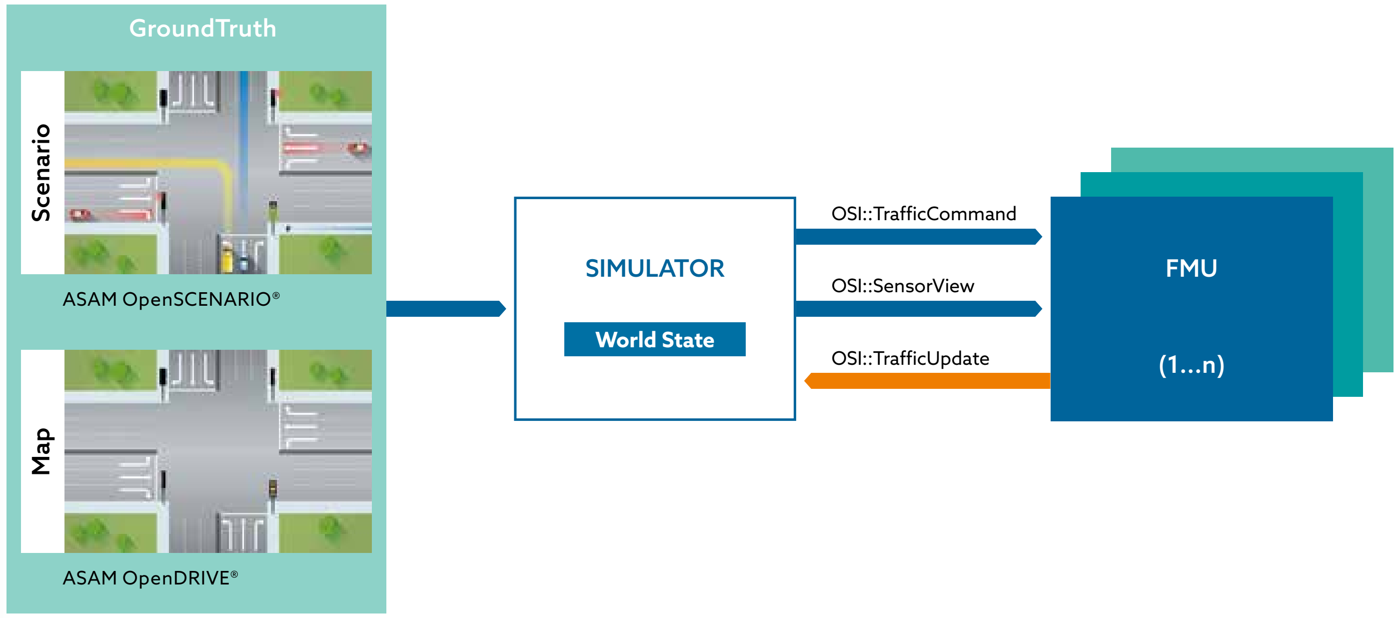


The current OSI logical flow

ASAM OSI contains an object-based environment description using the message format of the protocol buffer library developed and maintained by Google. ASAM OSI defines top-level messages that are used to exchange data between separate models. Top-level messages define the `GroundTruth` interface, the `SensorData` interface and, since ASAM OSI version 3.0.0, the `SensorView` / `SensorView` configuration interfaces and the `FeatureData` interface.

- The `GroundTruth` interface provides an exact view on the simulated objects in a global coordinate system, the ground truth world coordinate system.
- The `FeatureData` interface provides a list of simple features in

An Enhanced ASAM OSI Logical Flow – Iterartively Releasing in 2021

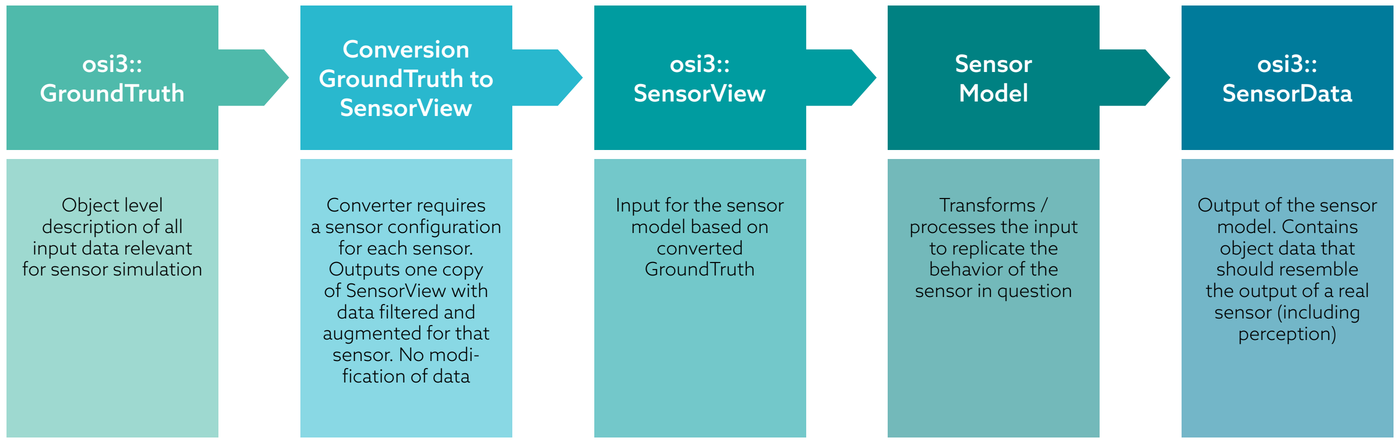


the reference frame of the respective sensor of a vehicle for environmental perception. It is generated from a `GroundTruth` message and may serve as input for a sensor model that simulates object detection or feature fusion of multiple sensors.

- The `SensorData` interface describes objects in the reference frame of a sensor for environmental perception. It is generated from a `GroundTruth` message and can either be used to directly connect to an automated driving function using ideal simulated data or may serve as input for a sensor model simulating limited perception as a replication of real-world sensor behavior.
- The `SensorView` Configuration interface is the configuration setting for the `SensorView` to be provided by the environment simulation. This message can be provided by the sensor model to the environment simulation, in which case it describes the input configuration that is desired by the sensor model.
- The `SensorView` interface is derived from `GroundTruth` and used as input to sensor models. The `SensorView` information is supposed to provide input to sensor models for simulation of actual real sensors.
- In future releases, ASAM OSI will provide new top-level message definitions. These include vehicle models using a human-machine interface, support for agents of traffic participants, and support for atomic actions of ASAM OpenSCENARIO.

The ongoing development activity at ASAM aims to further extend ASAM OSI in order to fulfill the requirement of being able to use it as a standardized interface between further simulation entities. One example of this enhanced flow is depicted on page 27 (bottom graphic).

Understanding the ASAM OSI Flow



This flow represents the status at time of writing (Q1 2021). Upcoming releases aim to extend this further (e.g. sensor specific views).

VERSION 1.0.0
IN NOV 2021

ASAM OpenLABEL

Standardized Labeling for Objects and Scenarios

ASAM OpenLABEL is currently under development. The project aims to standardize the annotation format and labeling methods for objects and scenarios. ASAM OpenLABEL will provide a guideline on how the labeling methods and definitions should be used.

From working with different customers, a significant fragmentation emerged in the way each individual organization categorizes and describes the objects populating the driving environment. Such categorizations and descriptions are the fundamental building block of any Autonomous Driving System's (ADS) perception stack, since it is through them that an ADS comes to a basic and profound understanding of the status of around its surrounding.

The lack of a common labeling standard in the industry is the root cause of several different issues:

- Hampered Vehicle2Vehicle Interaction: The different descriptions and understandings of surroundings may cause casualties in complex situations involving two or more different ADSs
- Precluded sharing: It is a highly difficult if not impossible task to share data across organizations that adopted different labeling taxonomies and specifications
- Reduced annotation quality: Each individual labeling task requires ad-hoc training and even development of custom software functions that translate into a higher probability of errors and thus a threat to safety
- Deprecation of old labels: Long-term operation of ADS development imply changes in quantity and comprehensiveness of labels to be produced considering the evolution of the driving scenes, new sensors, and scenarios. As a consequence, a flexible descriptive language is required to absorb future extensions and modifications of labels and guarantee backward-compatibility.

```
{
    "openlabel": {
        ...
        "objects": {
            "1": {
                "name": "van1",
                "type": "Van"
            },
            "2": {
                "name": "cyclist2",
                "type": "Cyclist"
            },
            ...
            "16": {
                "name": "Ego-vehicle",
                "type": "Car"
            },
            "17": {
                "name": "road17",
                "type": "Road",
            }
        }
    }
}
```

ASAM OpenLABEL JSON format snippet

JSON Format

The use of a standardized format will help save cost and resources in converting annotated data. ASAM OpenLABEL will be represented in a JSON format and can therefore be easily parsed by tools and applications. ASAM OpenLABEL will specify which coordinate systems are used as reference for the label. This already facilitates the conversion a lot.

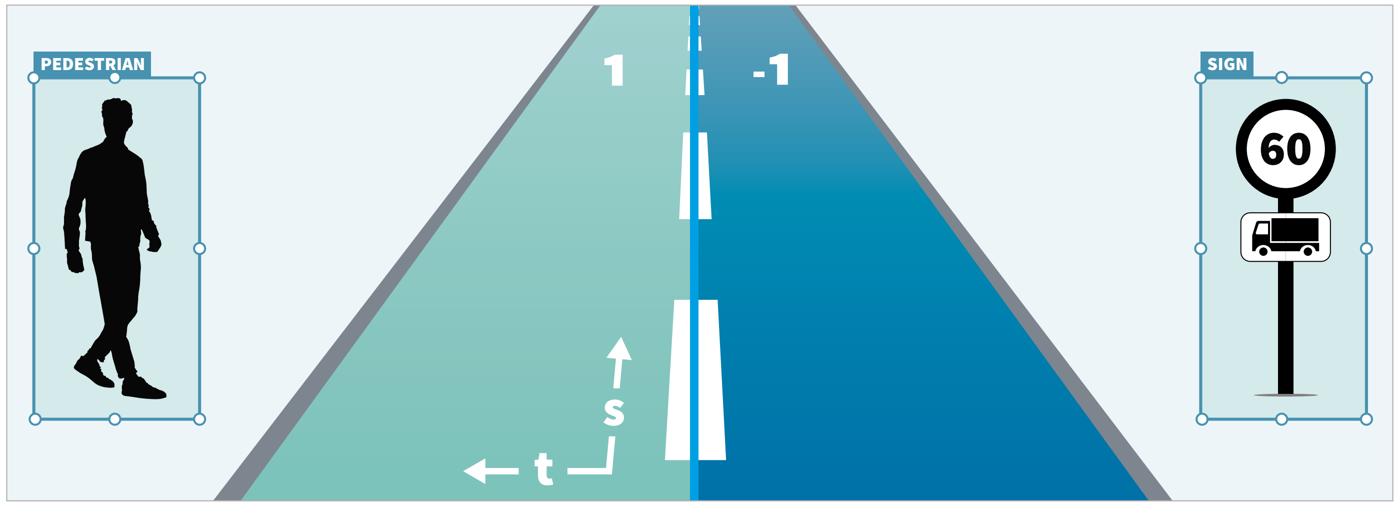
Extended Labeling Objects

ASAM OpenLABEL will also provide methods to label objects in a scene (one point in time/ frame) as well as across multiple scenes by enhancing the methods to label actions, intentions and relations between objects.

Labeling Different Data Types

The ASAM OpenLABEL format will be capable of managing different types of labeling methods, for different types of data. This includes 2D and 3D bounding boxes, the rotation of 3D bounding boxes, semantic segmentation of images and point clouds. These semantic segmentations can be either instance classes, single/multi-class, partial or full classes.

Example Tags for an Annotated Scene



It is important that the labeling fits into the taxonomy definitions of a user/company. For that reason, the project group intends to provide ASAM OpenLABEL with the ability to import ontologies and taxonomies for the labeling process. The ASAM OpenLABEL project group is closely interacting with the ASAM OpenXOntology project to align ASAM OpenLABEL with the OpenX domain model and to provide requirements for the ASAM OpenXOntology standard. As ASAM OpenLABEL and ASAM OpenXOntology are currently being developed in parallel, the ASAM OpenLABEL standard will be developed with an external ontology. The experience on using ASAM OpenLABEL with different ontologies can be used to give the user a guideline on how to import their own ontology and use this with ASAM OpenLABEL. It might be possible that the use of foreign ontologies will require a certain standardized ontology format.

The development of ASAM OpenLABEL started in January 2021. The standardization will be based on the concept paper and contain the following work packages:

1. **USER GUIDE:** The User guide will help future users of ASAM OpenLABEL to apply the standard for their use cases. The User guide will be accompanied by examples.
2. **HARMONIZATION:** The main task of this work package is to ensure the alignment of ASAM OpenLABEL with the other standards in the ASAM domain Simulation.
3. **LABELING:** The Object and Scene Labeling work group shall create the specification for the labeling of objects identified in a scene (one point in time).
4. **OBJECT LABELING:** This subgroup focusses on describing how single objects can be labelled.
5. **SCENE LABELING:** This subgroup focusses on how the labeled objects can be labeled in the context of a scene. This work package has several perspectives: conditional labels, event labels, action labels, relation labels.
6. **SCENARIO LABELING:** This work group will define scenario labels on a meta level. This includes labels that can be derived from the content of the scenario as well as labels which are non-derivable.
7. **DATA FORMAT:** The work package will create the JSON format based on the input given in the concept paper and provided by the specification work groups (2 – 4).
8. **STANDARD DOCUMENTATION:** This work package has a close interaction with all other work package and is responsible to create the final standard document. It will be mainly executed by a service provider.

The first version of ASAM OpenLABEL is foreseen to be released in Nov 2021.

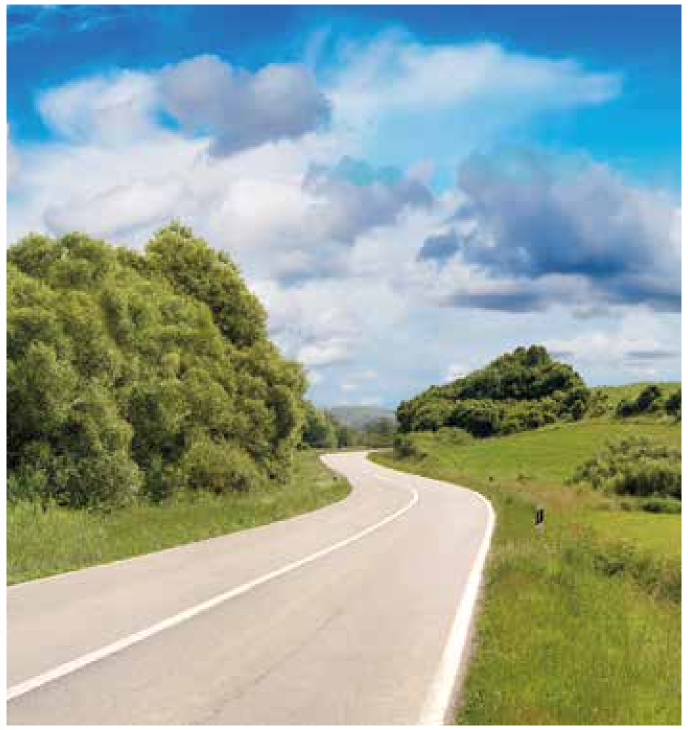
CONCEPT IN JUL 2021

ASAM OpenODD

Defining the Operational Design Domain for Automated Vehicles

ASAM OpenODD (Operational Design Domain) is still a very young standardization initiative within the ASAM Simulation domain. ASAM has started a concept project in Sep 2020, to create the base concept for a future ASAM OpenODD standard. The aim is to provide a format that is capable of representing a defined Operational Design Domain for connected automated vehicles (CAV).

An Operational Design Domain Definition (ODD) should be valid throughout the entire operating life of a vehicle and is part of its safety and operational concept. The ODD is used for the functional specification of connected automated vehicles. It specifies what environment parameters (static and dynamic) the CAV must be able to manage. They include all types of traffic participants, the weather conditions, the infrastructure, the location, the time of day and everything else that can have an impact on the driving situation.



Country road

To give an example: Looking at the picture on the bottom, an ODD would define the following parameters as suitable for the vehicle:

- Paved road
- Right hand traffic
- Country road
- No visibility limitation due to weather or time of day
- Expect all possible traffic participants
- Expect animals
- …

But there will be many more attributes in the ODD to describe this road and the environmental conditions.

The goal of the ASAM OpenODD project is to create a machine-interpretable format to represent the ODD specification. With this format an ODD description becomes exchangeable, comparable and processable. This new format will enable for example the following use case:

- A city defines an ODD for its inner city, using the ASAM OpenODD format. Now car manufactures can compare vehicle ODDs, defined in ASAM OpenODD, to their vehicle to find out if it is allowed to drive in this specific inner city. The advantage for homologation bodies will be that they can define ODDs against which they can check the vehicle's ODD.

- A second use case which will support the development of ADAS and AD systems is the use of the ODD to define the testcases that are necessary to validate the vehicle. There can be obvious limitations e.g. if the vehicle is not capable of speeds above 50 km/h, therefore highway tests are not necessary. This application of an ODD will help to focus the limited validation resources on the really needed scenarios.

The ODD must be represented so it can easily be used for simulation and other machine processed environments. The content of ASAM OpenODD will be derived from an abstract „Vehicle ODD", that provides the information in a usable manner. For the purpose of using an abstract vehicle ODD description (represented in ASAM OpenODD) for simulations and post-processing the format must fulfil the following requirements:

- searchability
- exchangeability
- extensibility
- machine readability
- measurability and verification
- human readability / constrained natural language

The concept project consists of five work packages targeting individual aspects of the standard:

1. **ATTRIBUTES:** This work package aims to provide a base set of relevant attributes for the ASAM OpenODD format.

2. **SPECIFICATION:** This work package is responsible for developing the semantics and syntax for the ASAM OpenODD description language, also enabling the use of different ontologies/taxonomies for the definition of ODDs.

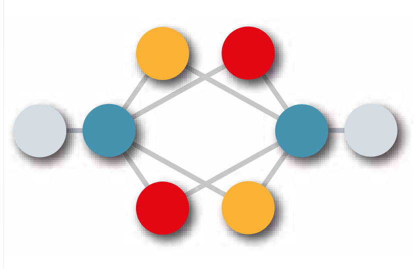
3. **METRICS:** This subgroup discusses the possibility of measurable metrics and what the ODD needs to be able to represent, so any application can perform analysis on the ODD.

4. **REPRESENTING UNCERTAINTY:** This workpackageaddresses the issue of representing uncertainty with the goal to enable the ODD format to handle rare events and misuse.

5. **USER GUIDE:** The last work package will start formulating a user guide for the ODD format. The first draft of the user guide will be completed in the subsequent standardization project.

The ASAM OpenODD standardization initiative takes into account and aims to complement the activities of BSI (BSI PAS 1883 provides a taxonomy for ODD) and ISO (ISO 34503 uses the taxonomy to provide a high-level definition format for ODD). All three projects are in close contact to avoid contradictions.

The concept for a future standard ASAM OpenODD is foreseen to be published in Nov 2021.



VERSION 1.0.0 IN JUL 2021

ASAM OpenXOntology

Core Domain Model for the ASAM Simulation Domain

The OpenX standards describe road networks, driving maneuvers and test scenarios for driving and traffic simulation. The standards share concepts from the area of road traffic, such as roads, lanes, and traffic participants. ASAM OpenXOntology provides an ontology-based architecture for these concepts and thus a common definition of the domain model for the ASAM OpenX standards. The ASAM OpenXOntology consists of multiple parts such as core, domain and application ontologies that build on each other.

Ontologies are a method to represent knowledge in a way that computers can understand. Like a terminology as defined in ISO 704, an ontology contains standardized definitions of concepts that are used in a particular area of knowledge, such as road traffic. These standardized definitions are used when data is exchanged by human parties and by computer programs that work independently. In this way, ontologies and terminologies enable both humans and machines to have a shared understanding of the meaning of the concepts.

Unlike terminologies and taxonomies, ontologies also describe how the defined concepts relate to each other. Logically formalized ontologies use predicate logic to describe these relations. In this way, ontologies enable humans and machines to use logical reasoning in order to gain additional knowledge about the data that is exchanged. In the context of this specification, the term ontology refers to logically formalized ontologies, particularly ontologies that are based on a description logic.

The ASAM OpenXOntology project started to address the identified need for common definitions to be used by the ASAM OpenX standards. There are several reasons why an ontology is beneficial to reach this goal, for example by providing common definitions of concepts. As the ASAM OpenXOntology is implemented using semantic web standards and OWL it is easily extendable by users or further standards. The ASAM OpenXOntology enables a computer program that implements an ontology reasoner to infer relationships between ontology classes that are not explicitly specified. Furthermore, ontologies can be used to evaluate the semantic similarity of different assertions made in the domain.

The ASAM OpenXOntology architecture covers the following concepts from the domain of road traffic:

- Road infrastructure (roads and lanes)
- Traffic infrastructure (traffic signs, signals, etc.)
- Temporal changes in the road and traffic infrastructures (road constructions, diversions, etc.)
- Dynamic traffic agents, such as cars, pedestrians, cyclists, etc.
- Environment (weather, time of day, etc.)
- V2X communication objects

ASAM OpenXOntology contains the following deliverables:

- OWL files for the core, domain, and application ontologies that are part of ASAM OpenXOntology
- ASAM OpenXOntology guide consisting of specification and user guide

Relations to Other Standards

ASAM OpenXOntology has relations to ISO 23150, SAE J3016 (2018) and BSI PAS 1883.

The following ASAM OpenX standards contribute to the first version of the ASAM OpenXOntology (V1.0.0):

- ASAM OpenDRIVE, version 1.6
- ASAM OpenSCENARIO, version 1.0
- ASAM OpenLABEL, not yet published
- ASAM OpenODD, not yet published
- OSI V3.2

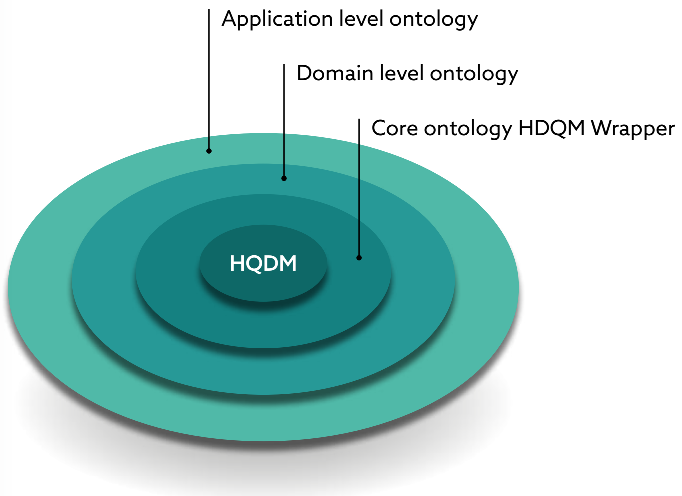
Architecture of ASAM OpenXOntology

ASAM OpenXOntology consists of multiple layers that build on each other:

- Core ontology
- Domain ontology
- Application ontology

Core Ontology

The core ontology is a set of basic concepts and relationships that serve as building blocks for more complex and domain-specific concepts.



ASAM OpenXOntology architecture

These concepts include:

- Physical objects and their changes in state
- Activities including actions and behaviors that involve the physical objects in active and passive roles
- Events that mark the changes in states of physical objects
- Critical points in time and triggers for activities

The core ontology also provides meta models for describing common compositional, spatial, and temporal relationships between individuals in the domain.

Domain Ontology

The domain ontology defines central concepts of the road traffic domain, for example, lanes, roads, and road surface. It contains only concepts that are shared by all ASAM OpenX standards using ASAM OpenXOntology. These shared concepts are summarized in the domain ontology in order to provide a consistent and meaningful underlying language for the ASAM OpenX standards.

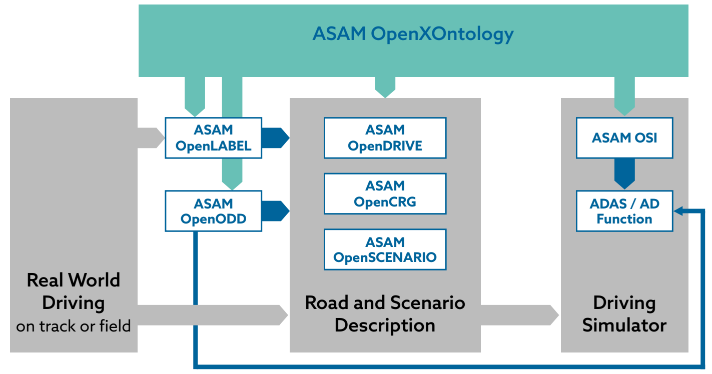
Application Ontology

There shall be one application ontology for every ASAM OpenX standard. It contains concepts that are only used in that specific standard, for example ASAM OpenDRIVE or ASAM OpenSCENARIO. Application layers use core-level and domain-level imports.

Usage of the Ontology

ASAM OpenDRIVE uses ASAM OpenXOntology definitions for static road infrastructure elements that are shared with other ASAM OpenX standards. Examples are lanes and roads. Also, ASAM OpenDRIVE uses connective and spatial relationships between the elements that are defined in ASAM OpenXOntology. Ambiguous terms that do not correspond with other ASAM standards might need a change in upcoming versions.

ASAM OpenSCENARIO retrieves definitions for spatial and temporal relationships between both dynamic and static traffic participants from ASAM OpenXOntology. In particular, the domain-specific language of ASAM OpenSCENARIO 2.0 will use concepts and relationships from the core ontology to provide clear and unambiguous, logically based definitions for the language terms. Ambiguous terms that do not correspond with other ASAM standards might need a change in upcoming versions.

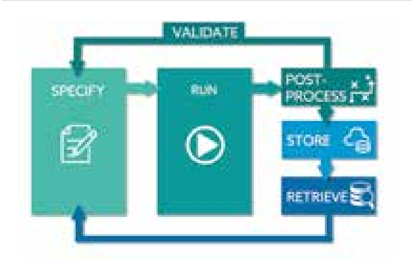


ASAM OpenXOntology within the ASAM OpenX framework

To a substantial part, the labels in ASAM OpenLABEL define entities within the road traffic domain and the type of the geometrical constructs that are adequate to capture those entities in multi sensor data streams, for example lidar 3D bounding boxes, 2D images boxes, or polygons. A common ontology that represents knowledge about the road traffic domain would provide a logical and more comprehensive description of the labels, pave the way for creating reasoning applications, and harmonize the ASAM OpenLABEL standard with other ASAM OpenX standards that will adopt it. The ASAM OpenLABEL project is closely connected to ASAM OpenXOntology because ASAM OpenXOntology provides the object descriptions for the labels. On the other hand, the ASAM OpenLABEL project delivers requirements to the ontology project with respect to the relevant entities that need to be labeled and their relationships.

Currently, the ASAM OpenODD concept is still under development. The base set of attributes is referenced to the existing ODD standards, for example, BSI PAS 1883, which serves as an underlying ontology to instantiate individual ODD specifications. In the coming phases of the ASAM OpenXOntology harmonization, such standards will be aligned with other domain concepts and form a common domain ontology. ASAM OpenODD will then be able to use concepts and relationships from the ASAM OpenXOntology to build specific ODDs. Ambiguous terms that do not correspond with other ASAM standards might need revision. The ASAM OpenXOntology will also set out the available relationships to be used when constructing the ODD specification. In addition, ASAM OpenXOntology will enable methods to extend the underlying ontology, e.g. adding a new subclass to rain intensity.

ASAM OSI (Open Simulation Interface) will use concepts and relationships of ASAM OpenXOntology to generate ground truths as input to sensor and sensor fusion models. ASAM OpenXOntology is expected to ensure the harmony between ASAM OSI, ASAM OpenODD, ASAM OpenSCENARIO, ASAM OpenDRIVE, and various sensor models. ASAM OSI currently defines a fixed message structure, entity classifications, and maneuver actions. Therefore, it is necessary to guarantee the connectivity and compatibility with the existing sensor model. That means that specifications made in the ontology regarding the protocol definitions have to be considered very carefully. The ontology should be used to close the gap between scenario engine, environment simulator, and the sensor model using input and output messages from ASAM OSI.



STUDY PROJECT

ASAM Test Specification

The introduction of scenario-based testing into the overall development processes of advanced driver assistance systems as well as automated driving has been one of the driving forces for the new standards being developed in the ASAM Simulation domain. This includes the development of the ASAM OpenSCENARIO 1.0 and 2.0 scenario specification language standards, as well as related content (ASAM OpenDRIVE, ASAM OpenCRG), meta-data (ASAM OpenLABEL), interface (ASAM OSI), operational design domain (ASAM OpenODD), and common ontology (ASAM OpenXOntology) standards.

The introduction of scenario-based testing is taking place in an industry which already is heavily invested in standardized testing and test automation. This investment is visible in the prominence of such standards in the ASAM test automation domain (e.g. ASAM OTX Extensions, ASAM XIL).

The introduction of scenario-based testing into these workflows leads to a series of design challenges on the interplay between scenarios, test cases, test platforms and test automation. There is currently no overall solidified industry consensus on the practical aspects of this, which could be relied on to shape the interplay of the parts and their respective standards into a harmonious whole.

This is in part also caused by a greatly increased set of stakeholders that are touched by scenario-based testing as contrasted to the set of stakeholders that were previously touched by the testing and test-automation standards: For the development of ADAS and AD functions, new stakeholders like homologation authorities, regulatory bodies, traffic researchers, research consortia, etc. are involved in the formulation, analysis, and promulgation of scenarios, which clearly transcends the set of traditional stakeholders of testing.

This study project is focused on the interplay between scenario-based testing and the existing testing and test automation landscape, in order to ensure that standardization within and outside of ASAM is shaped in ways that align the different standards as closely as possible while allowing for any necessary variety of industry practice.

This analysis shall be based on the actual use cases of scenario-based testing across the whole extended development process (including pre-processes, like development of homologation and regulatory rules and requirements, effectiveness assessments, etc.). It shall develop reference workflows that support these use cases.

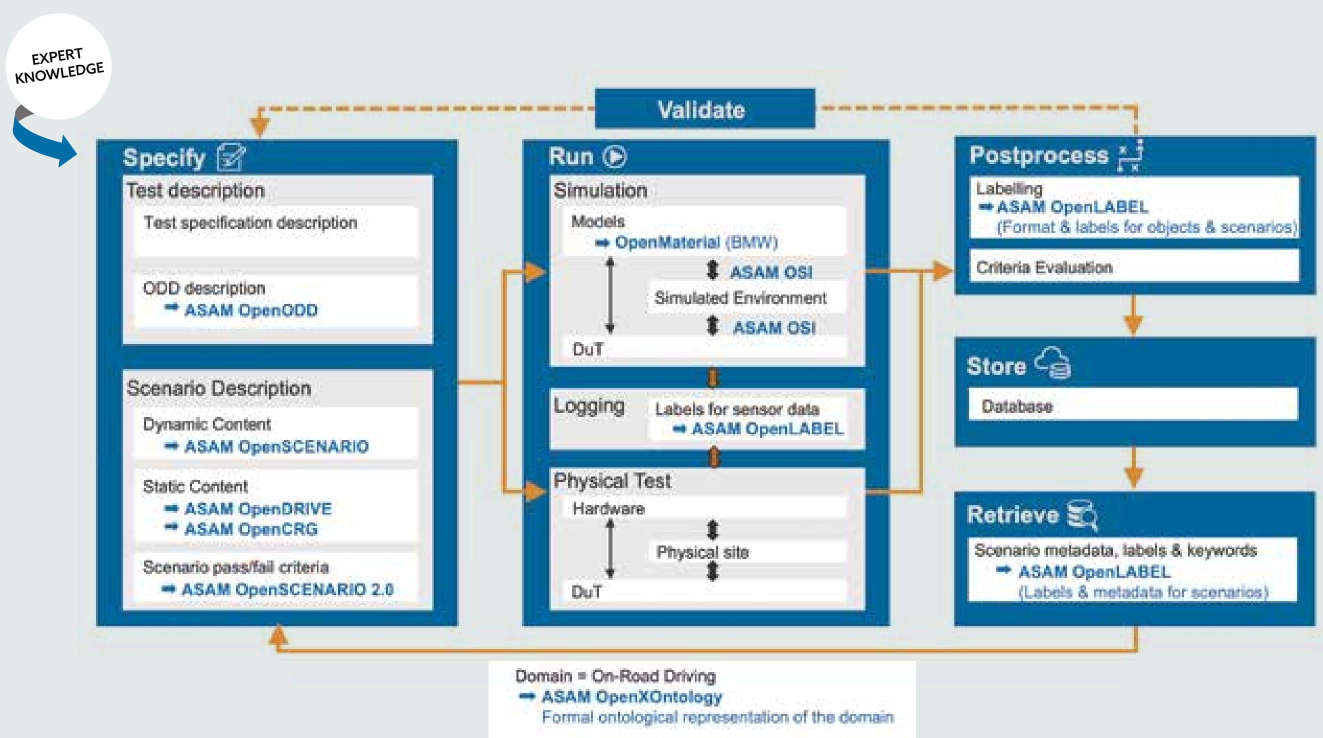
Based on those reference workflows, white gap analysis shall be undertaken to identify gaps and overlaps in the standardization picture which need to be addressed to enable the most effective implementation of those workflows to be achieved.

As a result a set of recommendations shall be created that address those deficiencies through standard extensions or new standardization projects, as well as through closer coordination between projects within and outside of ASAM.

One source of information for the study project will be the "usage and pragmatics" working group results of the ASAM OpenSCENARIO 2.0 concept project, which touched upon some of these issues, as well as results from the ongoing ASAM OpenSCENARIO 1.x and 2.0 projects. This analysis should in the end lead to a documented set of overall use cases for scenario-based testing, a set of potential workflows implementing those, together with identified roles, standards and their application.

Additionally, any identified gaps in the workflows shall be characterized, leading to the identification of potentially needed additions to existing standards, or even the need for completely new standards. Requirements for those standards or additions shall be collected and documented.

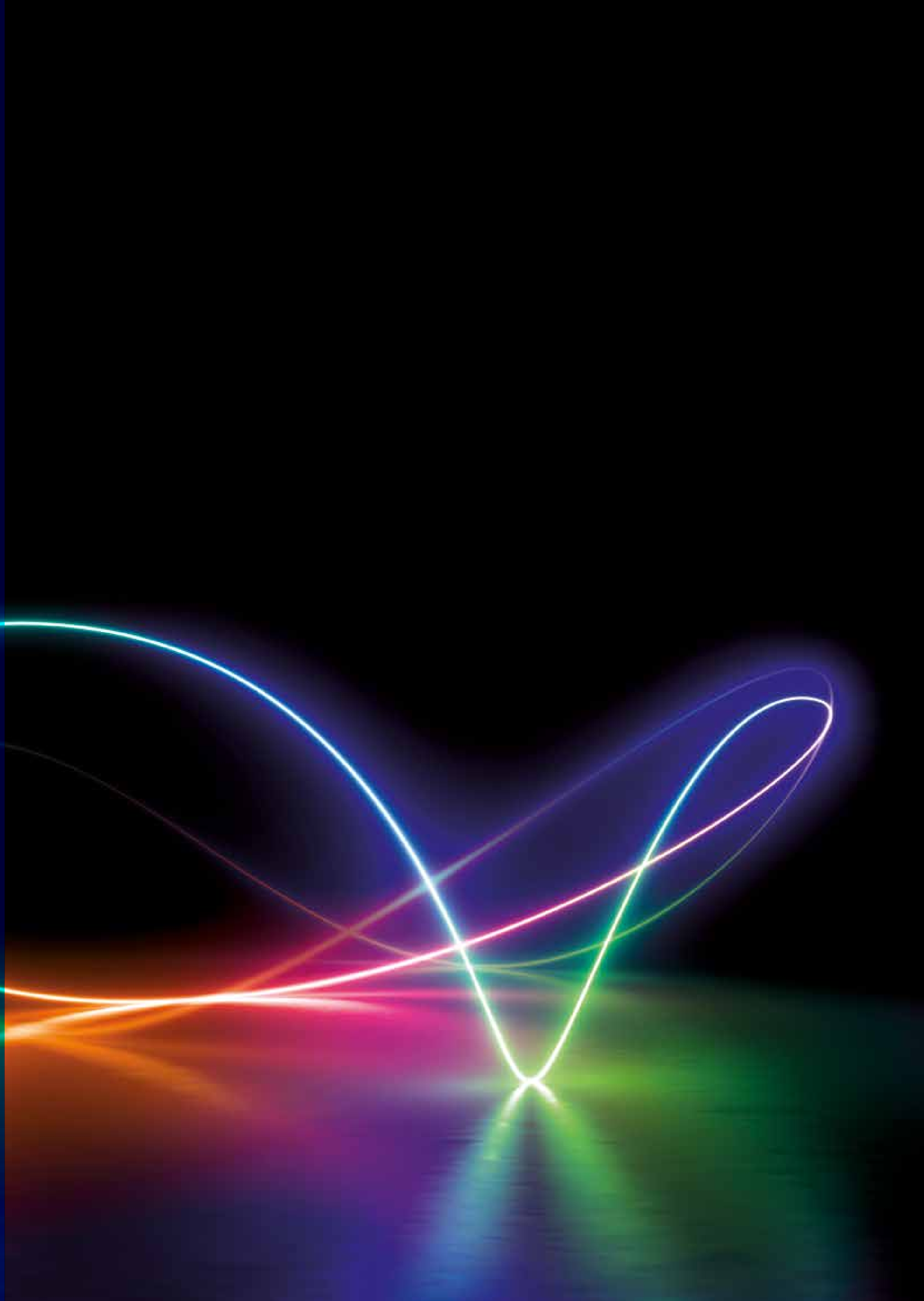
Scenario-Based Testing with ASAM OpenX



ASAM OpenX IN CONTEXT

The ASAM OpenX standards are only one part of the standardization landscape for validation of highly automated driving functions. Other organizations are also developing standards to accomplish the tasks.

In the following section, this guide highlights and describes the current landscape of standards supporting simulation.



ASAM OpenX in Context

Authors: Prof. Frank Köster, German Aerospace Center (DLR)
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Benjamin Engel, ASAM e.V.

SIMULATION-BASED TOOL-CHAINS UTILIZING STANDARDS

Nowadays, simulation is not just a tool restricted to uses in selected tasks during the development of complex technical components or systems. It has become a powerful tool, with high relevance for all development phases, ranging from the identification of first ideas and basic requirement elicitation up to the final test and assessment steps.

Current discussions regarding DevOps cycles (cf. Figure 1), which address entire product lifecycles lead to new application areas for simulation-based tools and their connection to innovative engineering and development approaches that will in the future rely heavily on operational data (closed loop) – e.g. for the monitoring of products under operation or also for their refinement and improvement.

DevOps describes the integration of activities from the area of systems development with systems operation. In general, the intention is to shorten the systems development life cycle and ensure high systems quality while providing continuous delivery. DevOps has its roots in the area of IT systems and software development but is today also discussed in other domains – e.g. automotive and industry.

To illustrate and exemplify the DevOps-Cycle, the Automated Lane Keeping System1 (ALKS) can be utilized. ALKS is specified as a SAE-Level 3 (Conditional Automation) application supporting the driver by controlling the longitudinal and lateral movements for velocities up to a maximum of 60 km/h. The Operational Design Domain (ODD) is restricted to roads where vulnerable traffic participants are prohibited and the traffic participants moving in the opposite direction are separated physically.

Further, the DevOps cycle`s individual phases, shown in graphic on page 39, are enhanced by simulation applications as well as examples of the ALKS function to explain the interdependencies and provide a first rough practical understanding.

The main phases of the DevOps cycle are:

PLAN – Deriving application requirements and planning the system and product release: Identify and select relevant scenarios for operation and the refinement of requirements based on expert knowledge and experience is a crucial task in the beginning of the development process. Regarding the ALKS application, the scenarios can be derived systematically with respect to the intended ODD and the system specification.

CONSTRUCT / IMPLEMENT – Constructing and implementing the system, including design and release approaches: Rapid Prototyping provides early insights into the system's development status and reveals implementation flaws. The implemented ALKS function is tested in early development stages to ensure that design as well as implementation problems can be identified. In this case, the use of simulation techniques provides a major advantage, because rapid prototyping can be performed while the real-world ALKS system does not have to be built in this phase.

BUILD – The implemented system is built and compiled: After the ALKS code is built and compiled the systematic testing in early development stages can be further enhanced by simulation methods. In this phase requirements established before can be verified while the code development continues.

TEST – Continuous tests are performed on the compiled system: In this stage systematic testing can be performed via further enhanced simulation environments. The requirements as well as the ODD description of the ALKS function are further improved until they reach a level of acceptable maturity. In this phase the need for automated testing becomes more and more relevant. Test automation is required to ensure efficiency while simultaneously managing the rising complexity.

RELEASE – The system is approved for release: The ALKS function is conform with the required KPIs. A proof of system safety is assured in this phase. The requirements are fulfilled and the systematic testing performed in previous phases provides a certain robustness of the current implementation.

DEPLOY – The system is deployed for customer usage: Integrity tests of the released system in the system context or its operational environment are performed.

OPERATE – The released system is observed while being used by customers: Further KPI fulfillments can be checked in the field operation, such as the impact of CAVs on traffic quality. The recorded data while the ALKS function operates is utilized to improve simulation models, find design flaws, and gather more insights into the system.

MONITOR – The long-time performance of the system can be monitored during operation: This phase allows for the identification of additional yet unknown relevant scenarios during long time operation. These relevant scenarios are difficult to identify, mostly because of the rare occurrence and low probability of such scenarios. Nonetheless, this phase can be considered very important for updates of the current ALKS function and for the development of the next generation of driving function applications.

These different phases and their integration in one continuous cycle lead to new requirements on simulation-based tools, their components and interfaces as well as relevant standards. This includes standardized scenario descriptions, the specification of interfaces, the description of data as well as in the context of processes / methodologies defined to guarantee traceability and a structured documentation of tool configurations or executed simulation runs.

Figure 2 (on next page) shows some essential components of a simulation environment needed to cover the major requirements for the various tasks that result from the different activities in the context of a DevOps cycle. Additionally, selected standards with relevance for the mentioned components and associated tasks are mentioned. In the following section the depicted components will be explained. The mentioned standards are also briefly described in separate subsections.

The **Configuration Management** manages the overall tool configurations for different simulation-based tasks. These different configurations can for example be specified, stored and recalled. The configurations are persistently stored within a **Repository** that also serves as a storage system for all other types of configurations, data and models etc. The access to the repository is encapsulated by **Store** and **Retrieve** components that are capable of processing complex queries.

Figure 1: DevOps-Cycle

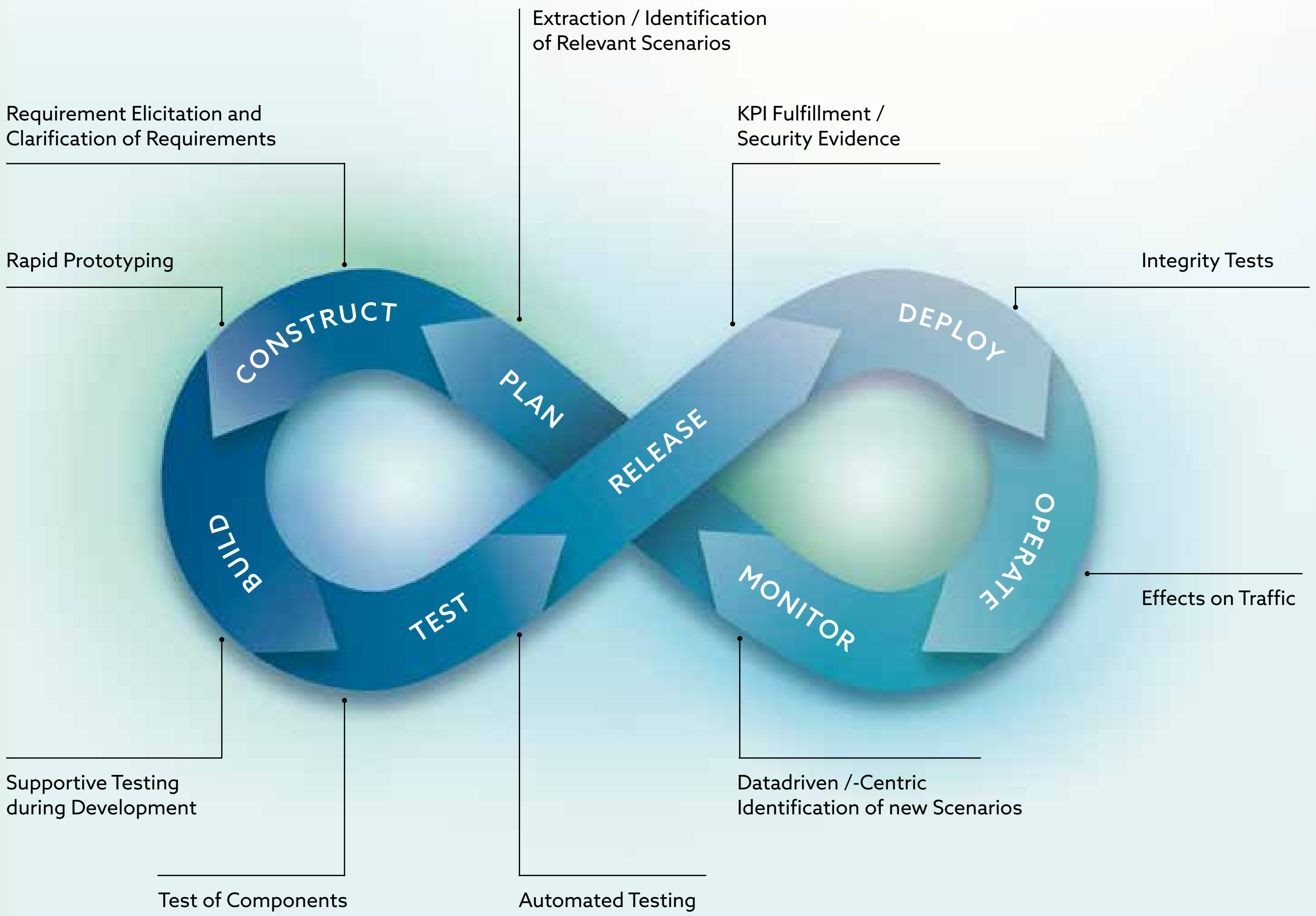
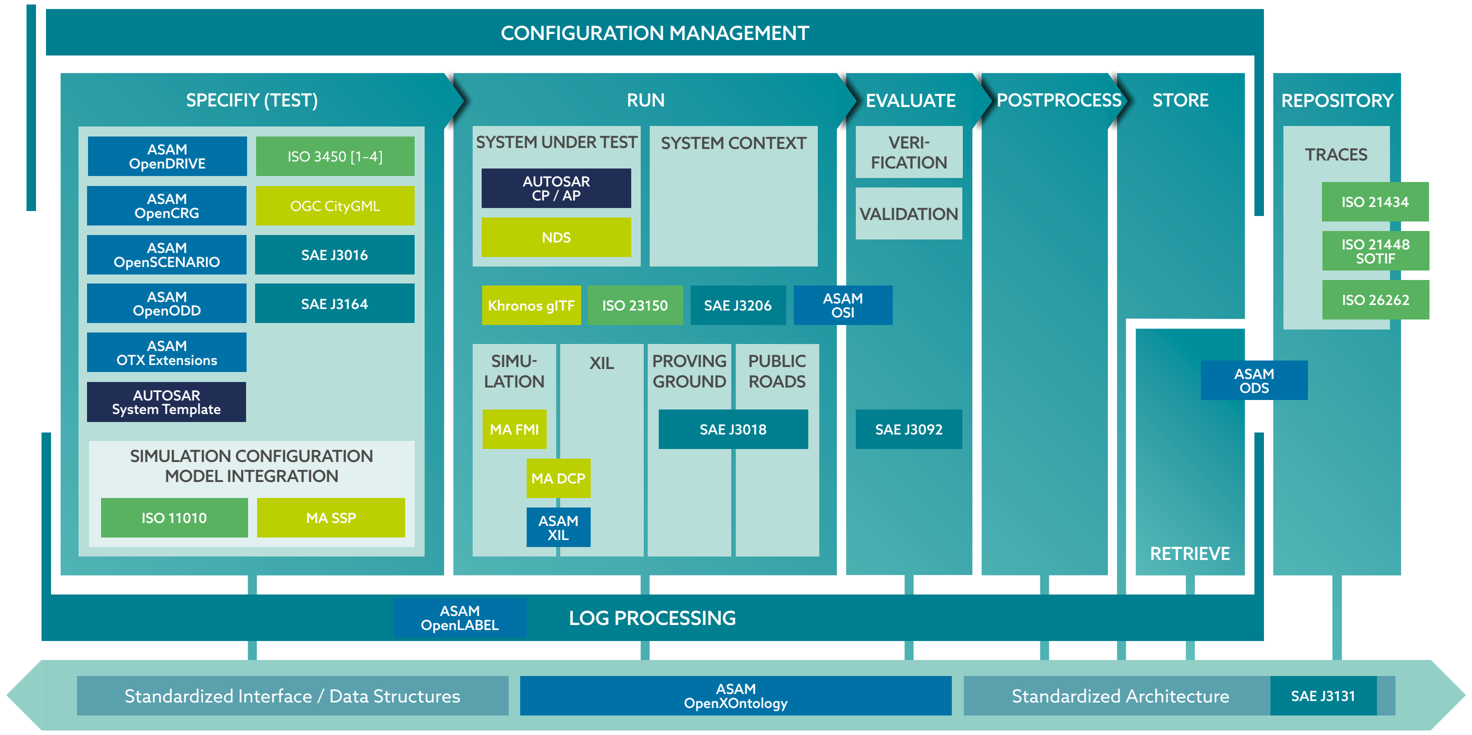


Figure 2: Abstract Architecture of a Simulation Environment



For example, the configurations of sequences of simulations runs managed by the **Specify (Test)** component are also stored within this repository. The **Simulation Configuration / Model Integration** component addresses the configuration of the simulation-core, including descriptions of the coupled models. The **Run** component controls the execution of simulation runs and provides recorded data together with all relevant associated configuration data to the **Evaluate** components. For instance, the data could be used for different purposes in the context of **Verification & Validation**. In many cases this requires specialized postprocessing **(Postprocess)**. Through such components as **Simulation, XIL, Proving Ground** and **Public Roads** the simulation environment can be connected to other tools and tool chains. The component **Log Processing** manages the entire data logging and is connected to all other components of the simulation environment.

The single interfaces between the mentioned components are represented here by an abstract bus system. This bus is able to process all types of relevant data and standards – it is the backbone of the simulation environment.

The labels in Figure 2 (e.g. ASAM OpenODD, ASAM OpenDRIVE and ASAM OpenSCENARIO) are intended specifically to associate both ASAM-standards and standards proposed by other standardization institutions with the different components of the abstract simulation environment. These standards are described in more detail in the following subsections.

After the description of these standards, this text provides a set of application examples that heavily rely on standards – in particular, standards maintained and provided by ASAM.

INFRASTRUCTURE STANDARDS

Representation Standards (Static Behavior)

ASAM OpenDRIVE

ASAM OpenDRIVE defines a file format for the precise description of road networks. The ASAM OpenDRIVE description format contains all static objects of a road network that allow realistic simulation of vehicles driving on roads. In order to render the complete environment, additional description formats for static 3D roadside objects, such as trees and buildings, are needed. The data of ASAM OpenDRIVE is organized in a hierarchical structure and serialized in an XML file format. → [p. 20]

ASAM OpenCRG

ASAM OpenCRG defines a file format for the description of road surfaces. It was originally developed to store high-precision elevation data from road surface scans. The primary use for this data is in tire, vibration or driving simulation. Precise elevation data allows realistic endurance simulation of vehicle components or the entire vehicle. For driving simulators, it allows a realistic 3D-rendering of the road surface. The file format can also be used for other types of road surface properties, e.g. for the friction coefficient or grey values. → [p. 22]

Khronos glTF

glTF™ (Graphic Language Transmission Format) is a standardized file format for three-dimensional scenes and models. The standard describes the efficient transmission and loading of 3D scenes and models by engines and applications. glTF minimizes the size of 3D assets, and the runtime processing needed to unpack and use them. glTF defines an extensible, publishing format that streamlines authoring workflows and interactive services by enabling the interoperable use of 3D content across the industry.

https://www.khronos.org/gltf/

OGC CityGML

The City Geography Markup Language (CityGML) is a concept for the modelling and exchange of 3D city and landscape models that is quickly being adopted on an international level. CityGML is a common information model for the representation of 3D urban objects. It defines the classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantical and appearance properties. Included are generalization hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. In contrast to other 3D vector formats, CityGML is based on a rich, general purpose information model in addition to geometry and graphics content that allows to employ virtual 3D city models for sophisticated analysis tasks in different application domains like simulations, urban data mining, facility management, and thematic inquiries. Targeted application areas explicitly include urban and landscape planning; architectural design; tourist and leisure activities; 3D cadastres; environmental simulations; mobile telecommunications; disaster management; homeland security; vehicle and pedestrian navigation; training simulators; and mobile robotics.

CityGML is realised as an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is implemented as an application schema for the Geography Markup Language version 3.1.1 (GML3), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211. CityGML is an official OGC Standard and can be used free of charge.

Overview on Standards for Simulation Across Organizations

Infrastructure Standards

Representation Standards (Static Behaviour)
- **ASAM OpenDRIVE**
- **ASAM OpenCRG**
- Khronos glTF
- OGC CityGML
- NDS

Represantation Standards (Dynamic Behaviour)
- **ASAM OpenSCENARIO**
- **ASAM OpenODD**
- ISO 34501
- ISO 34502
- ISO 34503
- ISO 34504

Interface Standards
- **ASAM OSI**
- AUTOSAR
- ISO 23150
- MA FMI
- MA SSP

Architectural Standards
- AUTOSAR
- SAE J3131

Automation Standards
- **ASAM XIL**
- MA DCP

Domain Representation | Taxonomy
- **ASAM OpenXOntology**
- **ASAM OpenLABEL**
- AVSC00002202004
- SAE J3016
- SAE J3164
- SAE J3206

Test Specification
- **ASAM OTX Extensions**
- ISO 13209 (OTX)

Data Handling
- **ASAM MDF**
- **ASAM ODS**

Method Standards
- ISO 11010
- SAE J3018
- SAE J3092

Process Standards

Safety Standards
- AVSC00001201911
- ISO 21448 (SOTIF)
- ISO 26262

Security Standards
- ISO/SAE DIS 21434

System Design
- AUTOSAR

Product Standards
- AUTOSAR
- UN R157

The CityGMLWiki is an open portal to publish and share information about CityGML. However, it is not the official website of the CityGML. Please find the official website of CityGML at http://www.citygml.org.

http://www.citygmlwiki.org/index.php?title=Citygml_Wiki

NDS

The Navigation Data Standard Association provides a standard for map data to be used in navigation systems. The NDS specification covers the data model, storage format, interfaces, and protocols. Along with NDS a set of online and offline tools is made available to NDS members, that cover multiple areas of application – starting with defining the standard up till analysing and transforming NDS maps. Extension mechanisms allow customization and support of a variety of use cases. Most NDS tools are compatible with the three major desktop platforms (Windows, macOS, Linux), and therefore give its user freedom of choice.
NDS members and map coverage include North America, EMEA, APAC, including China, South Korea, and Japan.

nds-association.org/nds-tools/
nds-association.org/

Representation Standards (Dynamic Behavior)

ASAM OpenSCENARIO

ASAM OpenSCENARIO defines a file format for the description of the dynamic content of driving and traffic simulators. The primary use-case of ASAM OpenSCENARIO is to describe complex, synchronized maneuvers that involve multiple entities like vehicles, pedestrians and other traffic participants. → [p. 24]

ASAM OpenODD

ASAM OpenODD is a standardized, machine-readable format for the definition of Operational Design Domains (ODDs). → [p. 31]

ISO/WD 34501 – Road vehicles — Terms and definitions of test scenarios for automated driving systems

The document specifies terms and definitions of test scenarios for Automated Driving Systems (ADSs). The contents are intended to be applied to Level 3 and higher ADS defined in ISO/SAE 22736.

The standard for terms and definitions is the basis for test scenarios for automated driving systems, and the development of appropriate international standards will play a key role in supporting the testing, evaluation and management of automated driving vehicles. This standard is used to harmonize and standardize the terminology and definition of test scenarios for automated driving systems on a global scale.

standardsdevelopment.bsigroup.com/projects/
9019-03292#/section

ISO/WD 34502 – Road vehicles — Engineering framework and process of scenario-based safety evaluation

This document provides guidance and a state-of-the-art engineering framework for automated driving (AD) system test scenarios and scenario-based safety evaluation process. The engineering framework clarifies the overall scenario-based safety evaluation process to apply during product development. The guidance and framework are intended to be applied to Level 3 and higher AD systems defined in ISO/SAE 22736.

standardsdevelopment.bsigroup.com/projects/
9019-03291#/section

ISO/AWI 34503 – Road vehicles — Taxonomy for operational design domain for automated driving systems

This document specifies the basic requirements for a hierarchical taxonomy for defining the Operational Design Domain (ODD) for an Automated Driving System (ADS). ODD includes static and dynamic attributes, that can be used to develop test scenarios, in which an ADS is designed to operate. This document also defines basic test procedures for attributes of the ODD.

This document is applicable to automated driving systems to Level 3 and higher ADS as defined in ISO/SAE 22736.

ISO/SAE 22736 defines the concept of Operational Design Domain (ODD). The definition of ODD is fundamental in ensuring safe operation of the ADS as it defines the operating conditions of the ADS.

While different kinds of ADS may be developed in the industry worldwide, there is a need to provide guidance on a framework for ODD definition for manufacturers, operators, end-users and regulators to ensure safe deployment of ADS. This document will assist manufacturers of ADS in the incorporation of minimum attributes for ODD definition and to allow end users, operators and regulators to reference a minimum set of attributes for the ODD definition.

standardsdevelopment.bsigroup.com/projects/
9019-03288#/ section

ISO/WD 34504 – Road vehicles — Scenario attributes and categorization

This document defines packages concerning the different attributes of a scenario that convey information required to construct a complete test scenario. Those attributes may refer to complementary data sources, such as the related road network, 3D scenes and models. To ensure a certain quality standard, measures for the integrity and integrability of these attributes are defined. Additionally, this work item defines a categorization of the scenarios by providing tags that carry qualitative or quantitative information about the scenarios.

standardsdevelopment.bsigroup.com/projects/
9019-03290#/section

Interface Standards

ASAM OSI

ASAM OSI is a generic interface for the environmental perception of automated driving functions in virtual scenarios. It allows users to connect any sensor with a standardized interface to any automated driving function and to any driving simulator tooling. → [p. 27]

AUTOSAR

AUTOSAR (AUTomotive Open System ARchitecture) standardizes the software architecture for intelligent mobility. Main goal of this initiative is the ability to exchange software modules as integration platform for hardware-independent software applications. Each software application (called component) has access to the standardized AUTOSAR APIs / services and can be deployed freely to any suitable device within the target vehicle.

The following platforms are defined:

AUTOSAR Classic is based on OSEK and is optimized for signal-based communication to be used for ECUs with hard real-time and safety constraints. Applications have access to the Runtime environment of a layered software architecture. Standardized are e.g. memory services, communication services and the I/O HW abstraction. Libraries, which contain a collection of functions for the related purposes are included in the deliverable. Implementations provided by software suppliers are available as C software stack. AUTOSAR communication services allow access to CAN, COM, Ethernet, FlexRay, Lin, SAE J 1939, UDP and XCP. The standard also describes the process for developing the xml system description of multi-ECU environments in the respective vehicle architecture.

AUTOSAR Adaptive is based on POSIX and optimized for service-oriented communication. This platform is used for high performance computing systems. The platform consists of APIs or services for functional clusters (e.g. update and configuration management [OTA], REST, identify and access management, diagnostics [UDS, DoIP], log and trace, communication management [SOME/IP, DDS], operating system). The APIs and services allow the access to the respective

hardware and functionality. A C++ standard library is contained for the APIs and services of the different functional clusters. Applications are built on the functionality provided by this middleware. A reference implementation is offered, which is called demonstrator.
Typical AUTOSAR use cases are Vehicle-2 X applications, highly automated driving (ADAS), which require mobility services for vehicle connectivity, remote diagnostics, and dynamical updates.

www.autosar.org

Modelica Association FMI – Functional Mock-up Interface

The Functional Mock-up Interface (FMI) is a free standard published by the Modelica Association that defines a container and interface to exchange dynamic models using a combination of XML files, binaries and C code zipped into a single file. FMI specifies a semantic and an application programming interface (API) to execute models in importing applications, like simulators. It supports two modes of operation of dynamic models: Model exchange (access to a system of hybrid ODEs) and co-simulation (a solver is part of the FMU).

At present FMI 2.0.2 is the latest released standard version, with work on finalizing a 3.0 major release progressing.

fmi-standard.org/

ISO 23150 - Road vehicles — Data communication between sensors and data fusion unit for automated driving functions — Logical interface

The upcoming ISO 23150 standard is developed under ISO/TC 22/SC 31 to standardize the logical interface between in-vehicle environment sensors – for example radar, lidar, camera, and ultrasonic sensors – and the fusion unit which generates an environment model and interprets the scene around the vehicle based on the sensor data. The interface is described in a modular and semantic representation and provides information on object level (e.g. potentially moving objects, road objects, static objects, etc.) as well as information on feature and detection level and sensor technology specific information. This standard does not provide electrical and mechanical interface specifications. Raw data interfaces are also excluded.
The ASAM OSI SensorData interface is closely coupled with this information and thus extra care is being taken in the ASAM OSI development projects to harmonize the two standards.

At the time of writing ISO23150 is available as a Final Draft International Standard.

www.iso.org

Modelica Association SSP – System Structure and Parametrization

The System Structure and Parametrization (SSP) standard is a tool-independent format for the description, packaging and exchange of system structures and their parameterization. The standard is comprised of a set of XML-based formats to describe a network of component models with their signal flow and parametrization, as well as a ZIP-based packaging format for efficient distribution of entire systems, including any referenced models and other resources. The standard is published by the Modelica Association. SSP fully supports the use of FMI for components, but is not restricted to FMI components.

At present SSP 1.0 is the latest released standard version, with work on a 2.0 release having started.

ssp-standard.org/

Architectural Standards

AUTOSAR → [p. 43]

SAE J3131 – Automated Driving Reference Architecture

SAE J3131 defines an automated driving reference architecture that contains functional modules supporting future application interfaces for Levels 3 through 5 (J3016). The architecture will model scenario-driven functional and nonfunctional requirements, automated driving applications, functional decomposition of an automated driving system, and relevant functional domains (i.e., functional groupings). Domains include, but are not limited to, automated driving (i.e., automation replacing the human driver), by-wire and active safety, and those related to automated recovery from faults and system failures (e.g., system bringing the vehicle to a safe state). The architecture will address Tier 1 and Tier 2 functional groupings. The document will include one example instantiation that divides the functionality into two functionality groupings and will detail the functional and information interface between the groups. A reference SysML model of architecture and edge cases will address system fallback to minimal risk state on freeways.

SAE J3131 is part of the SAE International On-Road Automated Driving (ORAD) Initiative.

www.sae.org/standards/content/j3131/

Automation Standards

ASAM XIL

ASAM XIL (Generic Simulator Interface) standardizes the communication between test automation software and X-in-the-loop testbenches. The standard defines a

- Testbench API (ECUC, ECUM, MA, Network, EES, Diag port) and a
- Framework API (object-oriented port independent access to variables).

The model access port is the central interface for managing access to the simulation model that is executed on the XIL simulator. This port provides read and write access to the simulation model, set-up of measuring (capturing), stimulus generation and target script execution, as well as metadata retrieval for model variables and tasks.

The diagnostic port reads data via a diagnostic system with diagnostic services data from an ECU. The ECUM and ECUC port access an ECU via a MC-Server. ECUM provides the functionalities of measurement and capturing, ECUC provides the functionalities of calibration and CAL page management. As the ECU communication is encapsulated by the respective MC- or D-Server the XIL API does not need any knowledge about the interface that is used for the communication with the ECUs.

The Electrical Error Simulation port provides a general API for electrical error simulation hardware. The API hides the used hardware, its driver software, and the communication. The EES port provides a defined set of functionalities in an abstract manner, e.g. the setup of different types of errors. The Network Port is designed to provide access to bus communication in a standardized way, allowing monitoring and transmitting bus data. This port provides functionality for read and write access for CAN frames, to set up captures of CAN frames and the replay of CAN frames.

The standard contains a C# and Python Technology reference, a XIL Support Library, a Test Suite, schemas, and a generic UML model. The assemblies are distributed as setup.

www.asam.net/standards/detail/xil/

Modelica Association DCP – Distributed Co-Simulation Protocol

The Distributed Co-Simulation Protocol (DCP) standard is an application level communication protocol published by the Modelica Association. It is designed to integrate models or real-time systems into simulation environments. It enables exchange of simulation-related configuration information and data by use of an underlying transport protocol (such as UDP, TCP, or CAN). At the same time, the DCP supports the integration of tools and real-time systems from different vendors. The DCP is intended to make simulation-based workflows more efficient, and to reduce the integration effort.

The DCP was designed with FMI compatibility in mind, but is not restricted to FMI or software models in general.
At present DCP 1.0 is the latest released standard version.

dcp-standard.org/dcp

Domain Representation / Taxonomy

ASAM OpenXOntology

The ASAM ontology provides a domain model for the domain of on road driving as addressed by the ASAM OpenX standards. It provides vocabulary for traffic infrastructure, interactions of traffic participants, and environmental conditions. This will also facilitate the use of artificial intelligence for ASAM OpenX applications. The project will release a minimal working example for public review by Q1 of 2020 that demonstrates some initial use cases of the ontology. Additionally, the standard will provide guidelines for:

- different tooling workflows that could leverage the ASAM OpenXOntology
- each ASAM OpenX standard on how to implement the ASAM OpenXOntology
- extending the ontology for application-specific use cases
- migration/phasing examples for each ASAM OpenX standard

→ [p. 32]

ASAM OpenLABEL

ASAM OpenLABEL is a common format, which can be used for the annotation of sensor data and scenarios created during the development of automated driving features. The format will be machine processable and human readable. It will include a user guide that will explain to any future user how to use the available labeling methods that are supported by ASAM OpenLABEL. This includes:

- labeling methodology
- labeling structure (including relations)
- file format and structure definitions
- scenario labeling

→ [p. 29]

AVSC00002202004

The Automated Vehicle Safety Consortium (AVSC) has developed a best practice for describing operation design domains (AVSC00002202004 Automated Vehicle Safety Consortium, "AVSC Best Practice for Describing an Operational Design Domain: Conceptual Framework and Lexicon," SAE Industry Technologies Consortia, 2020). This framework helps establish a common taxonomy and description for ODDs to support consistency amongst ODD developers and users.

The AVSC is a consortium of companies in the industry that are actively working in testing and on-road pilots of automated vehicles. The goal of the consortium is to develop trust between the public and AV manufacturers, particularly through developing best practices to be followed by developers. The consortium is working on a roadmap that provides an overview of multiple topics relevant to the AV industry in order to support collaboration in the industry.

avsc.sae-itc.org/

SAE J3016 | SAE J3164 | SAE J3206

These standards are part of the SAE ORAD (International On-Road Automated Driving) initiative. The ORAD committee is responsible for developing and maintaining SAE standards and content related to AD functionality from Level 3 to 5 as defined by SAE J3016. The committee consists of multiple task forces. The standards above are driven by the following task forces:

- **SAE J3016: Taxonomy and Definitions**
  Taxonomies and definitions for terms related to on-road driving
- **SAE J3164: Maneuvers & Behaviors**
  Definitions, taxonomies and best practices for behaviors and maneuvers of on road ADSs (Levels 3 – 5)
- **SAE J3206: Verification & Validation**
  Definitions, information, best practices, and testing methodologies to support the V&V of ADSs.

www.sae.org/standards/content/j3016_201806/
www.sae.org/standards/content/j3164/
www.sae.org/standards/content/j3206/

Test Specification

ASAM OTX Extensions

ASAM OTX (Open Test eXchange Format) is a platform and tester independent exchange format for formal description of executable test sequences that is standardized in ISO 13209 (OTX) and allows test sequences to be exchanged across department, tool, and process boundaries. The know-how stored in the sequences is not lost but can be reused even after many years.

OTX is an XML-based domain specific programming language. The test sequences are created using an authoring system. No programming language knowledge or knowledge of the APIs used, which encapsulate the access from the runtime system to the respective hardware (e.g., MVCI Server API for vehicle diagnostics), is required for test creation. This allows the developer to focus on the process under test. The formal description of the test sequences on symbolic level can be done graphically, in textual representation (pseudo code) or for developers also in a programming language (e.g., C# or JAVA). Furthermore, OTX maps various basic concepts that reflect the grown practical experience in creating, maintaining, and executing test sequences. For example, the basic test sequence can be described in a first step without having to describe exact technical details. These are then supplemented by the respective experts, so that a runnable description is created in the first place. The separation of design (authoring system) and execution (runtime system) makes it possible to transform the test for the respective target platform (Windows, Linus, Embedded) without loss of test content using code generators.

OTX can be extended by new libraries via standardized extension mechanisms. Thus, ASAM OTX extensions delivers a set of additional, generally usable OTX functionality, e.g.:

- General Read-Write Access to Files,
- XML Processing,
- Store arbitrary information on the current runtime,
- Configuration tasks,
- Extend OTX to functionality that is encapsulated in external services, part of a system, a device, a database, or a simple library,
- Capturing, evaluating, and persisting results of test sequences,
- Transport status information from inside a sequence to the environment,
- Advanced convenience functionality,
- Collection of communication data at runtime,
- Access to SQL databases,
- Evaluation test sequence results in a structured way,
- State Machine,
- Compressed data exchange (with a container format)

In the vehicle life cycle, OTX is successfully used during development, production and vehicle use (after sales and additionally inside the vehicle). Thus, the goal of exchanging and archiving verified, and field-tested test sequences is achieved.
ASAM OTX extensions contains an xsd template for each OTX extension and a common UML model.

www.asam.net/standards/detail/otx-extensions/

Data Handling

ASAM MDF

ASAM MDF (Measurement Data Format) is a binary file format to store measured or calculated data for post-measurement processing or long-term conservation. Common sources of the data to be stored are sensors, ECUs, or bus monitoring systems. ASAM MDF allows to achieve a high performance for both writing and reading signal data. It supports row-oriented storage (ideal for writing) and column-oriented storage (optimized for reading performance).

In addition to the plain measurement data, ASAM MDF stores descriptive and customizable meta data within the same file.

The information storage is defined for certain use cases:

- Bus logging (storage of bus traffic of common bus systems)
- Classification results (store classification results with description in a one- or two-dimensional way)
- Measurement environment (describes naming conventions to store information about how the measuring was obtained)
- Naming of channels and channel groups (describes how to set the different names for channels and channel groups for common use cases to provide important information to the user and to achieve a unique identification of the channels)

The standard contains XML schemas for meta data description.

www.asam.net/standards/detail/mdf/

ASAM ODS

ASAM ODS (Open Data Services) defines a generic data model (for universal interpretation of test data), interfaces (for model management, persistent data storage and data retrieval) and data exchange syntax and format. ODS servers are accessed by HTTP protocols with protobuf serialization, CORBA, or RPC.

ASAM ODS distinguishes between a base model, which is unique for all kind of applications and an application model, which is application-specific. All application elements in that model know which base element type they are related to. Base elements are defined among others for dimensions and units, administration, measurements, security and descriptive data. Application data models are defined for common use cases

- Bus data (supports CAN, LIN, FlexRay, MOST and Ethernet messages)
- Geometry (e.g. for the used coordinate system of sensor positions)
- Noise, vibration, harshness
- Workflow (based on the concept of Petri nets)
- Calibration (e.g. test stand data from sensors and amplifiers)

Additionally, a crash test data model (vehicle safety information model) is provided as ISO 22240. The data model is the prerequisite to navigate through domain specific or application specific data structures. Real values are finally stored in instances of application elements.

A big data connector describes how instance data and mass data will be presented as an export from an ODS data store for big data analysis systems (e.g. HADOOP). The export is defined to Avro, JSON and Parquet. ASAM ODS also supports the storage of binary measurement data in ASAM MDF. The standard contains XML schema, Google Protocol Buffers, the Step-Express file, the IDL description, the RPC interface, and xsd files.

ASAM ODS does not only allow to store the actual measured data and the data to describe the measurement, but it is also possible to describe data that is required as parameter for the execution of the test.

www.asam.net/standards/detail/ods/

PROCESS STANDARDS

Safety Standards

AVSC00001201911

The Automated Vehicle Safety Consortium (AVSC) has developed a best practice for selection, training and oversight procedures for in-vehicle fallback test drivers (AVSC00001201911 Automated Vehicle Safety Consortium, "AVSC Best Practice for In-Vehicle Fallback Test Driver Selection, Training, and Oversight Procedures for Automated Vehicles Under Test," SAE Industry Technologies Consortia, 2020). It describes qualifications and training for appropriate oversight of testing Level 4 and 5 AVs on public roads.

The AVSC is a consortium of companies in the industry that are actively working in testing and on-road pilots of automated vehicles. The goal of the consortium is to develop trust between the public and AV manufacturers, particularly through developing best practices to be followed by developers. The consortium is working on a roadmap that provides an overview of multiple topics relevant to the AV industry in order to support collaboration in the industry.

ISO/PAS 21448:2019 and ISO/DIS 21448 – Road vehicles Safety of the intended functionality

The Publicly Available Specification ISO/PAS 21448:2019, as well as the upcoming ISO/DIS 21448 are developed under ISO/TC 22/SC 32 with the goal of providing guidance on the applicable design, verification and validation measures needed to achieve the Safety Of The Intended Functionality (SOTIF), which is considered to be the absence of unreasonable risk due to hazards resulting from functional insufficiencies of the intended functionality or by reasonably foreseeable misuse by persons. This standard does not apply to faults covered by the ISO 26262 series or to hazards directly caused by the system technology (e.g. eye damage from a laser sensor).

The standard is intended to be applied to intended functionality where proper situational awareness is critical to safety, and where that situational awareness is derived from complex sensors and processing algorithms. Intended use and reasonably foreseeable misuse are considered in combination with potentially hazardous system behaviour when identifying hazardous events. Reasonably foreseeable misuse, which could lead directly to potentially hazardous system behaviour, is also considered as a possible event that could directly trigger a

SOTIF-related hazardous event. Intentional alteration to the system operation is considered feature abuse. Feature abuse is not in scope of this standard.

www.iso.org

ISO 26262 - ISO 26262 - Road vehicles — Functional safety

The ISO 26262 standard developed under ISO/TC 22/SC 32 is intended to be applied to safety-related systems that include one or more electrical and/or electronic (E/E) systems and that are installed in series production road vehicles, excluding mopeds. It addresses possible hazards caused by malfunctioning behaviour of safety-related E/E systems, including interaction of these systems. It does not address hazards related to electric shock, fire, smoke, heat, radiation, toxicity, flammability, reactivity, corrosion, release of energy and similar hazards, unless directly caused by malfunctioning behaviour of safety-related E/E systems.

The standard describes a framework for functional safety to assist the development of safety-related E/E systems. This framework is intended to be used to integrate functional safety activities into a company-specific development framework. Some requirements have a clear technical focus to implement functional safety into a product; others address the development process and can be seen as process requirements in order to demonstrate the capability of an organization with respect to functional safety.

www.iso.org

Security Standards

ISO/SAE DIS 21434 – Road vehicles — Cybersecurity engineering

The ISO/SAE DIS 21434 draft international standard currently under development by ISO/TC 22/SC 32, is due to be published in 2021 and aims to address cybersecurity in the engineering of electrical and electronic (E/E) systems within road vehicles. Use of the standard is intended to help manufacturers keep up with changing technologies and cyber-attack m. It will enable organizations to define cybersecurity policies and processes, manage cybersecurity risk and foster a cybersecurity culture. It can also be used to implement a cybersecurity management system, including management of road vehicle cybersecurity risk.

www.iso.org/news/ref2584.html

System Design

AUTOSAR

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METHOD STANDARDS

ISO 11010 - Passenger cars — Simulation model classification

The upcoming ISO 11010 standard is developed under ISO/TC 22/SC 33 with the goal of providing a standard for classifying models used in simulations for the development and test of road vehicles. The main purpose of this standard is to provide a framework that enables a systematic assignment of certain application, driving manoeuvres to required simulation models and their elements and characteristics. This document classifies the simulation models into certain model classes, their designation number and related elements, characteristics and common modelling method.

The current status of the standard is that Part 1, dealing with Vehicle Dynamics, is available as a Draft International Standard. Interest in creating further parts for other areas of the domain Simulation has been expressed and is currently being organized.

www.iso.org

SAE J3018 | SAE J3092

These standards are part of the SAE ORAD (International On-Road Automated Driving) initiative. The ORAD committee is responsible for developing and maintaining SAE standards and content related to AD functionality from Level 3 to 5 as defined by SAE J3016. The committee consists of multiple task forces.
The standards above are driven by the following task forces:

- **SAE J3018: Guidance for on-road testing**
  Guidelines for the safe conduct of on-road tests of vehicles equipped with prototype ADSs (Levels 3 – 5)
- **SAE J3092: Verification & Validation**
  Definitions, information, best practices, and testing methodologies to support the V&V of ADSs.

www.sae.org/standards/content/j3018_201503/

PRODUCT STANDARDS

AUTOSAR

→[p. 43]

UN-ECE regulation 157

The United Nations Economic Commission for Europe (UNECE) has adopted an international regulation for Automated Lane Keeping Systems (ALKS) for passenger cars. ALKS is a vehicle technology designed to control the lateral and longitudinal movement of a vehicle for an extended period without further driver command. During such times, the system is in primary control of the vehicle, and performs the driving task instead of the driver. ALKS can be activated under certain conditions on roads where pedestrians and cyclists are prohibited and which, by design, are equipped with a physical separation that divides the traffic moving in opposite directions. In its current form, the Regulation limits the operational speed of ALKS systems to a maximum of 60 km/h. This is the first regulation for the type approval of an automated driving function (SAE Level 3), agreed on by over 50 member countries. It defines safety requirements for:

- Emergency Maneuvers, in case of an imminent collision;
- Transition Demand, when the System asks the driver to take back control;
- Minimum Risk Maneuvers - when the driver does not respond to a transition demand, in all situations the system shall minimize risks to safety of the vehicle occupants and other road users.

To establish the basis for this UNECE regulation, the UNECE simultaneously passed regulations for cybersecurity and software updates.

undocs.org/ECE/TRANS/WP.29/2020/81

APPLI CATION

A key aspect of standards is their active use. Some of ASMA's members share how they are using ASAM OpenX standards, how these standards helped to improve processes and how they facilitate customer projects. Take advantage of their inspiring experiences...

3D Mapping Solutions GmbH

Integrating ASAM OpenDRIVE and ASAM OpenCRG Data

Featured Standards:

ASAM OpenDRIVE
ASAM OpenCRG

Authors:

Dr.-Ing. Sebastian Tuttas,
Head of Software Development

Philip Paulsteiner,
Head of HD Maps,
Development of HD Maps

SUMMARY

Challenge: For a client project, 3D Mapping Solutions required a full integration of OpenDrive and OpenCRG including complex inner-city junctions. 3D Mapping Solutions was the first to combine these two standards. Before its transfer to ASAM, the OpenDRIVE specification was not fully elaborated to give detailed guidelines on how to apply this combination.

Solution: During the project, valid solutions for the assignment of positions in the axis definition of OpenDRIVE and OpenCRG were found, filling the interpretation gaps within the specification.

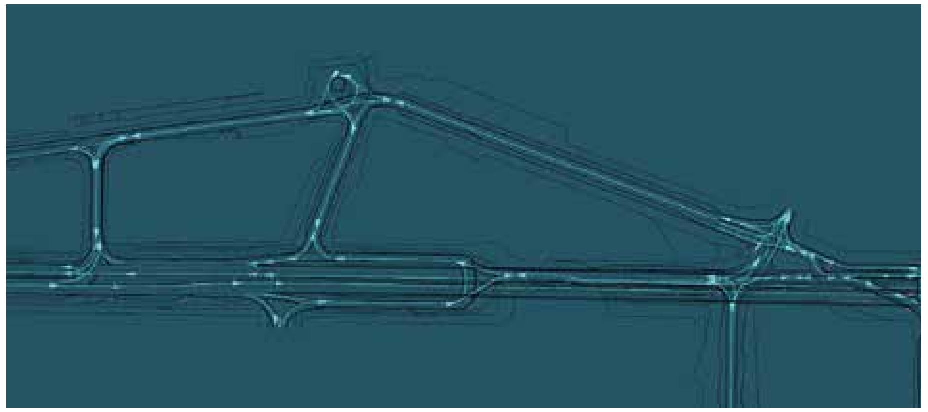
Key Benefits: The results of the project show that simulations based on OpenDRIVE can be enriched with extremely detailed descriptions of the road surface based on OpenCRG including intersections and roundabouts.
The experience from this project was incorporated into the process of transferring both standards to ASAM. Staff members of 3D Mapping Solutions have participated in both the ASAM OpenDRIVE and the ASAM OpenCRG working group and made sure to complement the first ASAM version of OpenDRIVE (V1.6.) by guidelines on how to combine data of ASAM OpenDRIVE with data from ASAM OpenCRG. 3D Mapping Solutions will continue to contribute to this important feature.

SITUATION

The project area is an inner-city road network in Wolfsburg with multiple complex intersections.
Based on measurements from a mobile mapping system with high precision laser scanners and calibrated camera data, an OpenDRIVE map combined with OpenCRG was created with all objects and a very detailed road surface description.

SUCCESS STRATEGY

The high precision measurement system is equipped with two high-resolution laser scanners, which can acquire the road surface as well as the environment with mm-accuracy. This has the advantage that the data base is the same for the creation of the OpenDRIVE HD Map as well as for the surface description of the road.
The lane definitions, road borders and other OpenDRIVE objects as well as the road surface heights have all been derived from this homogenous data set. This is the basis for solving the mathematical dependencies between the different axis definitions. For each surface element represented in OpenCRG, several OpenDRIVE axes need to derive the height information.
This solution enabled 3D Mapping Solutions to unambiguously integrate OpenCRG in an OpenDRIVE Map as early as in OpenDRIVE version 1.4. The experience gained in this project influenced the development of ASAM OpenDRIVE V1.6.



Source: 3D Mapping Solutions GmbH

Overview of the ODR axes in the project area

CHALLENGES

Challenges emerged from the complex axes in the junction areas in combination with the fact that the integration of OpenDRIVE and OpenCRG was not sufficiently described in the OpenDRIVE specification at that time. A further challenge was the differing definition of the axis representation in OpenDRIVE and OpenCRG.

BUSINESS BENEFITS

- The project has proven, that data can be provided in high quality for both standards based on precise and homogenous data.
- 3D Mapping Solutions was the first to support the combination of OpenCRG and OpenDRIVE for complex maps based on real world measurement data.
- The experience of this project helped to improve the ASAM versions of the simulation standards OpenCRG and OpenDRIVE: It has contributed to a better understanding of the possibilities and benefits of a combined usage of OpenDRIVE and OpenCRG. Based on our example, more users will be capable of adopting OpenDRIVE and OpenCRG to meet the increasing simulation demand.

OUTLOOK

With increasing demand for testing and simulation in virtual environments, this combined model of road description (OpenDRIVE) with detailed road surface description (OpenCRG) becomes more and more important because it enables certified simulation of ADAS systems in virtual reality, based on high precision mapping data.
The combined model of OpenDRIVE and OpenCRG is indispensable for all systems, which require road surface as well as the HD Map in a perfectly aligned combination.
Furthermore, the ASAM OpenDRIVE Maintenance project plans to further develop and improve the ASAM OpenDRIVE specification to make the combined use of OpenDRIVE and OpenCRG even more convenient.

Source: 3D Mapping Solutions GmbH

3D Visualization of the OpenDRIVE Map, together with the OpenCRG road surface
(relative height differences of the road surface are represented by a continuous colormap)

"The ASAM initiative to take over the standards OpenDRIVE and OpenCRG as well as the ongoing OpenX standard development activities enable 3D Mapping Solutions to provide HD Maps and simulation solutions of outstanding quality, which can be used for multiple simulation purposes of our customers in various simulation software packages or simulator platforms."

GUNNAR GRÄFE,
CEO, 3D Mapping Solutions GmbH

Advanced Data Controls Corp.

Combining OpenDRIVE data with high-fidelity virtual environments

Featured Standard:
ASAM OpenDRIVE

Authors:
Yasuyuki Nakanishi,
Manager

Richa Venkataraghavan,
Manager

SUMMARY

Challenge: Advanced Data Controls Corp. has received requests by several Japanese OEM companies to create a photorealistic "camera in the loop" simulation using a high-performance game engine for ADAS validation. Thus, a PBR-based (Physically Based Rendering) test system using "Unreal Engine 4" was launched in 2014. As there was no suitable standard available, we started a research project to implement our simulation framework with original protocol and various environment models using Unreal Engine.

Two key challenges arose from this research and implementation experience:

1. We needed standardization of interchangeable simulation interfaces for "vehicle dynamics" and "sensor models." As the core of our products, we decided to focus on ASAM-compliant test environments for AV testing solutions.
2. We needed modeling resources to develop high-end PBR-based environment models.

As a solution to 1: We joined ASAM in 2018 and are actively participating in the ASAM OSI project since February 2020. Currently, we are also participating in the standardization of ASAM OpenXOntology, ASAM OpenODD, and ASAM OpenLABEL.

VERTechs Demo

Day & weather variation in the virtual environment for generating various scenarios.

As a solution to 2: We established "VERTechs Inc." in 2016 as an environment model provider for AV virtual testing.

VERTechs is a company that targets the Sil development of ADAS and AD by providing databases and building test environment data to be the best in automotive simulation. Over four years, we have provided virtual environments for clients in the automotive industry for :

- AI training data creation,
- Reinforcement learning,
- Virtual sensor models, and Software in the Loop Simulations (SiLS)

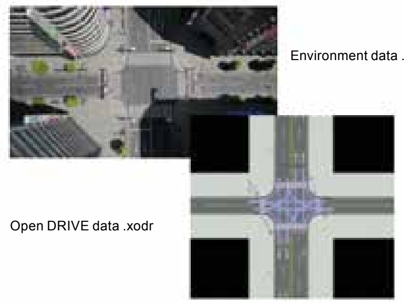
More recently, we have added the capability to create geo-referenced data with ASAM OpenDRIVE to include location accuracy to obtain the best possible results that a virtual environment could deliver. With ASAM, we are also looking forward to the standardization of ODD to create environments according to client safety evaluation requirements.

Key Benefits: ASAM OpenDRIVE data turned out to be a big time and cost saver for us. If not for ASAM OpenDRIVE, we would rely only on point cloud data for location accuracy.
Once the data is generated, our client could add actors and sensors to the scenario and generate synthetic lane and object detections to test the driving algorithms.
By developing PBR environment data through VERTechs, we are also ready to provide OpenODD-compatible weather conditions in the future.

SITUATION

Advanced Data Controls Corp's Vehicle Test Center (VTC/Now on ABD) has 18 years of experience in "Conformance Test Service" for the Japanese automobile industry market in collaboration with c&s GmbH in Germany. In addition, as a simulation domain, we have supported CAN and FlexRay topology simulations with the VHDL-AMS transceiver model and have provided large-scale SIL integration. To create modeling resources to develop high-end PBR-based environment models, we have established „VERTechs Inc." in 2016.

VERTechs has successfully created several virtual environments for OEM companies using game engine technology, taking advantage of high-fidelity graphics and user-friendly GUI. Our virtual environments vary from urban cities to warehouses and vineyards, where autonomous vehicles are necessary for the future. We have also created digital twins of urban cities that range in size from a few hundred meters to as big as 5 kilometers for several OEM companies and Tier 1 suppliers.



Open drive and fbx data combined in simulation software

VERTechs combined ASAM OpenDRIVE data with a high-fidelity virtual environment for one of our projects: We created a digital twin of the Hamamatsu area located in the south of Japan was created for our customer, an OEM that tested driving scenarios on prescan simulation software. When the OEM entrusted us with this project, the client looked for ground truth to test their driving algorithm. Apart from providing a visually realistic twin city in fbx format to the client, we decided to incorporate ASAM OpenDRIVE data for geo-reference. We used RoadRunner 2019.1.4 for creating OpenDRIVE data and Maya for creating FBX data.

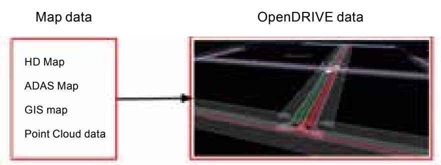
CHALLENGES

In comparison to the information contained in ADAS map data, we faced several challenges due to the current limitations of the ASAM OpenDRIVE format. ASAM OpenDRIVE is relatively new, so even though it allows for the inclusion of many different road data types, some kinds of data are not officially part of the format yet. Localization of Japanese signs was also an additional challenge. Hence, software that can read the ASAM OpenDRIVE format usually only supports what is described in the official specification.
As we took a manual approach for data creation, we were limited to each software's capabilities. We are now in the process of developing an automatic data creation pipeline. With this, we will have the freedom of converting HD data information into ASAM OpenDRIVE data.

SUCCESS STRATEGY

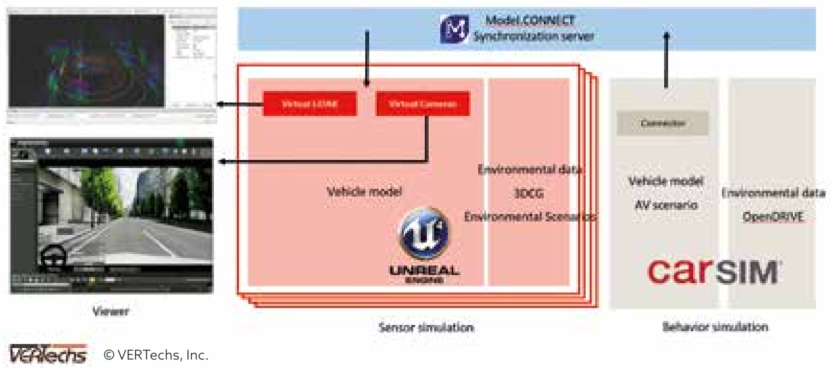
To generate ASAM OpenDRIVE data, we combined information from

- HD maps,
- ADAS maps,
- GIS map,
- point cloud data provided by mapping company.



Creation of road network data for simulation

VERTechs converted ADAS map data into FBX data and ASAM OpenDRIVE data. The total area created was 5 kilometers.
RoadRunner helped us create a .xodr file previewed with the OpenDRIVE Viewer 1.9.1 (Linux version). With this, ASAM OpenDRIVE helped us provide accuracy in road information through Geo-referencing.



Framework for scalability and flexibility using Unreal Engine 4 for sensor simulation, CarSIM for behavior simulation, Model.CONNECT as a server.

Apart from the road network, we also created other vital elements of the environment necessary for autonomous driving. These included location-specific objects such as foliage, buildings, streetlamps, directional signs, red cones, etc. The client then imported the FBX data and the ASAM OpenDRIVE data into Prescan simulation software, and a combination of both solved the localization problem. In the end, the client could successfully drive an autonomous vehicle in our virtual environment with verified data and their choice of simulation software.

BUSINESS BENEFITS

The services that we can provide to automotive clients have increased after the usage of ASAM OpenDRIVE data. We are not only able to provide a realistic visual model of the real-world location but also combine it with accurate road information with a navigable scene for Japanese automotive companies. Working with ASAM OpenDRIVE, an industry-standard data format has helped us to work together among multiple simulations while maintaining the strengths of the high-quality 3DCG.

Source of images: Advanced Data Controls Corp.

Cruden

Common ground for easy integration between driving simulators and engineering tools?

Featured Standard:
ASAM OpenDRIVE

Author:
Nico Kruithof,
Computer Scientist

SUMMARY
The ASAM OpenDRIVE standard provides a means to use the same road definition for both Cruden's driving simulators and third-party engineering tools. This is particularly important for traffic simulations which receive ASAM OpenDRIVE layers from Cruden's own 3D environments, as well as for Cruden's ASAM OpenDRIVE-based ADAS Toolbox, which facilitates ADAS experiments with a human driver in the loop.

Cruden uses ASAM's software libraries to support the implementation of ASAM OpenDRIVE. They reduce the effort needed to work with the standards immensely. They also reduce the level of inconsistencies between different implementations of the standard by different companies.

The joint use of ASAM OpenDRIVE creates the flexibility to use different engineering tools, such as VIRES VTD or dSPACE ASM, around the driving simulator. This provides great benefits for both Cruden and its customers. The ability to integrate different tools results in cost and time savings in vehicle development.

APPLICATION STORY
Cruden's driver-in-the-loop (DIL) simulators typically simulate vehicle dynamics, NVH performance, ADAS functions and other vehicle features in high-definition 3D environments that are created in-house. However, it is essential for our automotive customers to be able to integrate the DIL simulator with other simulation tools. These might include VIRES VTD, the traffic simulation tool for which Cruden first generated ASAM OpenDRIVE layers from its 3D environments, or dSPACE ASM, which can also run in co-simulation with a Cruden driving simulator.

Audi and Volkswagen are among the OEMs for whom Cruden has integrated a driving simulator with the VIRES VTD traffic simulator.

This integration enables to develop ADAS functions or components in offline simulation with specialized tools but also to test them in the immersive environment of a driving simulator, all on the same virtual roads.

To achieve this, Cruden creates an ASAM OpenDRIVE definition of the road network from the 3D virtual environment designed for highly immersive DIL simulation. This ASAM OpenDRIVE layer is the foundation for the 3D environment that customers need to run in their preferred tool. They can then, for example, simulate traffic in their traffic simulation tool of choice and pass information back to the Cruden simulator about the position, direction and speed of vehicles, so that traffic can also be shown with a driver onboard. By providing information of the ego-vehicle from the simulator, the traffic simulation responds directly/naturally to the drivers input.

Cruden has additionally developed an ADAS Toolbox for its simulators, also based on ASAM OpenDRIVE definitions. This toolbox enables engineers or behavioural researchers to introduce basic models of new ADAS controllers to simulator experiments with human drivers in the loop.

Cruden was assisted in both creating and making use of ASAM OpenDRIVE layers with the help of ASAM's software libraries. These libraries implement the specifications of the standard. They make it practical to integrate or use road definitions defined by the ASAM standards into a Cruden DIL simulator. Using these libraries reduces the risk of different providers interpreting the standard in a different way and having inconsistencies in the co-simulation.

Cruden uses the software libraries e.g. to check on lane positions for developing lane assist algorithms. At first, driving on ASAM OpenDRIVE layers in the Cruden simulator was difficult as a human in the loop is less predictable than scripted driver behaviour in an offline simulation, especially at intersections. The ASAM OpenDRIVE query was used both to query the road height and lateral position within the lane. When approaching a junction, the current lane splits in several lanes, one for each road. In a traffic simulation, the path of the traffic vehicles through the road network is known and, at a junction, the correct lane can be selected to continue. However, from the input of the driver in the simulator, it is not immediately clear in which direction he/she will continue. With an incorrect lane, the lateral position in the lane, used for the lane assist algorithm, might be incorrect. The solution was to temporarily turn off the ADAS system when approaching a junction. When the driver leaves the intersection, the correct lane is detected and the lane assist routine is enabled again – much like what happens when a driver ignores the instructions of a car's navigation system.

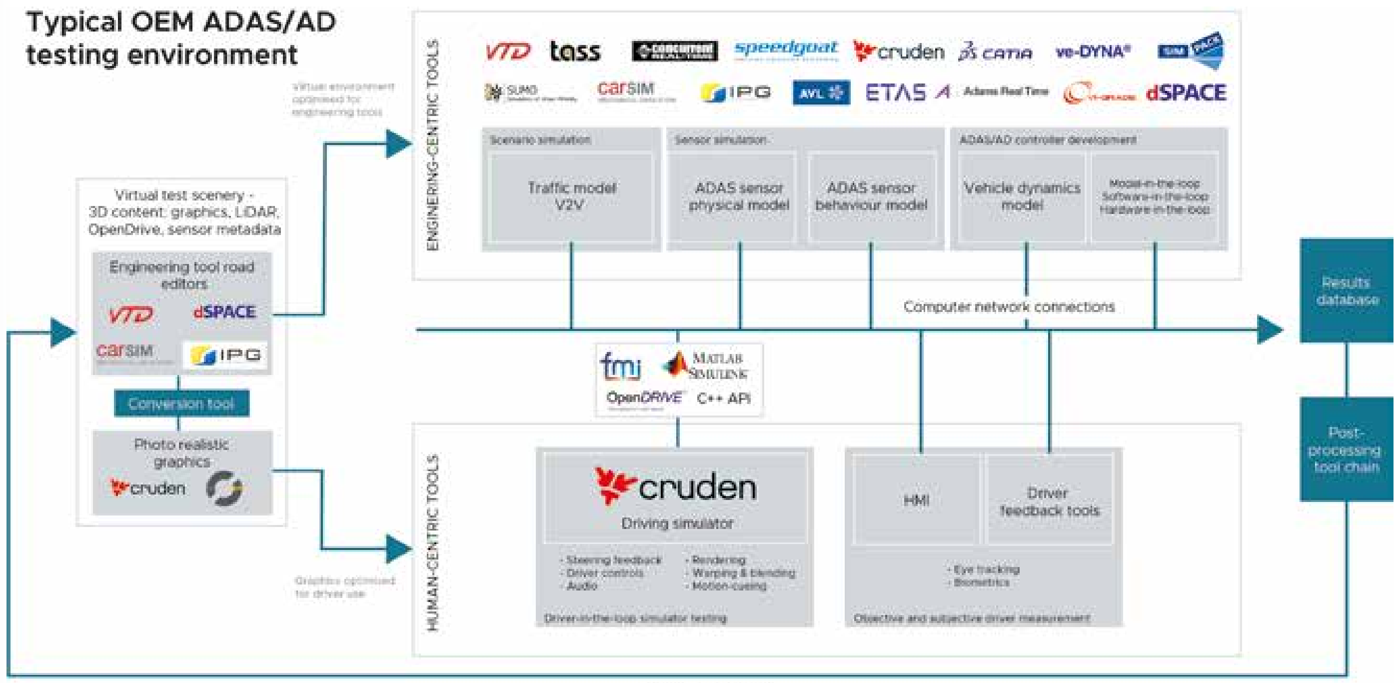
A further use case is Cruden's integration with MathWorks (formerly VectorZero) RoadRunner, an interactive editor to design 3D scenes for simulating and testing automated driving systems. Since RoadRunner also generates ASAM OpenDRIVE layers, it is very easy to create scenes that work both in the Cruden software and the engineering tools integrated with the driving simulator.

It's this flexibility in using different engineering tools around the driving simulator that provides the greatest benefit to Cruden and its customers. This is why Cruden has decided to rely on ASAM OpenDRIVE.

By embracing ASAM OpenDRIVE, Cruden can offer driving simulators that can be easily integrated with whichever engineering tools its customers want to use. If a customer decides to switch to a different engineering tool or implement an additional one for certain research or development work, it can do so with minimum effort.

"It's very difficult to create a standard oneself that's sufficient to work in all cases. So if one already exists, it makes sense to use it. The ASAM OpenDRIVE standard gives us a platform that is well thought out and encompasses all the details that we will ever need."

NICO KRUITHOF,
Computer Scientist



Source: Cruden b.v.

Virtual City Systems GmbH

ASAM OpenDRIVE Reaches New Top Speeds in the Race for Autonomous Driving Solutions

Featured Standard:

ASAM OpenDrive

Authors:

Sarah Waldrip,
Science Writer

Dr. Stefan Trometer,
Managing Director

SUMMARY

Virtual testing is essential for the development of safe and reliable autonomous vehicles. Until recently, however, the virtual representations of urban environments and urban street spaces were created with fundamentally different data modelling approaches, which prevented the development of integrated driving applications that could simultaneously account for environmental features, road conditions and other road properties on a large scale. To overcome these complex technical limitations, GIS experts at Virtual City Systems engaged with ASAM OpenX working groups to further develop existing data standards as well as create a new software solution that converts ASAM's OpenDRIVE standard data format for describing 3D road spaces into GIS data formats such as CityGML, the global standard data format for semantic 3D city models. These developments enabled a standardized methodology for designing a virtual test field to be established in the city of Ingolstadt as part of the research and development project SAVe under the leadership of AUDI AG. The final software product will enable previously impossible automotive and mobility applications, which in turn will support Smart City initiatives and Digital Twins.

Autonomous driving is entirely reliant on vehicle sensors that can respond to the surrounding environment in real time. In the development of these sensors, virtual testing saves enormous amounts of time and money and ensures the vehicles are safe and reliable before putting them on the road with human drivers. However, this testing requires an exact virtual representation of the environment, which has presented a major technical challenge for engineers and software developers. Virtual City Systems has been contributing to the development of integrated virtual mobility applications through its participation in ASAM OpenX activities and particularly the SAVe research and development project. SAVe, which stands for functionality and traffic safety in automated and networked driving, is led by AUDI AG in the automobile company's home city of Ingolstadt. The project received 4 million Euro in funding from the German Federal Ministry of Transport and Digital Infrastructure and is supported by Virtual City Systems and partners like 3D Mapping Solutions, Carrissma (Center of Automotive Research on Integrated Safety Systems at TH Ingolstadt), and many others.

Virtual City System's primary role as experts for geodata-based 3D city model solutions in the SAVe project was to help develop the methodology for a virtual autonomous driving test field in Ingolstadt. To do this, the team would have to first overcome the limitations of current modelling methods and bring them together under a common standardized data format.

Merging digital lanes with environmental models in Ingolstadt posed technical challenges

"Traditionally, these virtual images are created by two different technical disciplines using different acquisition methods," explains Stefan Trometer, Managing Director of Business Development at Virtual City Systems. "Environmental models, which include objects such as buildings and vegetation, are typically based on the official cadastral survey and generated according to the principal of boundary surface representation. In contrast, street space models, which include features like lanes and street signs, are captured and distributed by surveying companies as parametric models for driving simulation software tools."

Source: SAVe & Virtual City Systems

A crossing in the city of Ingolstadt is virtually represented with both detailed street space information and urban environmental model as basis for various mobility applications

ASAM OpenDRIVE had already established an open, globally accepted format for the semantic and detailed 3D descriptions of road spaces. Like ASAM OpenDRIVE, CityGML is a globally used data format that standardizes the modelling, storage and exchange of semantic 3D city models for use in the context of urban simulations and analyses. With this foundation in place, Virtual City Systems was able to develop a strategy for integrating the street space models of Ingolstadt into their CityGML-based city model based on the high quality of data captured by project partners, like 3D Mapping Solutions and the surveying authorities. This forms the ideal basis for mobility applications in the specific urban environment.

"We chose an ASAM-based solution because we believe in globally accepted open standards as key driver for innovation in a quickly developing digital world," Trometer says. "For us as company with a strong focus on GIS, we appreciated OpenDRIVE as a globally accepted and open standard for our own developments to build on. Beyond this, the ASAM organization under the lead of Klaus Estenfeld is a highly professional, efficient, and pleasant co-operative partner."

This cooperation among the project partners and stakeholders, both within the automotive industry and in the wider urban simulation domain, was crucial for the success of the project, which is now entering its final phase. The detailed road space model according to the ASAM OpenDRIVE data format can now be visualized in its urban context through a web-based and interactive client, which in turn supports further analyses such as view shed analyses and the animation of traffic simulations.

Benefits of integrated data standards are far-reaching

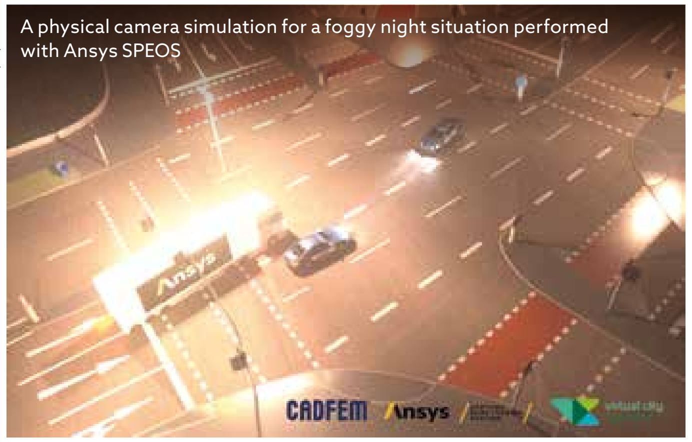
One of the other major benefits of integrating the ASAM OpenDRIVE and CityGML standardized data formats is the added ability to enhance Smart City applications in both directions: Information from the city about infrastructure can directly support mobility optimization and safety measures, and information from vehicles and roadways can support city applications like monitoring weather conditions and traffic delays in hyper-specific detail. This interconnectivity improves the security for Ingolstadt residents, particularly as autonomous vehicles are still a new safety consideration for pedestrians and drivers, and it also has the potential to support a more robust Digital Twin that will improve the overall quality of life and civil participation, not to mention the time and money saved for countless city projects.

Aside from these possibilities that arise from integration of street space models and 3D city models, there are also a lot of automotive applications that become feasible. Testing vehicles, sensors and systems in an accurate virtual environment can validate models and results and push the envelope forward in automotive simulations in general.

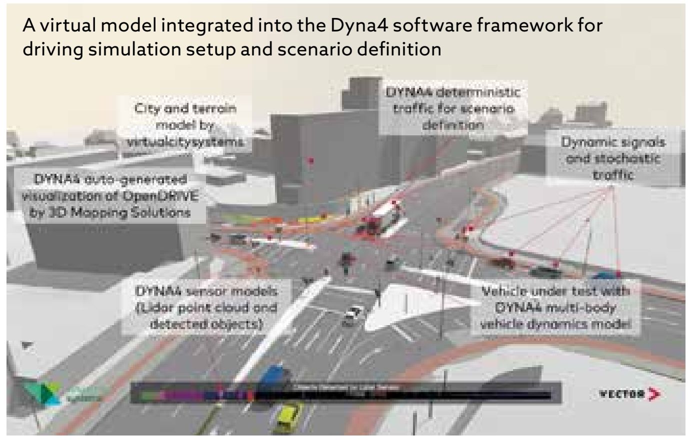
"In addition to technical questions, we will also answer important social questions with the developed methodologies, methods, processes, and workflows. In the final development stage, we want to create a real-time, capable model for the planning and control of urban and suburban mobility. This model is at the same time a 'virtual sandbox' for the development and testing of services (mobility and more) in urban space."

LUTZ MORICH,
SAVe project leader from AUDI AG

Source: CADFEM & Virtual City Systems



A physical camera simulation for a foggy night situation performed with Ansys SPEOS



A virtual model integrated into the Dyna4 software framework for driving simulation setup and scenario definition

Source: Vector & Virtual City Systems

Automotive Artificial Intelligence (AAI) GmbH

AAI Scenario Cloning & Extraction: A Tool for Digitizing and Extracting Test Drive Data into Scenario Templates

Featured Standards:

ASAM OpenSCENARIO
ASAM OpenDRIVE

Authors:

Oliver Grimm ,
Product Strategy

Jonathan Schmalhofer,
Product Strategy

SUMMARY

Challenge: Automotive OEMs or OESs collected a huge amount of sensor data from their vehicles fleets during testing and validation of their ADAS and AD systems. Often that data remains not fully utilized and benefits are not taken.

Solution: AAI developed methods to digitize existing test drive data for simulated tests by applying AI methods. We focus on extracting critical scenarios, provide a test drive quality report and store the gained scenarios in ASAM OpenSCENARIO® and ASAM OpenDRIVE® formats.

Key Benefits: The solution enables customers to replay complete test drives in simulation for performance, quality analysis and the identification of high-quality scenarios. The scenarios can be classified by their criticality and be used for testing and validating ADAS and AD functions.

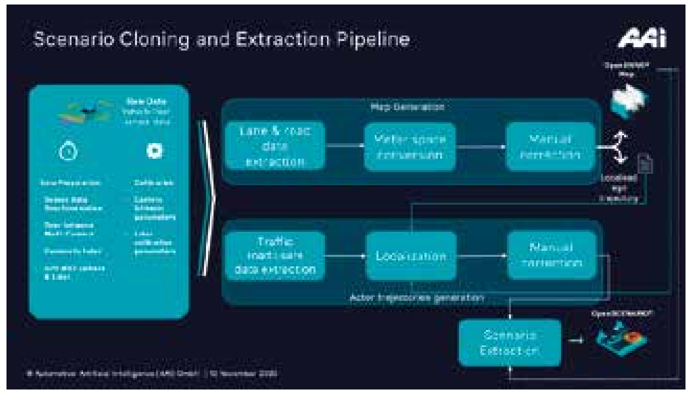
APPLICATION STORY

Many companies engaged in the automotive sector, are already in possession of petabytes of sensor recordings from field operation tests. Since physical test drives are still a proven way to conduct testing and validation of advanced driving assist and automated driving functions, the amount of sensor data is ever increasing. However, one task to solve is to efficiently extract precious insights from the collected data lakes for repeatable future use.
One approach is to store the sensor recordings from all installed sensors in a timely synchronized manner including their internal raw data. Having this collected enables a one-to-one replay of the recorded test drive by feeding the recordings to a Hardware- or Software-in-the-Loop (HiL or SiL) setup, and "replay" a test drive. However, the data produced by a multitude of test vehicles can easily consume petabytes of data storage, where due to the nature of test drives, not every collected minute is worth storing, since the recorded scene is not resembling an interesting situation. A one-hour test drive, where the test vehicle is equipped with 4 cameras and 4 Lidars, easily sums up in more than 300 GB of sensor data.
An alternative is to develop methods to derive a deterministic description of specific traffic situations or interesting incidents as a reusable scenario, with multiple purposes in mind. Examples are regression testing in simulation, test drive analysis by extracting key performance indicators from it, manipulation and variation of recorded tests, and finally enriching your scenario database.

To realize this, AAI has developed a two-fold approach:
Firstly, critical traffic situations are identified and classified into scenario categories (according to so-called Pegasus categories or maneuver types, like cut-in, hard brakes). This happens in real-time during the test drive. Offering this, only relevant time frames are marked for later data processing, which saves the time for engineers to carefully review the data recordings afterward. On top, a comparison between the subjective and objective criticality assessment of the traffic situations can be performed during the ongoing test drive.
As a second step, the data matching the previously marked time frames are post-processed by AAI's Scenario Cloning pipeline (c.f. Fig. 1).
As a prerequisite, the sensor data, consisting of a minimum of one front camera feed and GPS/IMU data, will be synchronized and the sensor parameters calibrated. To increase the precision and richness of the scenario, multiple cameras and multiple Lidars can be utilized as well.
A local map of the test vehicle's surroundings is generated, and the vehicle is precisely located. All cues from the surrounding important for scenarios are added to the map.
The next step is to detect and trace all traffic participants within the sensor range of the test vehicle and localize them on the map.
For ensuring to generate the highest quality scenarios, we are convinced that a final quality check and the possibility to perform manual corrections are important. Therefore, we integrated our annotation tool for enabling the engineer to perform manual corrections as the last step before outputting the maps and scenarios in ASAM OpenDRIVE® and ASAM OpenSCENARIO® formats.
Importing the generated scenarios into a simulation environment will create a feedback loop. Data can not only be replayed and analyzed but can also be used for conducting deterministically defined test cases (c.f. Fig. 2).
The benefits of choosing the well-established formats ASAM OpenDRIVE® and ASAM OpenSCENARIO® are perceivable in the achieved comparability, exchangeability, and thus overall flexibility for our customers. Besides proprietary formats, the majority of ADAS simulation tools now support these ASAM formats as well. This allows our customers to make use of our maps and scenarios independent of their currently employed tool setup.
Additionally, no efforts for developing and maintaining an internal proprietary format are required, leading to a simplified and accelerated development roadmap with our own organization.

"I chose an ASAM based solution, because the well-defined standards ASAM OpenDRIVE and ASAM OpenSCENARIO ensure compatible formats for usage of AAI's product's outcomes across different simulation tool chains."

INTAKHAB KHAN,
Managing Director of Automotive Artificial Intelligence (AAI) GmbH



Source: Automotive Artificial Intelligence (AAI) GmbH

Figure 1: Simplified Scenario Cloning and Extraction pipeline.

Source: Automotive Artificial Intelligence (AAI) GmbH

Figure 2: Exemplary "cloned" scene: Large image shows the annotated camera scene, the small image shows the replicated scenario.

AKKA GmbH & Co. KGaA

Artificial intelligence to attain seamless and effective laboratory and real-world test for autonomous vehicles

Featured Standards:

ASAM OpenLABEL
ASAM OpenSCENARIO

Author:

M.Eng. Harsha Jakkanahalli Vishnukumar,
Project Manager & Architect AI-Core

SUMMARY

The EE Test Solutions & Diagnostics department at AKKA GmbH & Co. KgaA are working closely with OEMs and suppliers to test, verify, and validate Advanced Driver Assistance Systems (ADAS) and Autonomous Driving functions. Testing is divided broadly into laboratory and real-world tests. There are static and dynamic testing methods in the laboratory, which include tests in a virtual environment or simulators (including reply, open-loop, and closed-loop). Real-world testing is either conducted on a proving ground or real-road. The research and development in autonomous driving and ADAS conduct reliability tests by Naturalistic Field Operational Tests (N-FOT), covering millions of test kilometers in the real-world, generating Big Data.

CHALLENGE

The challenge with highly automated driving is to ensure functional safety. With level 3 automation according to BASt or level 4 of the SAE classification, conventional validation strategies for driver assistance systems reach their limits, since the driver no longer has to be at disposal for fallback control. Consequently, all conceivable situations must be controllable by the automated driving system, which means that the requirement specifications to be fulfilled by the system are no longer fully available or known. Hence the current release practice with mainly real-world tests is no longer applicable for automated driving functions. For this reason, future trials are increasingly being shifted from real-world to virtual in simulated platforms. The transfer of test activities into a virtual environment poses a challenge due to real-world virtualization, accurate sensor modeling, manual test case or scenario creation without complete requirement specifications for highly automated driving. In real-world testing, the N-FOT approach alone can not cover all critical driving situations and scenarios in the real-world. Though it offers realism and unique scenarios from the real-world, such tests can be time-consuming, resource-intensive, and dangerous.

In the state-of-the-art approaches, the data gathered from the real-world is pre-processed for use in calculating the system-under-test's (SUT's) key performance indicators (KPI), conducting replay tests, and using the data to create test cases and scenarios. The use of recorded Big Data (which is usually in petabytes) is resource-intensive. Manual creation of scenario requires specification requirements, which is not fully available for highly automated driving functions. On the other hand, one needs to think about a scenario to create them. Classical computer programs and classical data mining techniques can extract only a fraction of required data since it is challenging to program all required characteristics of scenarios. Extraction of information from real-world data is achieved today by manual labeling. Manual labeling of time-irrelevant (objects, segments in individual frames) and time-relevant (sequences, scenarios) is not a viable option due to the inconsistency, time and resource-intensive nature, and quality. For these reasons, researchers concentrate on generating scenarios automatically and extracting them from real-world recorded data. Based on the state-of-the-art research and automated scenario generation techniques, valid scenarios found after automated generation are comparatively sparse. Though scenario-based approach promises a systematic way for testing ADAS and autonomous vehicles, possessing valid and meaningful scenarios poses a major challenge.

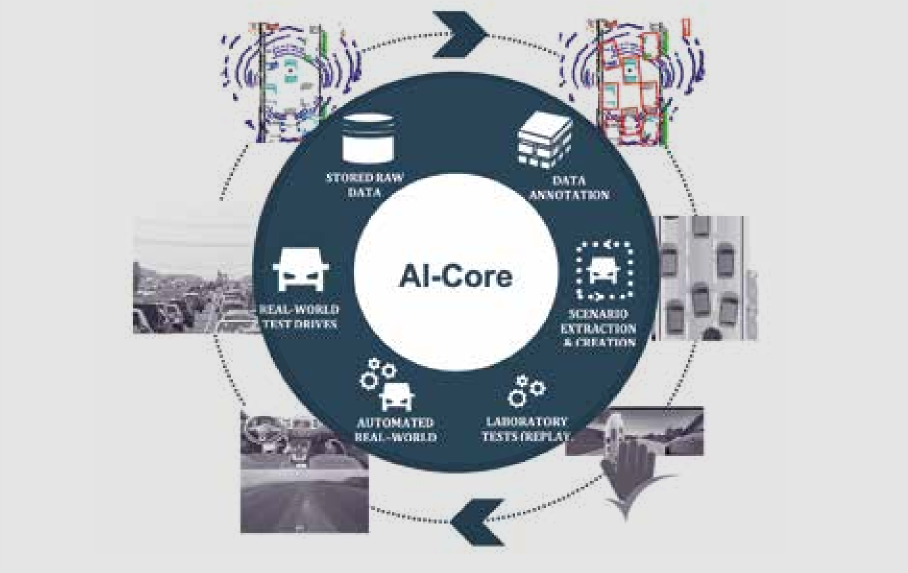
As a summary, four main challenges can be derived:

- Multi-dimensional aspect and non-deterministic behavior of surrounding environment causing an exponential rise of possible scenarios
- For highly automated driving, the requirement specification as yet unspecified, unknown, or incomplete
- Agility in software development causing the need for extensive but faster and shorter iterative testing
- Big data from ADAS and autonomous vehicles during testing causing manual and classical data labeling and extraction approaches to under-perform or fail completely

SUCCESS STRATEGY

AI-Core offers solutions to address the challenges in the test, verification, and validation of Autonomous Driving systems. The existing or newly gathered real-world raw data can be considered as input. A group of deep neural networks (DNN) within AI-Core will extract the time-irrelevant information. The extracted information is again fed into a set of Recurrent-DNN to extract abstract scene-related information. The extracted information can be transformed into the ASAM OpenLABEL format. With real-world raw data and extracted information, the data is again fed to a set of AI-Core-based DNNs to extract scenarios. The scenarios here contain both static and dynamic information from the surrounding environment, and hence the ASAM OpenSCENARIO format can be used here. The techniques used to detect and extract scenarios additionally will find novel scenarios in the available data without requiring any new training for the model-based algorithms used in AI-Core. The extracted labels and scenarios can be further used for KPI analysis of system- or function-under-test, open-loop tests, replay, and XiL tests. Though the real-world data covers real-life scenarios, critical scenarios are sparse. AI-Core offers two novel approaches, one method using latent space vectors and another

SUCCESS STRATEGY / SOLUTION: AI-Core



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using multiple reinforcement learning approaches. Both methods are used to generate scenarios concentrating on the boundary conditions, failures, and hotspots where the system-under-test fails or at the boundary of a threshold. The created new scenarios contain all information (ASAM OpenSCENARIO compatible) in order to be replicated in a virtual environment for testing. To complete the whole cycle, we extend the critical and mandatory scenario tests to the real-world using our Automated Testing Ground (ATG) platform. Here, vehicles are driven by driving robots and drive-by-wire technology together with automated surrounding actors in a closed proving ground.

Scenarios extracted and newly created by AI-Core can be reused in iterative automated testing and testing during development to gain qualitative and quantitative insights to understand the maturity of system-under-test. ASAM OpenLABEL and OpenSCENARIO standards can be used throughout the iterative testing cycle as shown in the Figure 1.

BUSINESS BENEFITS

- AI-Core saves cost and time on labeling and scenario extraction and also improves the quality
- The accuracy of scenario detection and classification is 99,3%
- Scenarios can be grouped based on the scenario classes. Novel or unknown scenarios are automatically detected to be validated by a human reviewer
- A large set of usable scenarios can be newly created concentrating on failures to improve the coverage of critical and boundary scenarios for testing
- Data can be filtered based on the detected scenarios or scenes, which saves time and efforts in analyzing or testing
- The workflow and methodology is efficient and adaptable to the changing needs and hence can be adapted to iterative agile development cycles
- The methodologies and processes are independent and hence not confined to a specific OEM or supplier
- Provides flexibility to test virtually and in real-world round the clock

"The way to achieve Autonomous Driving to reach the global market is by standardization of methods and approaches to support development, testing, and validation throughout the automotive industry. By the approach of strong partnerships with the industry and academia, evaluating the present and future technology demands and trends, ASAM standards such as OpenSCENARIO 2.0 and upcoming OpenLABEL could be an opening door to the next step for future testing, verification, validation, and development. Hence I support ASAM."

M.ENG. HARSHA JAKKANAHALLI VISHNUKUMAR,
Project Manager and Architect AI-Core
(Managing Director and CEO AKKA Technologies India)

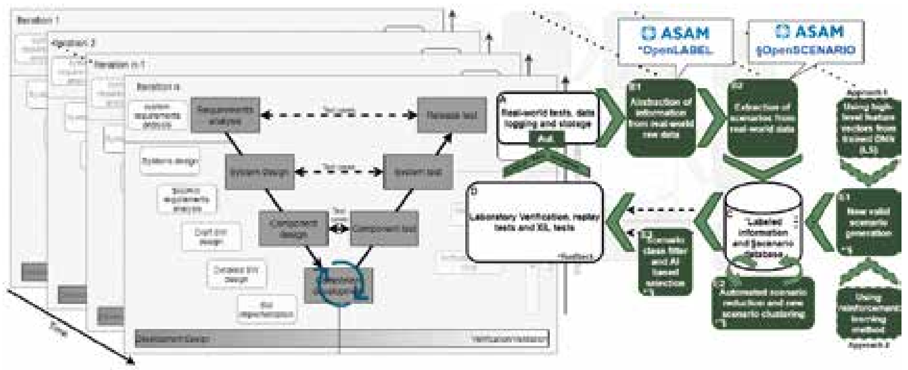

Fig. 1 (Derived from Dissertation work of M.Eng. Harsha Jakkanahalli Vishnukumar)

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FIVE

The Five Platform: A modern cloud-based platform for development and assurance of Automated Driving Systems

Featured Standards:

ASAM OpenDRIVE
ASAM OpenSCENARIO
ASAM OSI

Author:

Iain Whiteside,
Principal Scientist

SUMMARY

Five spent its first four years developing one of Europe's most advanced Autonomous Driving Systems (ADS) for deployment in an urban environment - London, UK. The complexity of the Operational Design Domain (ODD) along with the target system reliability (SAE L4) led Five to building substantial new infrastructure to support extensive simulation-based development and analysis. Five has spent the last 18 months commercialising this platform for use by 3rd party system developers.

One of the key challenges for customers adopting a simulation-based development and assurance platform that meets the complexity and reliability needs of SAE L3 (and above) systems, is in making use of their extensive legacy assets. OEMs and Tier 1s have spent significant time and effort building scenario databases and validating vehicle, tyre, road and physics models. Making use of these assets by integrating with their existing simulation infrastructure — whether off-the-shelf or internally-built— can often be a painful and time consuming process.

To ease this burden, the Five platform supports: a) a co-simulation model using the ASAM OSI standard, offering a clean and well-understood interface to an ADS or host simulator; b) the import and reuse of existing ASAM OpenDRIVE maps and ASAM OpenSCENARIO scenarios, which ensures that any existing customer content can be reused.

The key benefit of supporting the ASAM simulation standards in our platform is that it greatly eases the process of integrating customers; relieving any woes of vendor lock-in reduces a buying hurdle for us and enables our customers to feel the benefits of the platform as soon as possible.

APPLICATION STORY

Five is an automated driving technology company founded and based in the UK. Its cloud-based development and assurance platform helps automotive companies and their suppliers to speed up the development of automated driving systems (ADS) whilst reducing the cost of doing so. Five's initial focus was on developing Europe's most sophisticated self-driving system. In 2017, Five attracted UK government support for StreetWise, a pioneering project to develop, integrate, test and demonstrate a safe and highly functional self-driving system on the streets of London.

Five recognised early that the key to developing a safe self-driving system that could cope with the complex operational design domain (ODD) that London offered was efficient use of simulation. The cloud-based platform that Five built – initially for their own ADS – enabled Five to:

- Gain more coverage: reducing the cost associated with achieving a given level of test coverage when compared to flows based on a mix of photoreal simulation and physical testing, both on test track and on public roads.
- Find problems quicker: reducing the time and cost required to find problems in motion planning subsystems when compared against a flow based on bug fixes proven against a scenario replay regression suite and then physical testing.

While developing simulation infrastructure to support Five's internal stack development, the interface between stack and simulator, as to between simulation and scenarios, could be proprietary and deeply integrated, i.e. Five could be sure to address the real issues experienced in developing these complex systems. The challenge as they pivoted to commercialize their development and assurance platform for 3rd party use, was to provide a clean integration with customer simulators (in a co-simulation model) and ADS, without losing the benefits previously experienced through deeply integrated, proprietary interfaces.

Source: FIVE

A screenshot from the Five scenario editor.

It very quickly became apparent that the emerging ASAM OpenX standards offered a good solution for these potential pains. In particular:

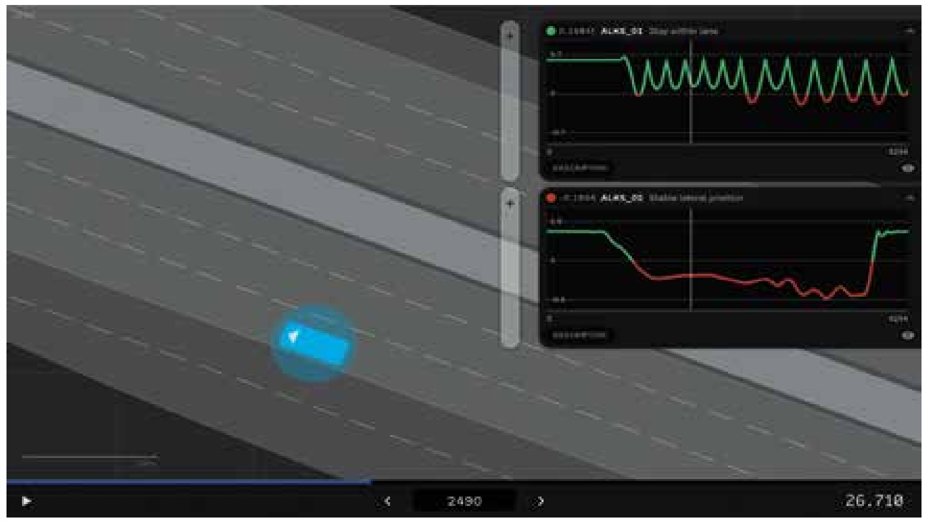
- ASAM OpenDRIVE was already well established as the de-facto standard for High Definition maps in simulation and it was already well supported in the Five platform. A lot of the work performed by ASAM on the OpenDRIVE Transfer project was on clarifying several ambiguities and inconsistencies that has helped Five provide both a robust map import function.
- ASAM OpenSCENARIO, the dynamic scene cousin to ASAM OpenDRIVE, also benefited greatly from the ASAM OpenSCENARIO 1.0 Transfer project, which has enabled the Five platform to adopt ASAM OpenSCENARIO as its scenario representation format. The Five platform is also poised to support OpenSCENARIO 2.0 as it matures over the next year.
- The newest ASAM standard in the simulation domain, ASAM OSI, provides an exact and detailed specification through which simulators can communicate with ADS systems in a standardized manner. In the Five platform, a customer need only implement a clear interface based directly on this standard to communicate. The Five team has deep experience using OSI and offers technical support, making integration take an average of less than one week per customer.

A challenge for us is the fast moving nature of ASAM OpenX standards. All of the standards mentioned, as well as others such as ASAM OpenODD and ASAM OpenLABEL that we intend to support, are under active development. We have inevitably found that different customers support different versions of the standards, requiring migration paths. However, the ASAM projects have this migration support as an explicit goal, reducing the effort required from individual users of the standard.

Five benefits greatly from the collaboration of ASAM and its members in creating simulation domain standards that bring us all closer to Five's vision of a world where safe, green and accessible autonomous mobility improves the world in which we live.

"Open standards are essential to the development of and investment behind an ecosystem of vendors that can support advanced ADAS and self-driving system development. Five supports ASAM in particular because they have the most relevant and expert contributors in the industry. Their efforts in creating standards for the simulation domain helps Five deliver a platform that speeds up the development of automated driving systems whilst reducing the cost of doing so."

STAN BOLAND,
CEO, Founder



Source: FIVE

Evaluating an ALKS function in the Five platform, using customizable road rules.

HORIBA Europe GmbH (HORIBA) + 3D Mapping Solutions GmbH (3DM)

ASAM OpenDRIVE and ASAM OpenSCENARIO for ViL-Testing on Chassis Dynamometers

Featured Standards:

ASAM OpenDRIVE
ASAM OpenSCENARIO

Author:

André Engelbert,
Global Application Manager CAV,
HORIBA Europe GmbH

“The OpenDRIVE and OpenSCENARIO standards created by the ASAM initiative and the ongoing OpenX standard developments enable 3D Mapping to provide HD Map and simulation solutions of outstanding quality, which can be used for multiple simulation purposes of our customers in various simulation software packages or simulator platforms.”

DR. GUNNAR GRÄFE,
CEO, 3D Mapping Solutions GmbH

SUMMARY

Challenge

Currently, vehicle-in-the-loop (ViL) testing on chassis dynamometers is becoming a worthy alternative to testing procedures conducted on real proving grounds, test tracks and public roads. In particular for the testing of advanced driver assistance systems (ADAS) and autonomous driving functionalities the ViL approach entails significant advantages such as the reduction of testing time and costs, enhanced reproducibility, safety and the fact that testing can be conducted already during early development stages. For ViL testing, the vehicle under test does not interact with real traffic participants or road signs. Instead, the chassis dynamometer is equipped with a set of devices - so called stimulators - each responsible for stimulating a respective sensor system (i.e. camera, lidar, radar) and therefore creating an artificial environment, the vehicle under test (VuT) may interact with. However, to obtain results which are as close to reality as possible, appropriate data input formats are required. One aspect of such a virtual environmental twin are the simulated tracks onto which the VuT is driving. Besides the realistic physical input variables determining the simulated road load, the simulated track must also provide objects such as signs, lane markings and other traffic control elements which may be perceived by the VuT’s sensors.

Solution

ASAM OpenDRIVE is an ideally suited format, which includes all necessary static aspects of the virtual environmental twin in form of an XML syntax: The various road geometry parameters as for example distance, curvature and elevation can be derived to simulate the respective road load by means of the dynamometer. Besides, these data describe the 3D layout of the simulated track but also additional objects such as road signs, traffic lights, surface profiles, railroad elements, tunnels, bridges linked to the road geometry. In addition to ASAM OpenDRIVE, the ASAM OpenSCENARIO format is used to insert all the relevant dynamic elements such as traffic participants or special target vehicles. From these datasets the respective parameters for the particular test cell devices as camera, lidar and radar stimulators are derived to create the artificial environment.

Key-Benefits

- Single data format, providing comprehensive information to obtain a detailed and realistic virtual environment for ViL testing
- Closed and controllable data flow
- Enabling porting of HD mapped real world traffic networks with a high degree of itemization and geometric accuracy to the HiL and ViL test cell
- Various proprietary and open source tools available to create and modify ASAM OpenDRIVE data
- The foreseen combination to other Open Standards like ASAM OpenSCENARIO can be beneficial to enhance the artificial environment…
- Creation of artificial traffic and the implementation of traffic management tooling is possible
- HORIBA provides single source solutions such as fully equipped test cells as well as single standing devices, which may be integrated in existing chassis dynamometers
- 3D Mapping Solutions provides HD maps of real road networks, proving grounds and race tracks available as ODR files

Application Story

HORIBAs future test cell combines chassis dynamometers with the datasets from 3DM (Figure 1). By means of a virtual environmental twin the application is able to bring every real existing street into the test cell. Therefore, the van-based survey system from 3D Mapping Solutions is used worldwide for digitizing proving grounds, race tracks and public road networks with high accuracy and resolution using high-resolution scanners and multiple calibrated cameras (Figure 2).

Afterwards, the digital road data is used to create an identical digital environmental twin of the real-world road as base for a valid simulation. All road and traffic related objects are precisely extracted from the scanner and camera data and processed to the corresponding virtual objects (Figure 3).

The technology is used to produce precise high-definition reference maps in ASAM OpenDRIVE format or to generate high-fidelity 3D environments including appropriate textures and material representations.

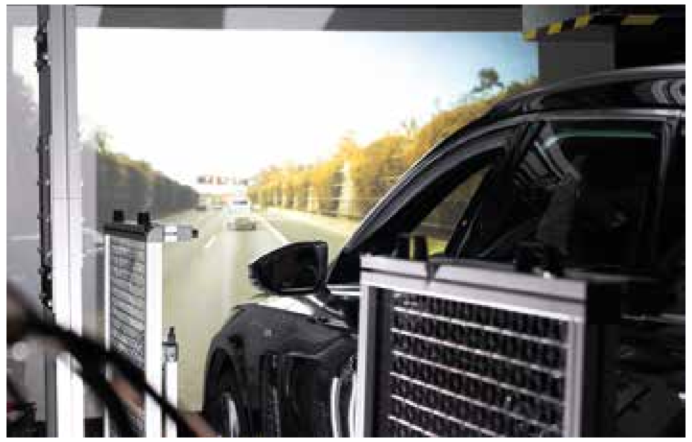
With the support of ASAM OpenDRIVE, HORIBA provides testing applications and supports development phases as early as possible. Moreover, use cases in the homologation of ADAS and autonomous features as well as aftermarket business cases such as periodical technical inspections, are supported (Figure 4).

“New vehicle technologies demand suitable test methods. By combining our chassis dynamometers with the ASAM OpenDRIVE and ASAM OpenSCENARIO standards we are closing the gap between the real world and laboratory-based testing.”

ANDRE ENGELBERT,
Global Application Manager,
HORIBA Europe GmbH

“The next evolution of testing starts right here. We are very delighted to move one stage ahead to support autonomous driving and ADAS testing on HORIBA chassis dynamometers.”

DR. ROBERT PLANK,
President HORIBA Europe GmbH



Source: HORIBA Europe GmbH

Figure 1: HORIBAs future test cell with an 3DM camera image.

Source: 3D Mapping Solutions GmbH

Figure 2: 3D Mapping laser scanner point cloud

Source: 3D Mapping Solutions GmbH

Figure 3: Digital environmental twin a real-world road.

Source: HORIBA Europe GmbH

Figure 4: HORIBA ADAS & AD Dynamometer with Sensor Stimulation.

IPG Automotive GmbH

Using ASAM Simulation Standards in CarMaker within the PEGASUS Project

Featured Standards:

ASAM OpenDRIVE
ASAM OpenSCENARIO

Author:

Martin Herrmann,
Business Development Manager ADAS & Automated Driving

SUMMARY

In future, establishing standardized processes in automotive development for the validation and release of automated driving functions will be necessary to be able to provide a generally accepted proof of safety. IPG Automotive promoted this necessity in the PEGASUS research project (project for the establishment of generally accepted quality criteria, tools and methods as well as scenarios and situations for the release of highly-automated driving functions). This project initiated a general discussion on validation processes within the German automotive industry [1].
Simulation as a part of the developed validation methodology, complemented by proving ground and field tests, is already being used to varying degrees in the industry. However, due to the use of solutions from different providers, the results are not necessarily comparable. PEGASUS fostered a common understanding of scenario and road definitions (ASAM OpenSCENARIO and ASAM OpenDRIVE) as well as sensor model interfaces (Open Simulation Interface, ASAM OSI) [2].
This laid the groundwork to use simple scenarios and sensor models across companies, departments and tools within the project. Prototypical implementations were successful and accelerated the transfer of the mentioned formats to ASAM e.V., where the standardization was to take place.

APPLICATION STORY

Before the launch of the PEGASUS project, standardized, independent formats for scenario and road description did not exist. It was therefore not possible to create a tool-independent and machine-readable scenario catalog. In fact, there were already OpenDRIVE and OpenSCENARIO initiatives with different levels of development, but the rights of the formats belonged to a competitor. An adaptation across all tool developers was therefore not feasible. Moreover, the many existing dialects and interpretations of the OpenDRIVE format made sharing existing road models more difficult.

The PEGASUS research project offered a platform for open discussions and encouraged experiments: Easy scenarios were described in different abstraction levels to finally define them as a concrete scenario in the OpenSCENARIO format. The scenario and the road network included in the OpenDRIVE file were imported and translated into CarMaker formats. Using this approach, the comparison of interpretations between the project partners could be tested.

Especially the interpretation of the OpenSCENARIO format was challenging during the project, because in contrast to the OpenDRIVE format, it did not yet have a longstanding testing record. Over the next years, OpenSCENARIO will therefore undergo a maturing process and will be developed further with the support of ASAM e.V. and its member companies.

Furthermore, in the beginning, there were no established standard sensor model interfaces with regard to the transmitted information and the packaging. The thereby caused high diversity of models in productive use resulted in considerable efforts in model building and the integration of sensor models into the simulation environment. For that reason, exchanging and comparing models from different suppliers was complicated.

A proposal submitted by the BMW Group [3], the Open Simulation Interface, was then intensively discussed and developed with sensor and tool manufacturers as well as OEMs. The goal was to create a format for the integration of sensor models and driving functions that is independent of sensor technology and simulation tools. Within the scope of PEGASUS, identical sensor models were used for the first time in different simulation tools without adapting the model interfaces. IPG Automotive implemented the ability to provide ideal environmental information for this purpose: OSI:GroundTruth as well as OSI Sensor Model Packaging (OSMP) extended the already existing Functional Mock-up Interfaces (FMI) in CarMaker.

Object-based, phenomenological sensor models that model the physical effects on the basis of ideal object lists from the environment simulation could therefore be integrated into the simulation platform. So far, only object-based sensor models could guarantee comparability between different simulation environments with this approach. Models based on geometry using ray tracing or rasterization techniques require standardized 3D models and formats as well as material definitions. This topic could not be discussed in depth in the context of PEGASUS.

The implementation of standard formats and interfaces in the simulation platforms CarMaker, TruckMaker and MotorcycleMaker facilitates significant savings in time and costs for OEMs and suppliers exchanging models and scenarios. Besides, the user gains additional flexibility when choosing a simulation tool. To increase the efficiency of development processes in the automotive industry and to make the use of simulation easier, IPG Automotive will continue to support the development and the implementation of the OpenX standards in ASAM-related and public research projects.

The following companies were involved in the PEGASUS project:
Audi AG, ADC Automotive Distance Control Systems GmbH, BMW Group, Continental Teves AG & Co. oHG, Daimler AG, German Aerospace Center (DLR), Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka), iMAR Company for inertial measurement, automation and control systems GmbH, IPG Automotive GmbH, Opel Automobile GmbH, QTronic GmbH, Robert Bosch GmbH, Technical University of Darmstadt – FZD, TraceTronic GmbH, TÜV SÜD Auto Service GmbH, VIRES Simulationstechnologie GmbH, Volkswagen AG.

Furthermore, the following affiliated partners participated in the PEGASUS project:
Federal Highway Research Institute, dSPACE GmbH, OFFIS e.V., Institute for Automotive Engineering – RWTH Aachen University (ika), Technical University of Braunschweig – Institute for Control Systems

The research project was promoted by the Federal Ministry for Economic Affairs and Energy on the basis of a decision by the German Bundestag.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

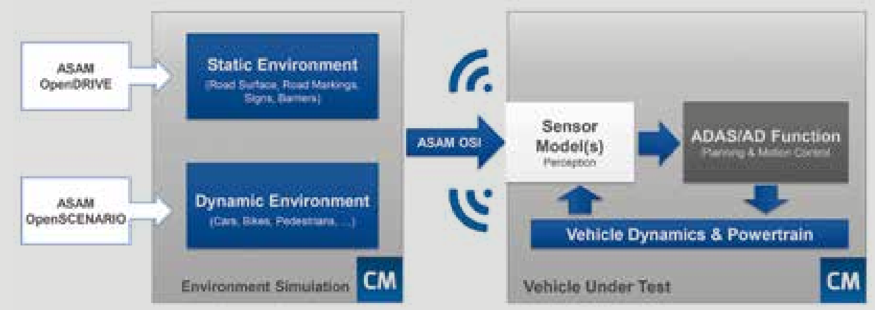
"ASAM provides an open and independent platform for discussion to improve cooperation with our clients and partners."

JOSEF HENNING,
General Manager Product & Solution Management,
IPG Automotive GmbH

Simulation of autonomous driving functions in a detailed environment with road users from different object classes

Source: IPG Automotive GmbH

Use of the ASAM simulation formats on the CarMaker simulation platform in the PEGASUS context – scenario definition and "ground truth" input for sensor models



Source: IPG Automotive GmbH

LiangDao GmbH

Accelerating Data-driven Testing and Validation with OpenX standards in China and Germany

Featured Standards:

ASAM OpenDRIVE
ASAM OpenCRG
ASAM OpenSCENARIO

Author:

Dr. Yang Ji,
CEO LiangDao GmbH

SUMMARY

Challenge: LiangDao is providing regionally representative scenario data services for the cooperative development, testing and validation of ADAS/AD functionalities to automotive customers in China and Germany. Data interoperability and exchange are the key challenges.

Solution: LiangDao adapted its data acquisition and software toolchain to the ASAM simulation standards to provide a standard-based scenario database and efficient scenario search services.

Key benefits: ASAM simulation standards are valuable tools for innovative start-up companies supporting the digital transformation in the automotive sectors. Both the high recognition and the practical applicability of the standards are extremely beneficial.

DESCRIPTION OF THE SITUATION

The core business of LiangDao is data and software. We design and set up in-vehicle data acquisition systems with a focus on LiDAR sensors that collect real-world traffic scenarios data in different regions of Europe and China. Subsequently, these data will be processed by LiangDao's perception algorithms. The resulting traffic object and scenario data will be stored in a central database and provided to LiangDao's customers, such as Volkswagen Group and Great Wall Motors.

INITIAL SITUATION

To meet the requirements of scenario data for different customers, LiangDao must provide different data interfaces without a common standard. The challenge of data operability remains the bottleneck in LiangDao's core business to deliver high quality data services to global customers. Therefore, we have started to transform both the data model and the data interface according to ASAM simulation standards such as ASAM OpenSCENARIO, ASAM OpenDRIVE and ASAM OpenCRG on the one hand. On the other hand, we support our customers in adopting the standards in their systems. A standard based scenario data strategy is beneficial for all data suppliers and accelerates the entire development process.

SUCCESS STRATEGY / SOLUTION

The strategy for success is primarily a mind-set change process, which is to be initialized among OEMs and suppliers. In the age of digitalization, customer requirements change very quickly. The time for development, test and validation is limited and the technical challenges of autonomous driving become more complicated. There is no place for data business protectionism on a specific in-house data format. Together we will be successful on the market with customized innovative applications based on open data standards.

CHALLENGES DURING THE PROJECT

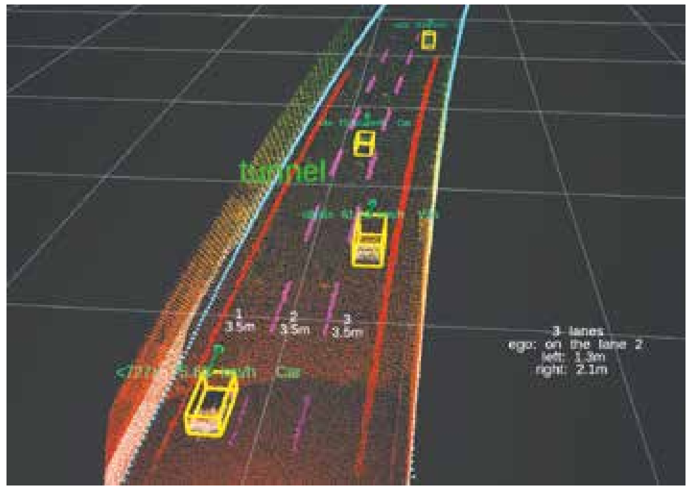
The biggest challenge in initiating this mind change is the definition of a suitable transformation strategy. There are different existing data formats. And not all traffic scenario data, for example meta data about the driving environment, can be completely sorted with the existing standards. For this reason, we look forward to working with other ASAM members to advance the further development of the OpenX standards. Thanks to the development system at ASAM, we believe that the newly emerging requirements will be implemented quickly in the upcoming standards.

BUSINESS BENEFITS

With the decision to consistently implement the ASAM OpenX standards, we can provide data services for various customers. The development effort for the development and maintenance of different data interfaces is enormously reduced. This has helped us to focus on the core competence of our data business and to increase the quality of our products and services.

"We chose an ASAM based solution because it enables the growth of data driven business in the challenging time of digital transformation, especially in the automotive industry. Only with standards, we will succeed and accelerate the implementation of autonomous driving."

DR. YANG JI,
CEO, LiangDao GmbH,
VP Beijing LiangDao Intelligence Automotive Technology



Source: Beijing LiangDao Intelligence Automotive Technology Co. Ltd.

Source: LiangDao GmbH

The generated scenario has been tested with VIRES Virtual Test Drive, which fully supports the OpenX standards.

RA Consulting GmbH

OpenSCENARIO API: An open source library promotes the new ASAM OpenSCENARIO standard

Featured Standards:

ASAM OpenSCENARIO
ASAM OpenDRIVE

Author:

Andreas Hege,
Chief Operating Officer (COO)

SUMMARY

ASAM OpenSCENARIO provides a solution space for describing and executing the dynamic content of driving and traffic situations. In both areas, development and validation, the simulation domain needs machine readable reproducible descriptions of maneuvers connecting to complex external systems like sensor models, driver models and road network models. ASAM standards such as ASAM OSI or ASAM OpenDRIVE cover these systems and share common concepts with ASAM OpenSCENARIO such as road coordinate system or the description of traffic participants.
Published in early 2020, the ASAM OpenSCENARIO 1.0 standard offers a detailed data model and an exchange format (XML) for the shared use of driving and traffic situations. Various simulation environments have already implemented ASAM OpenSCENARIO (e.g. esmini [5]). OEMs and tool vendors have started a broad initiative to develop tools and to use ASAM OpenSCENARIO as an abstract shared language to describe maneuvers for development and homologation. For example, in automated lane keeping systems (ALKS).
To create a common basis for the development, RA Consulting has initiated the open source project OpenSCENARIO API [1]. It defines a completely standard-compliant software API for reading, writing and checking scenarios. It is available in C++ and in Java and is published under Apache 2.0 license. The library offers both an integrable API and a checker framework. This extension point allows the definition of customer specific validations.
RA Consulting's portfolio includes automotive products such as DiagRA MCD Toolset and ODX Viewer. Their customers benefit from professional components such as A2L library, ODX API and MCD3 toolset, all implementing ASAM standards. RA Consulting's expertise in the areas of software architecture, development and data modelling was used when founding and creating the OpenSCENARIO API project.

APPLICATION STORY

It is extremely time consuming and multiplies the effort to implement different versions of the API for each OEM and tool vendor, for this standard. Each implementation could end up with slightly different results. The development and implementation of reading, writing and validation features follows the same patterns, only to end up on slightly different solutions. Another reason why various OEMs and tool providers are pooling their efforts in software development is to build strong supply chains based on the ASAM OpenSCENARIO standard. The semantic validation on both sides, the supplier, and the customer, requires a common tool to verify the delivered goods as a reference for the quality along the entire supply chain. There is no dispute about defects that one checker implementation finds and the other leaves undetected.

Various vendors integrate the library into their editors, their simulation environments, and their infrastructure. The OpenSCENARIO API is already the backbone of scenario testing in the public ALKS scenario project, provided by BMW AG. Other OEMs like Volvo Cars are currently evaluating the library.

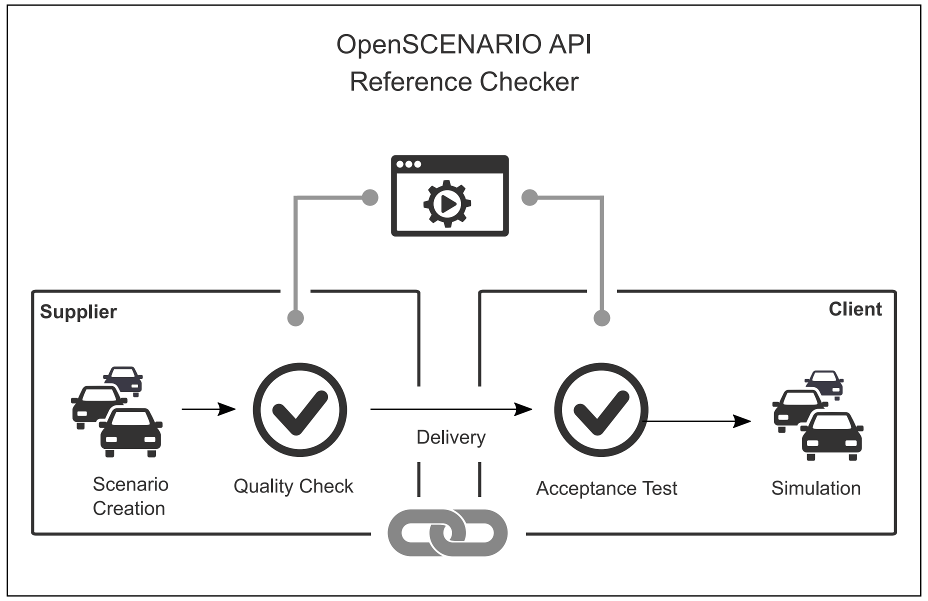
SUCCESS STRATEGY

The OpenSCENARIO API was created fully compliant to the ASAM OpenSCENARIO standard 1.0. It offers the following features:

- **Standalone checker:** An executable checker gives precise warnings and errors regarding a row- and column-based file location.
- **Browsing and editing.** An API for browsing through a scenario tree and editing list objects. It is ready to be integrated in editors, simulators, comparators and other tools.

This includes aspects that go far beyond simple XML schema validation:

- Resolving $-notated parameters.
- Resolving catalogue references.
- Resolving object references.
- Checking model constraints from the standard (range checker rules).



Source: RA Consulting GmbH

Strong supplier chain using the ASAM OpenSCENARIO API as a reference checker.

Architectural features:

- **Abstracting from storage media:** Read from archive files, from databases or from the cloud by writing your own resource locator classes.
- **Abstracting from storage formats:** Write your own loader class to read from binary files, from JSON files, etc.
- **Checker rule API:** Write your own checker rules. E.g. deduced from the authoring guidelines of your company.

The open source project OpenSCENARIO API [1] provides complete source code (C++, Java) and instructions how to build the software components on different operating systems and platforms. Tutorials on how to use the standalone checker and how to integrate the library are provided.

CHALLENGES

OpenSCENARIO API checker as a continuous integration component

At the end of 2020, the United Nations regulations for Automated Lane Keeping Systems (ALKS Regulation UN R157" ECE/TRANS/WP.29/2020/81) will soon come into force in Germany. It offers the opportunity to OEMs to implement a first automated driving system in series vehicles. BMW AG has taken on the task of implementing the test scenarios from the ALKS regulations using ASAM OpenSCENARIO and ASAM OpenDRIVE. The publication includes XML files executable with standard compliant simulators. The project has been opened to specific contributors. To ensure scenario quality and to guarantee the validity against the ASAM OpenSCENARIO 1.0 model, the OpenSCENARIO API checker component is deployed into the continuous integration (CI) environment of the hosting repository. The component is provided as a configurable github action [3], [4]. Whenever a new scenario or a changed scenario is pushed to the repository, the checker validates the files against the ASAM OpenSCENARIO model constraints. The component is configurable in different variants and can be equipped with customer-specific checker rules. E.g. to enforce project specific authoring policies or other extended rules. For a detailed article to use the checker rule framework, see the "Tutorial on Checker Rules" in the OpenSCENARIO API github project [1].

BUSINESS BENEFITS

- A standalone checker that validates business rules far beyond simple schema validation. Like checking catalogue references, resolving $-notated parameters or checking user defined rules.
- A sophisticated and standard compliant software library to read, to write and to validate ASAM OpenSCENARIO 1.0 files. Distributed under the Apache 2.0 license and ready to be used.
- Various extension points to read from archive-files, or from cloud applications, or to store scenarios in databases and binary files.
- A lively community of ASAM OpenSCENARIO users. Authors, developers, simulation engineers.

"It was fascinating to see how only a few months after the release of ASAM OpenSCENARIO V1.0 interested developers at BMW, Volvo (esmini [5]) and RA Consulting demonstrated the common understanding of defining scenarios in the standard with the concatenation of their projects."

CARLO VAN DRIESTEN,
Systems Architect for Virtual Test & Validation, BMW AG

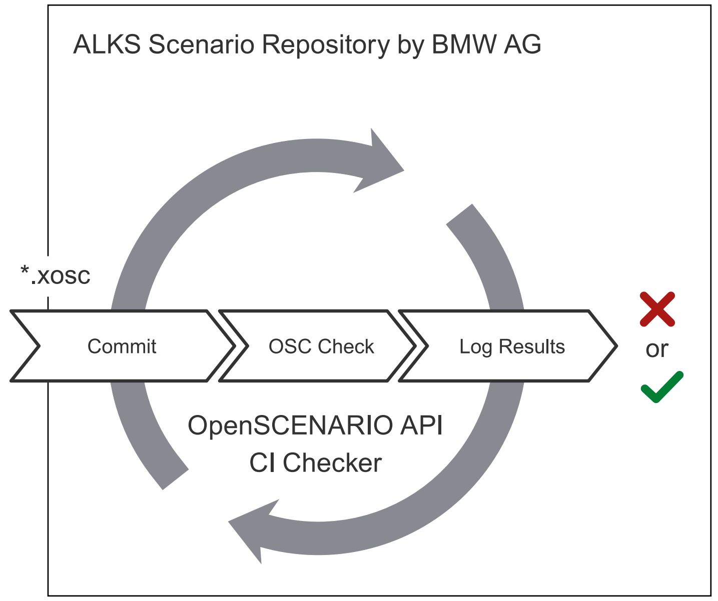
[1] The OpenSCENARIO API open source project:
https://github.com/RA-Consulting-GmbH/openscenario.api.test/

[2] OSC-ALKS-scenarios provided by BMW AG:
https://github.com/arauschert/OSC-ALKS-scenarios

[3] github Action Project : Integrating the OpenSCENARIO API into a github action.
https://github.com/ahege/openscenario.ci.test

[4] Registered github Action im Marketplace (v3.0.3): Published github Action
https://github.com/marketplace/actions/openscenario-checker-action

[5] esmini: Environment Simulator Minimalistic
https://github.com/esmini/esmini



Source: RA Consulting GmbH

OpenSCENARIO API as a continuous integration element in the ALKS repository

Siemens Digital Industries Software

Enabling automated vehicle verification and validation with real world data and ASAM standards

Featured Standards:

ASAM OpenDRIVE
ASAM OpenSCENARIO

Author:

Joan Roca,
Product Manager

"At Siemens we support ASAM because we believe that standardized solutions benefit the whole industry and accelerate the development and adoption of safer, more sustainable and more accessible means of transport by both authorities as well as general public, leading to a conscientious society."

JOAN ROCA,
Product Manager of
Simcenter Prescan,
Siemens Digital Industries Software

SUMMARY

- Millions of hours of recorded data are being generated during the development and testing of the next generation of autonomous vehicles. This data is stored and used for improving the development process, but without proper tooling it is not feasible to manually process it
- In order to achieve the safety standards required by both the authorities and the society to make the automated vehicle a reality, it is important to exploit every single bit of data available to improve neural networks, sensors, HMIs, comfort, …
- The usage of that data makes sure that after real world testing, we can confront our decision and driving algorithms as well as our sensor fusion algorithms with the same situations found during real-world testing, as well as enabling variations over those encountered scenarios
- ASAM OpenDRIVE and ASAM OpenSCENARIO offer the foundation to generate simulation scenarios that can be easily stored, shared and test automated. In this way, not only are we able to virtually replay the scenarios encountered while testing but also virtually enhance them and add variations to challenge our application with edge cases derived from the initial recorded data

APPLICATION STORY

At Siemens we are developing the virtual validation and verification solutions that will enable the development and certification of the automated vehicles of the future.

Customers face the ever-increasing challenge of validating their ADAS algorithms and meeting the authorities' requirements when certifying a newly developed vehicle. Simulation is already playing an important role in the industry to solve this challenge and it will play an even more essential role in ensuring the safety of the newly developed self-driving vehicles.

But virtual testing doesn't come without challenges. One of the focus areas of the auto makers nowadays is to make virtual testing as efficient as possible, by using edge test case detection. These edge cases need to be detected before the vehicle fleet is in service. As part of our validation and verification framework, we have set up a methodology to find such edge cases. We start with leveraging the data collected from vehicles which are on the road, that can be the test fleet or regular cars. This data is converted into simulation scenarios, which are then used for determining critical scenarios by varying the scenario parameters. The simulation results provide a feedback loop to improve and adapt the algorithms improving their robustness.

In order to satisfy this need, at Siemens we are enabling the pipeline that allows the import of real-world data into simulation. First of all, the data is collected in the vehicle. In order to turn all this data into relevant simulations, we need to make sure that the recordings are enriched with as much metadata as possible. The SCAPTOR solution offers in-vehicle tagging capabilities to ensure that the posterior automated tagging already has a basis to work with. Thanks to these two technologies, manual tagging is kept at a minimum, thus reducing costs on the whole pipeline. Subsequently, it is important to identify the relevant information, or the edge cases that we will challenge our application with. In order to guarantee efficiency and visibility, a fast and reliable searching tool is required, which will quickly identify and help visualize the stretches of data from our database that are relevant to us and to our test case. Finally, this data will be further processed into ASAM's OpenDRIVE and OpenSCENARIO open simulation formats.

The key benefits of using ASAM OpenDRIVE and ASAM OpenSCENARIO are enhanced shareability, storage and test automation capabilities, making them the obvious choice for our framework. Compared with test data, the logical road and scenario description in ASAM OpenDRIVE and ASAM OpenSCENARIO is the key to easily apply variations of the measured traffic situation, and thus be able to cover a large parameter space of the adjacent situations. Once the real-world data has been transformed into ASAM OpenSCENARIO models, it can be replayed in Simcenter Prescan. In Prescan, users can choose to virtually modify the sensors, algorithms and even the vehicle characteristics to ensure that the challenging situation can be overcome by the next generation of vehicles. Also, with our framework users will be able to explore and vary these challenging situations to ensure that all concrete scenarios can be derived from a logical scenario, guaranteeing full coverage of a specific scene.

Similarly, databases with critical scenarios can be created and later used to check the compliance of newly developed vehicle models and algorithms. These databases can then be used in a test campaign to ensure that all requirements are satisfied first in a high-fidelity simulation environment such as Simcenter Prescan, which provides validated sensor models, vehicle dynamics and asset quality and material definition. After the simulation-based validation and certification, users can proceed to proving grounds for their real-life test campaign with their validated simulation tests results. By using simulation first, we can displace the risk and the edge test detection to a virtual environment, ensuring safety is prioritized early in the process, reducing development time and reducing also time between prototype iterations (rapid prototyping). Furthermore, ASAM OpenSCENARIO databases with edge cases can be used in a cloud computing environment to ensure continuous integration of newly developed algorithms, enabling nightly verification in a CI/CD environment.

All in all, it is important to support all possible data streams when overcoming the multiple challenges that developing ADAS applications and autonomous vehicles entails. Even when using high fidelity simulation, real data plays an important role, enhanced by our edge case detection and test coverage methodologies, and bringing real-life traffic situations into play. Combining real-life data with synthetically generated data (either fictional scenarios or extrapolated from real data via test automation) will be key for functional test coverage and will ensure that the autonomous vehicles are faced with realistic traffic situations before getting on the road, making them safer and more comfortable to operate.

Tata Consultancy Services (TCS)

Enabling simulation across multiple tools by adopting ASAM OpenSCENARIO 1.0.0

Featured Standard:

ASAM OpenSCENARIO

Authors:

Laksh Parthasarathy,
Global Head –
Connected & Autonomous Vehicles,
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Sanjay Dulepet,
Head of Product Development –
Connected & Autonomous Vehicles,
TCS

Vignesh Amur,
Consultant –
Connected & Autonomous Vehicles,
TCS

SUMMARY

The development of Automated Driving Systems (ADS) is set to dominate the budgets of OEMs over the next 10 years, with a huge rise of start-ups and investments in the surrounding ecosystem. To be able to successfully deploy these systems and ensure the safety, it is necessary to use simulation. This was the case for a Large European Automotive OEM who was evaluating a business strategy to deploy Autonomous Vehicles for the purpose of goods delivery.

After evaluation of the requirements, it was decided to leverage TCS Autoscape™ - suite of solutions for Autonomous Vehicles development and validation, for the project. TCS Autoscape™ provides an end-to-end solution for Autonomous Vehicles: Data Ingestion and processing (TCS Data Services); highly automated data annotation at scale (TCS Data Annotation Studio); and a behaviour competency based, coverage driven, simulation validation solution (TCS SIMPLE).

Challenge: TCS maintains a comprehensive scenario library, which is a key component of TCS SIMPLE, that is intended to be utilised to validate the L4 system that is to be deployed. While evaluating the various simulation tools in the market, it was felt that multiple simulators would need to be used based on the varying capability and fidelity of the tools. At the time of populating the scenario library, TCS used a format that was not widely compatible due to a lack of standards in the industry. This meant that integrating with various simulation tools was a laborious and time-consuming effort.

Solution: TCS was able to take advantage of ASAM OpenSCENARIO 1.0.0 and create the scenario library using this format. The goal was to be able to run the scenarios across multifarious simulators which was enabled by ASAM OpenSCENARIO.

Key Benefits: By utilising ASAM OpenSCENARIO, TCS is able to run the scenario across multiple simulators hence making TCS SIMPLE simulator agnostic which is not only a key USP of the tool, but also an essential requirement of the project. ASAM OpenSCENARIO also enables TCS SIMPLE to automate the test execution simultaneously across the different simulators which leads to improved time to market and the ability to reduce the need for physical testing.

SITUATION

A large European Automotive OEM is looking to develop L4 capability in order to deploy a fleet of vehicles that can provide a goods delivery service. A key element to successfully deploy autonomous vehicles is in the verification and validation of the software stack that is being deployed. As it stands, the majority of the validation in the industry, includes physical testing with simulation not being fully utilised. TCS Autoscape™ suite of solutions was positioned to enable development and validation activities, with TCS SIMPLE being assessed to see if it could handle the simulation aspect of the validation requirements. SIMPLE boasts a comprehensive scenario library that can be used to accelerate the validation process – the tool is able to maximise the coverage whilst minimising the number of test cases.

It was a requirement that different simulation tools will be used along the development process due to the fact that these tools had varying capabilities and fidelity of testing. The challenge here was that the scenario library developed by TCS was not in a standardised format making it hard to utilise them across the various simulation tools. Additionally, the simulation tools used their own proprietary format to describe the scenarios, however they had recently enabled compatibility with the OpenSCENARIO format.

In order to minimise the manual effort of conforming to proprietary formats used by the simulation tools, and for SIMPLE to become simulation tool agnostic, it was decided that SIMPLE's scenario library be converted to the standardised ASAM OpenSCENARIO 1.0.0 format.

"ASAM OpenSCENARIO 1.0.0 brought a world of a difference: By adhering to the standards, you can run test suites, irrespective of the simulator vendors. Hence, no more hassles with the requirements that vary according to vendors. It is a win-win situation for all."

SANJAY DULEPET,
Head of Product Development –
Connected and Autonomous Vehicles,
TCS

SUCCESS STRATEGY

The goal was to create scenarios in a format that made it portable across simulation tools. In order for this to succeed, a comprehensive plan for a proof of concept was created:

- Understand the OpenSCENARIO format as well as the large range of Actions and Conditions supported – the clear and concise documentation provided for the standard helped accelerate this
- Convert some sample scenarios from SIMPLE's Scenario Library to the OpenSCENARIO format
- Run scenarios across the simulators identified for the project
- Automate the execution process and the creation of variations of the scenario (altering weather and actor parameters)

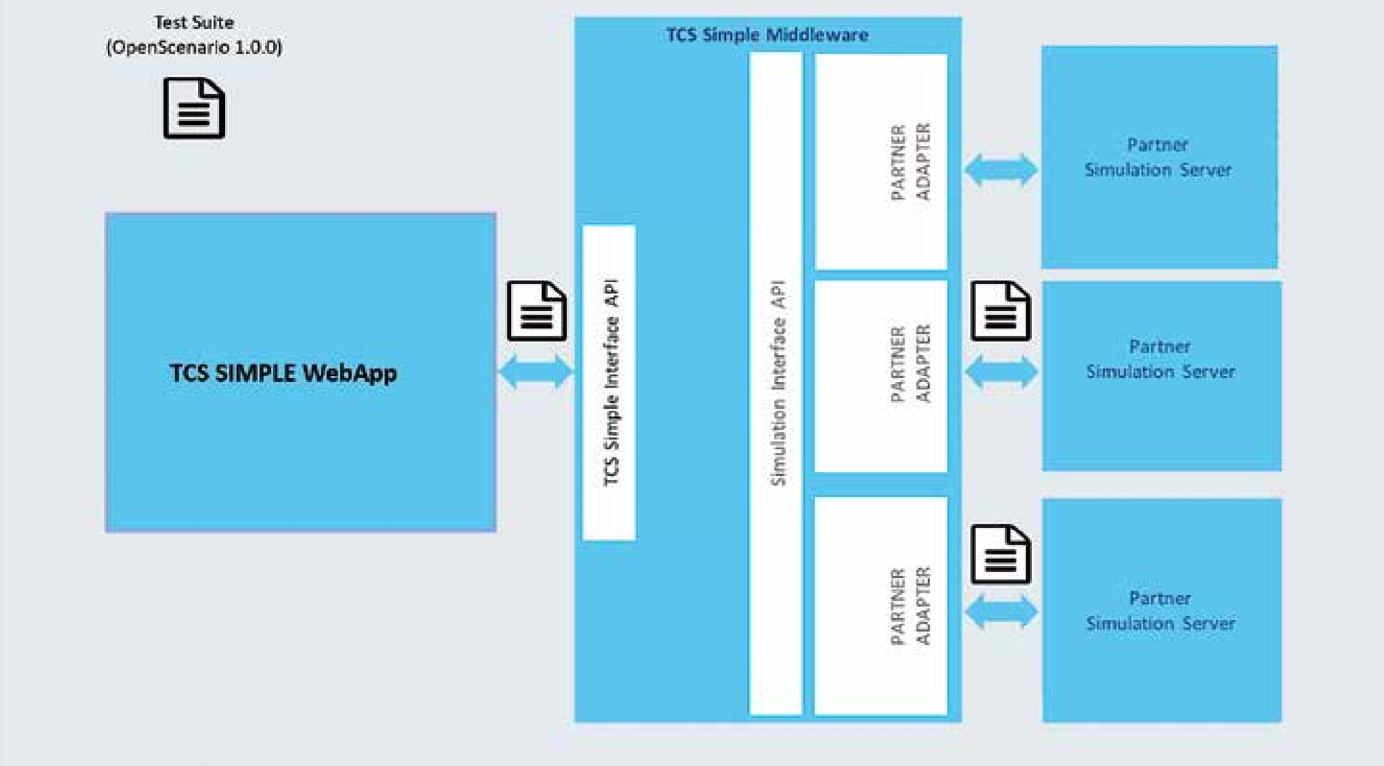
CHALLENGES

It is necessary to automate the round trip test suite execution at scale in a simulator environment of choice. However, the challenge is in managing the differences in the test suite's representation to execute the test suite. The various simulators that differ in capabilities necessitate the need to develop and maintain portable test suites. Adopting ASAM OpenSCENARIO 1.0.0 standards mitigates these challenges. Adhering to the standards makes TCS SIMPLE simulator agnostic benefiting the users.

BUSINESS BENEFITS

In a pilot exercise, ASAM OpenSCENARIO enabled TCS to demonstrate scenarios across multiple simulators which was a requirement for the project. By automating the execution of the scenarios across multiple simulators, TCS was able to improve on-time metrics for the customer which will improve the time to market. It was estimated that, leveraging this approach, TCS would be able to reduce the need to physically test the vehicle by around 55% which not only translates to significant cost savings, it also has a positive impact on the environment, as well as provide the confidence to deploy on public roads for physical testing.

Architecture for using ASAM OpenSCENARIO 1.0.0 to make SIMPLE simulator agnostic



dSPACE GmbH & Hella GmbH & Co. KGaA

Validating Radar-Sensor Software with a Triple Punch: Early Testing, Quality Ground Truth and an Open Interface

Featured Standard:

ASAM OSI

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SUMMARY

dSPACE software-in-the-loop (SIL) sensor simulation is used at Hella to test and validate sensor software in the early stages of the development cycle. In order to compare the computational output of the software with the expected results, high-quality ground truth information is needed from the simulation.

In addition to the simulated sensor environment data, the dSPACE simulation models provide time-synchronous ground truth information using the ASAM Open-Simulation-Interface (ASAM OSI) standard. This information is used by Hella to validate the results of their radar perception software stack.

The ASAM OSI standard provides highly sophisticated options to distribute ground truth information. By obtaining this information, together with the simulated sensor environment from the dSPACE simulation, Hella is able to perform an accurate validation of their complex radar-sensor software.

APPLICATION STORY

Best strategy: shifting testing to early development cycle stage

A couple of years ago Hella, was one of the first automotive suppliers to recognize the urgent need for SIL testing as an efficient strategy to shift testing efforts into the early stages of the development cycle. With this strategy in place, problems and errors can be revealed and resolved in an early phase. Developers are not limited to unit tests anymore, but they are enabled to perform highly sophisticated tests during development that are otherwise only possible with expensively recorded real-world data.

Based on a good, long-term business relationship, dSPACE and Hella decided to tackle this problem together in a joint project. dSPACE provides an extensive portfolio of simulation models suited for hardware-in-the-loop (HIL), as well as SIL validation use-cases, and focused on the field of ADAS/AD and sensor simulation. Furthermore, the holistic dSPACE toolchain allows users to create complex scenarios and test cases to validate perception algorithms, as well as complete AD driving functionality in closed-loop setups.

Within the joint project, Hella utilizes the powerful dSPACE simulation toolchain to validate their sensor software, while dSPACE is leveraging Hella's years of experience in the field of radar signal processing to continuously improve their physics-based radar simulation.

Two mandatory requirements for validation

In order to perform an accurate validation of a perception software stack, based on a SIL simulation, two important parts are mandatory. The first part is an accurate simulation of the input of the perception software (i.e. the signals and the environment that the software is perceiving). This information should be as close as possible to reality, because ultimately the validated sensor software is supposed to work in real world scenarios.

For this part, the dSPACE portfolio offers extensive simulation models, covering vehicle-dynamics-, traffic-, and of course, physics-based sensor simulation. The second part is providing accurate ground truth information that can be used to validate the perception results of the system-under-test. This ground truth information needs to meet certain criteria. It should be a superset of the output of the perception stack, which means all types of signals that are part of the result should be also contained within the ground truth data. This allows a matching of results and ground truth information, and thus, a validation of the results. Furthermore, it is important that the ground truth information corresponds to the result data (i.e. it is originated from the same point in time).

Solution approach based on standards using ASAM OSI-GT

From the beginning of the project, it became clear that it is desirable to apply a standardized solution for providing ground truth data to the system-under-test.

ASAM OSI provides a generic interface for the environment perception in virtual scenarios. The contained ground truth interface (ASAM OSI-GT) provides sophisticated information about all objects within the simulated scenario in a global coordinate system, and is therefore, not only suited for validation of perception algorithms, but also for the validation of sensor fusion applications.

The ASAM OSI-GT interface was suited for the project for multiple reasons. The dSPACE simulation environment was already generating ASAM OSI-GT-compliant data, which had been used in other areas of application. By applying the already existing solution to this project, significant time, and therefore cost savings, could be achieved.

The "time-to-action" was significantly reduced as well. By agreeing on using ASAM OSI, both parties were able to directly start with the necessary implementations due to the well documented and standardized ASAM OSI-GT interface without having to work out an interface description from scratch.

In addition, ASAM OSI can be used directly with C++ programming language, which is heavily used in Hella's system-under-test.

In a short time, Hella was able to utilize the ASAM OSI ground truth provided from the dSPACE simulation environment to validate the output of their radar perception software.

The following images illustrate the validation process within the Hella software, based on an example. The Hella software observes the traffic behind the car, based on multiple radar sensors that are equipped at the back of the car. In the visualization, the dotted bounding-boxes indicate ground truth information based on ASAM OSI-GT, which are obtained directly from the dSPACE simulation, whereas the bounding-boxes with solid lines are showing the perception results of the Hella software stack.

This information can then be used to judge the quality of the current status of the software.

A challenge: provision of consistent data

During the project it became obvious, that the selected approach for providing ground truth information was the right choice. ASAM OSI was suitable for all intended validation tasks. It supports all required data to perform a matching of the ground truth data to the perception results from the Hella software stack.

An important challenge during the project was to provide all relevant data in a synchronous manner -- even when the data originated from different sources. Matching of results and ground truth data is only meaningful if they belong to the exact same point in time. Therefore, dSPACE implemented a timestamp-based synchronization mechanism into their data exchange solution to provide time-synchronous ASAM OSI ground truth data in all cases (e.g. even when the simulation is running faster than real time).

This mechanism also emerged from the project and became an integral part of the dSPACE solution.

BENEFITS AT A GLANCE

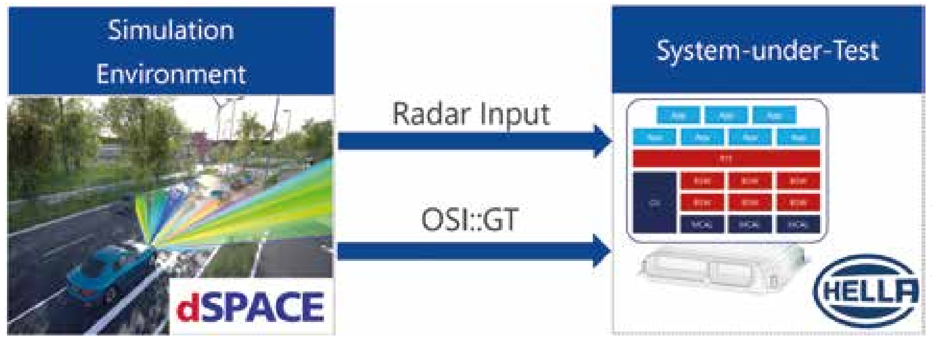
A summary of benefits derived from the dSPACE and Hella project include:

- **Gained flexibility:** Updates do not break the interface due to backwards compatibility of ASAM OSI.
- **Time savings:** Using a standard allows both parties to implement against the interface independently from one another.
- **Increased quality:** ASAM OSI provides a high-quality interface for ground truth data.
- **Cost savings:** Using a standard allows the re-use of the solution in other projects and areas.

"After dealing with many customer specific simulation interface definitions, we are looking forward to utilizing ASAM OSI as common standard – to increase the development efficiency and to support our customers much faster."

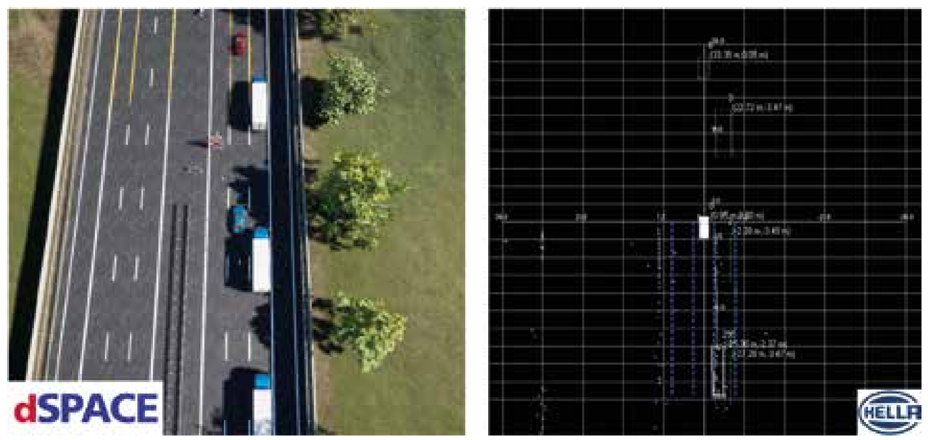
DR. ERNST WARSITZ,
Radar Signal Processing and Sensor Modelling, HELLA GmbH & Co. KGaA

SIMULATION OVERVIEW



Source: dSPACE GmbH

VALIDATION OF PERCEPTION RESULTS BASED ON ASAM OSI



Source: dSPACE GmbH

Note: Since this article has been published, dSPACE and Hella are working together on a different project where ASAM OSI is used again.

University of Applied Sciences Kempten, DENSO AUTOMOTIVE Deutschland GmbH, PMSF IT Consulting

Virtual Validation Platform for AD/ADAS Systems using Kempten Digital City

Featured Standard:

ASAM OSI

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Simulation of autonomous driving needs a realistic representation of the environment. There are several options. We propose a methhod, which uses highly accurate global geo-information (GIS) data from the City of Kempten for testing sensors, sensor fusion and driving functions (algorithms). The geo-information data is converted into an ASAM Open Simulation Interface (ASAM OSI) representation and benchmarked against ASAM OSI ground-truth data. This allows virtual validation and testing against highly accurate geo-referenced data and a realistic environment representation.

The master course "Advanced Driver Assistance Systems" was established in 2014 by Prof. Stefan-Alexander Schneider at the University of Applied Sciences Kempten (UAS Kempten). Thanks to the close cooperation between the City of Kempten and the University, Prof. Schneider started utilizing the geo-referenced data of City Kempten for validation and verification of autonomous driving systems in test drives and simulations. Toward this aim, the UAS and the City of Kempten signed a research contract, which allows UAS to access the GIS data. The City of Kempten recorded over the last years a large amount of geo-referenced data (3D-buildings, traffic signs, traffic lights, hydrant, vegetation, …). In parallel, UAS Kempten and DENSO AUTOMOTIVE Deutschland GmbH launched a new project. One of the main goals of the project was the generation of a high-fidelity virtual environment based on realistic geo-referenced data to validate AD/ADAS related functions. Another target was to unify the sources of the information from the City of Kempten to create a complete virtual test environment using standardized interfaces. The core virtual test environment was developed based on PMSF FMI Bench as simulation engine and its osi3test framework for ASAM OSI-based testing and visualization.

During the project, a new test system architecture was developed as shown in Figure 1. The first step was to create the virtual environment based on the GIS data. In our case, we used ASAM OSI as API to access data from the simulation environment. ASAM OSI has an object-based environment and differentiates ground-truth, sensor view and sensor data. This structure allows an easy way to compare simulation ground-truth and real captured data. The main challenge was the conversion of the GIS data to OSI. The GIS data has different attributes, which cannot be directly mapped into an ASAM OSI representation. E.g., a traffic sign in the GIS data is globally referenced but usually, from an ASAM OSI view, the data is locally referenced. A second challenge was that GIS data is represented by points, lines, and polygons. Therefore, transformations to an ASAM OSI representation of the objects were neces-sary. During the project, the virtual environment was generated for a 1.6 km route in Kempten City. Figure 2 shows the visual correlation between reality (a) and simulation (b) of the same view. The red dots in Figure 2 (b) are the GPS data, which were recorded during the test drive. Note that what we compare is the exact positions of real objects (such as traffic signs) and their virtual counterparts at data level.

There are several ways to compare reality with the virtual environment. For this purpose, we performed a test drive with different sensors (lidar, camera, IMU and GPS), and reconstructed the drive in the simulation environment using the GPS data. At first, a list of the detected objects was generated using the sensor data, and the performance of real sensors and algorithms were benchmarked against ground truth data. Afterwards, the same procedure was repeated in the simulation environment. That means the sensor data was generated from the simulation with sensor behavior models. The output of the virtual test drive was a second object list. The comparison of two object lists indicates the performance of simulation against real test drives. The final performance report was a benchmark about the quality of sensors, sensor fusion and driving functions (algorithms). Early results showed that the developed simulation environment is sufficiently accurate.

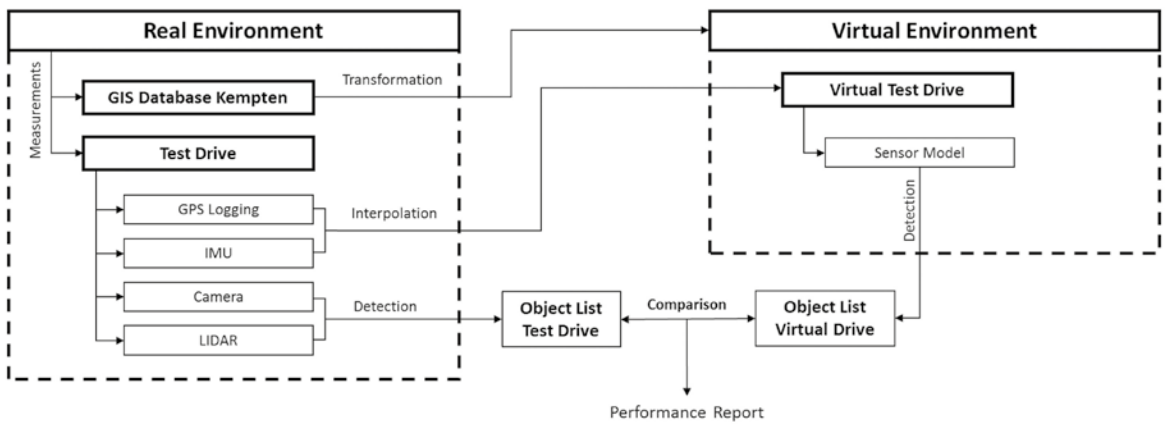
This new approach provides many benefits. Such highly accurate simulation platform shall enable reducing the number of test drives, which are required for validation of AD/ADAS function in order to reduce development risk, time and cost. Overall, the project is promoting a uniform format (ASAM OSI) for benchmarking real and virtual tests across platforms, enabled by the ASAM OSI standardization activities. This new approach will be further developed by a startup called ADSUMA which is funded by the EXIST scholarship.

"The role of software in automotive development is increasing. For example, in automated driving, software replaces the human driver. Assuring the safety of such systems while keeping the validation costs in feasible limits is a big challenge. ASAM OpenX standards help us towards achieving scenario-based testing and validation of AD/ADAS functions in simulations. ASAM standard data formats that describe road networks, scenarios, road conditions will be an enabling factor for future automotive systems."

DR. HASAN ESEN,
Head of Systems Engineering R&D,
DENSO AUTOMOTIVE Deutschland GmbH

Figure 1

Workflow of the comparison, test drive in reality vs. virtual environment test drive.



Source: Master thesis Marcel Sachse

Figure 2

(a) Reality: Picture from the test drive.

(b) Simulation: Reconstructed test drive. Red dots are the GPS.

Source: Master thesis Marcel Sachse; PMSF FMI Bench

Vector Informatik GmbH

Using ASAM OSI to Facilitate Closed-Loop System Tests for Assisted and Automated Driving

Featured Standard:
ASAM OSI

Author:
Dr. Jakob Kaths,
Product Owner

INTRODUCTION

The approach for simulation-based testing of assisted and automated driving (ADAS/AD) functions does not differ substantially from the one taken for other control functions: The system under test needs to be separated and embedded in a plausible simulation of the remaining system. While most control functions can be interfaced on a signal-based approach, ADAS/AD functions typically require input from environment sensors – often in form of object lists. Although their content is widely comparable across different implementations, the structure of the complex data and the interpretation details differ significantly. This hampers the interfacing of simulation tools to ADAS/AD functions and the exchange of object lists between different tools alike, because custom mappings are not only tedious to provide, but also error prone. ASAM OSI can help to overcome these hurdles, leading to an easier, more reliable and re-usable interfacing between different tools and with the system under test.

APPLICATION STORY

Closed-Loop System Tests for Assisted and Automated Driving

Functions are typically developed and tested in different stages:

- Model-in-the-Loop (MiL) for function design,
- Software-in-the-Loop (SiL) for testing of electronic control unit (ECU) software without real hardware or,
- Hardware-in-the-Loop (HiL) for executing the function as embedded software on an ECU.

It is desirable to design tests only once and reuse them across these development stages. Therefore, the testing tool must allow flexible interfacing with the system under test independent of the currently available execution platform. CANoe with vTESTstudio are Vector's tools for test design and test execution from MiL to HiL. The open interfaces allow the integration of ECU software in all development phases:

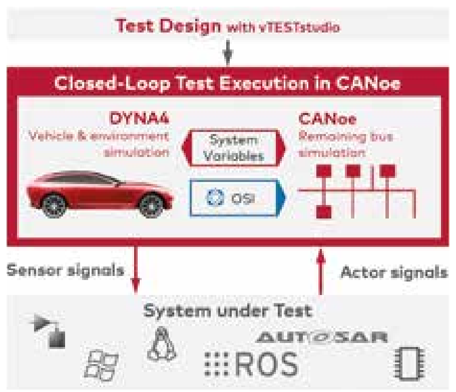
- Integration of controller models, e.g. as Simulink models or FMUs (MiL)
- Integration of C-code with the SiL Adapter Builder or entire virtual ECUs with vVIRTUAL target (SiL)
- Integration of real ECU hardware (HiL)

The remaining bus simulation reflects the network communication realistically and enables the integration of the system under test. Using this interface for mere stimulation of the system under test is often not sufficient, especially in the case of complex ADAS/AD functions that influence the driving behavior of the vehicle. Physical models for the vehicle and its environment are therefore needed to conduct closed-loop system tests in which the actuator commands are fed into the simulation, which in return responds with realistic sensor feedback. Vector DYNA4 provides such models for virtual test drives including the driving dynamics of the vehicle under test, its environment sensors, and the static and dynamic environment. The seamless integration of the domain-specific tools CANoe and DYNA4 with the help of ASAM OSI will be explained in more detail below.

Object Representation with ASAM OSI for Seamless Tool Integration

While the exchange of basic actor and sensor signals between CANoe and DYNA4 is easy to accomplish with system variables, the handling of object lists from ADAS sensors proves complicated. The lack of an object model on the CANoe side made the representation of objects difficult as the user had to map object information to the classical signal-based architecture. An internal object representation is therefore necessary. Instead of coming up with a proprietary definition, Vector decided to use ASAM OSI as a basis for CANoe's object model. Object information from various sources can now be used to fill this object model with data.

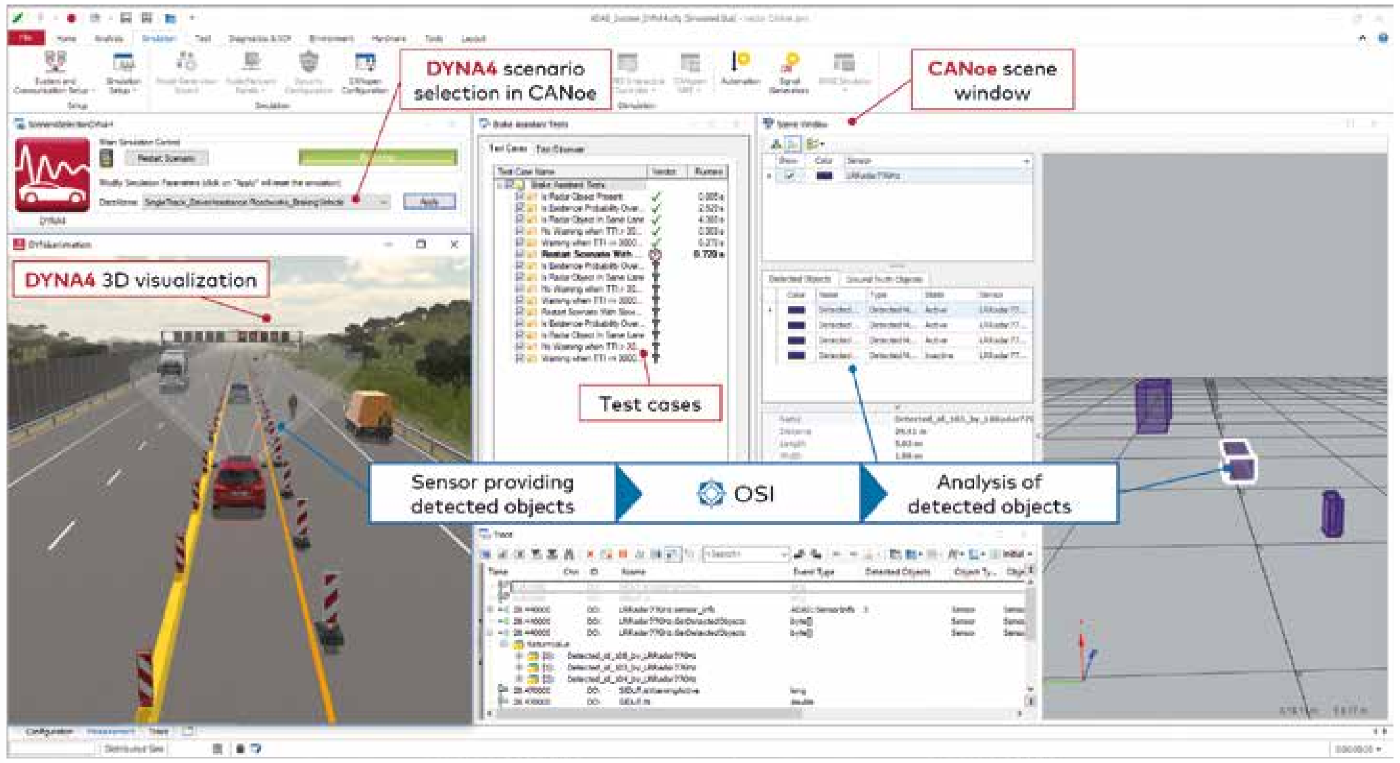
In this way, analysis features such as the visualization of objects, are enabled and tests can be re-used easily. These benefits are independent of the source of the object-lists and its support of ASAM OSI. Naturally, if the source does support the standard, the interfacing becomes even easier. This holds true not only for the system under test, but also for coupled tools like DYNA4. Consequently, DYNA4's traffic and object-based sensor models have been extended to provide ASAM OSI-compliant information. Prior to this development, feeding object list information from DYNA4 into CANoe required the unraveling of DYNA4's proprietary object list structure and the re-packaging into structured variables for use in CANoe. This is now at your fingertips by simply transmitting the ASAM OSI stream from DYNA4 to CANoe. The figure below depicts the enhanced coupling of CANoe and DYNA4.



Source: Vector Informatik GmbH

Closed-loop test execution with CANoe and DYNA4

In an exemplary SiL setup (see annotated screenshot), the DYNA4 sensor model provides an ASAM OSI stream containing detected objects such as vehicles and pedestrians. This stream is received and managed in CANoe and is the basis for stimulating the system under test, in this example a C-coded autonomous emergency braking (AEB) function. Based on the object list, various AEB function tests can be executed and additionally automated in CANoe. Possible actuations of the AEB are fed back to the DYNA4 vehicle model via system variables, ultimately resulting in a closed-loop system test.



Source: Vector Informatik GmbH

Screenshot of a CANoe configuration with integrated DYNA4 models using the ASAM OSI object representation

Further developments regarding the ASAM OSI support are underway for future releases. To name a few: DYNA4 will provide detected road features and less pre-processed sensor data like camera pictures or lidar point clouds. CANoe's Scene Window will be extended to support the display of a wider range of object types. And above all, an easy-to-use API specifically for ADAS tests in CANoe is planned. This will allow to query the underlying ASAM OSI object model for the definition of tests, e.g. with CANoe's script language CAPL or C# test nodes. This will be useful, for example, to trigger a desired action in case a moving object lies within a certain user-defined distance.

KEY BENEFITS OF ASAM OSI

The integration of ASAM OSI into CANoe and DYNA4 contributes to the main goals of the standard - an increase of modularity and integrability of simulation components as well as a streamlined compatibility between automated driving functions and simulation frameworks.

More specifically, the ASAM OSI-based object representation does not only facilitate the interfacing between CANoe and the system under test. The user also saves a lot of time due to the re-usability of tests and analysis routines. These benefits persist, even if the system under test does not directly support ASAM OSI. In the case of DYNA4, the ASAM OSI integration helps to avoid mapping issues thus ensuring high quality, for example, when exchanging DYNA4's integrated sensor models with custom sensor models. In this application story, the benefits for the individual tools have been combined, leading to an increased quality and time saving when using them jointly. As a result, more time and effort can be spent on the actual task – the development and comprehensive test of complex functions for assisted and automated driving.

"The ASAM standards do not only facilitate shaping a seamless toolchain from our own tools. They also help us to pursue our goal of delivering open tools that can be integrated easily into our customers' development environments and workflows."

DR. STEFAN KRAUSS,
Managing Director,
Vector Informatik

Vicomtech

Semantic Labelling with ASAM OpenLABEL for SAE L3+ AD Development

Featured Standard:

ASAM OpenLABEL

Author:

Dr. Marcos Nieto,
Principal Researcher

SUMMARY

Object labelling in images and point clouds has been historically used for ML (Machine Learning) training and during the last decade to generate ground truth in the automotive sector. The industry is now facing the need to add more complexity to labels as their use goes beyond their initial purpose. Modern instrumented vehicles are equipped with numerous sensors, some of them act as reference systems, generating data that needs to be labelled, including different 2D-3D geometries, pose information, time-variable intrinsic parameters, sensor-level timestamping, static and non-static attributes of objects, etc. In addition, higher-level expression (semantics), such as events, activities or relations between labelled elements will become a requirement as the automated driving (AD) functions grow in complexity and scope.

APPLICATION STORY

In Vicomtech we have been working on large scale annotation of multi-sensor dataset since we lead and coordinated the H2020 projects Cloud-LSVA (GA 688099) and VI-DAS (GA 690772) between 2015 and 2019. A consortium formed by players such as Valeo, IBM, Intempora, Honda Research Institute, TomTom or Intel found challenges as varied as data formatting, algorithm development, annotation UIs, cloud resources orchestration and processing at the edge.

During that time, we already foresaw that traditional annotation approaches were not sufficient for building autonomous driving, so we created an annotation language and toolkit (VCD, Video Content Description) that would allow us to label not only objects, but also calibration and synchronization information, static and dynamic attributes, and also the events and actions that occurred in the scene, and even the relationships between objects, events and actions.

The main problem arose immediately, when a myriad of vendors and ADAS development projects created an equally large number of AD datasets (e.g., Uber Pit30M, Pandaset, Waymo, nuScenes, Audi A2D2, just to name a few appeared since 2019) and annotation definitions. It is possible to use one dataset or another, but what if someone wanted to use them all? Or fuse labels from different projects or vendors? Simple: it's not possible. The datasets not only differ in data format (structure of labels in files), labelling meaning and depth ("Car" vs "Pickup"), but also in annotation criteria. Annotation guidelines are frequently biased by application needs, often contradictory across projects. Visibility, occlusion/precedence, range, start-end frames for actions and composition are just some of the topics that not only produce headaches labelling companies, but also, as being non-standardised, will produce non-compatible, non-universal and non-reusable labels in the long term.

In addition, the evolution of ADAS/AD development will eventually bring the need to train and test not only perception systems, but also understanding, decision, and control components in SAE Level 3+ cars. Labelling needs will go way beyond the well-established image-level industry. Vehicle-testing will require complex labels, including information of calibration, timestamping, pose, attributes, actions, events, relationships, etc. Such levels of labelling complexity remain unsolved (and unstandardised) in the industry.

The solution can start being drafted by introducing the concept of semantic labelling. Labels cannot be limited to generating consumable content for an application or purpose, but must be universal, exact, and unambiguous and provide rich information not only about the objects in the scene, but also which actions are they doing, events which trigger such activities, causality relationships, and groups of these elements corresponding to higher-level manoeuvres or descriptions. And this is exactly the purpose of ASAM OpenLABEL, an initiative created just in time to gather practitioners of the industry and academia, experts in labelling, machine learning and AD development and testing, to produce the first worldwide standard on object and semantic labelling. Ontologies can contribute to the solution of the problem of interoperability and large-scale content management. The annotations of objects, actions, events, can be created as instances (individuals) of concepts (classes) in the ontology, and thus represented in OWL (Web Ontology Language) and serialized in XML or JSON files as RDF triples (Resource Description Framework).

The ontology can also contain restrictions and definition of ranges, multiple inheritance, and properties. Any application can then not only read, but also intelligently understand, for the first time in history, the content of the labelled dataset: update or extend contents, add detail, translate, modify, and use reasoners to find non-explicit information. All of it without the need to require additional explanations to interpret the labels apart from the standard.

This vision has still multiple challenges ahead. Namely:

- Labelling has become much more than image tagging. Producing a single standard for object labelling and semantic labelling is a huge challenge that the ASAM OpenLABEL working group is willing to address. Structure, purpose, scope, and format will be the main pillars of the incoming ASAM OpenLABEL standardization project.
- Alignment with ASAM OpenXOntology activities is a must to guarantee inter-standard semantic compatibility
- How to re-build established labelling mechanisms to incorporate the novel ASAM OpenLABEL pillars is an open point the industry needs to face. How to automatically produce multi-sensor pre-annotations? How to create graphical UI to label relationships in an efficient way (see Figure 1)?
- Producing standardized annotation criteria which are not product-oriented, but universal and common sense-guided.

In summary, the timing of the development of these standards (ASAM OpenLABEL, ASAM OpenXOntology, ASAM OpenSCENARIO, ASAM OpenODD) raises hopes that ASAM will produce not a sparse set of standards for various unrelated phases of ADAS/AD development, but a family of carefully harmonized, and interoperable standards. From the perspective of the labeling industry, ASAM proposes recommendations for the long-term validity and utilization of labeled material. It also allows the introduction of technologies and experiences in labeling (e.g. semi-automatic labeling using active learning and cloud-clusters orchestration) which allows us to think that we are taking steps for bridging the gap of real-to-virtual testing for growingly complex ADAS functions (towards validation of SAE L3-4-5 autonomous driving).

"I participate in ASAM because it provided me a full set of existing and ongoing standardization projects which cover all the stages of ADAS/AD development. My focus is on ASAM OpenLABEL, which is way more than traditional image tagging, opening the door to high-level semantic labelling, supported by the powerful and ambitious ASAM OpenXOntology transversal activities."

DR. MARCOS NIETO,
Vicomtech,
Principal Researcher

Source: Vicomtech

Semantic labelling UI. Object labels, actions, events, and relationships (RDF triples) to produce semantic descriptions of the scene.

Hyundai Autron

HIL Automated Testing Software Based on ASAM XIL With Domains Verification

Featured Standard:

ASAM XIL

Author:

Junsik YIM,
Leading Research Engineer

SUMMARY

Challenge: Today, the automotive industry is already dealing with highly electrified and motorized vehicles. With the development of autonomous driving, additional complexity is added. The general rule is: The more complex the vehicle, the more verification is needed at the development state. But vehicle testing requires a lot of manpower and time.

Solution: To keep the effort as low as possible, the importance of HIL (hardware-in-the-loop) verification, which is simulating the environment, is increasing. In this study, a HIL automation verification tool was developed based on the ASAM XIL framework API and applied to the verification of the convenience/chassis domain using C# language. The study confirmed that a common test case can be created and a vendor-independent verification environment can be developed.

Key benefits:

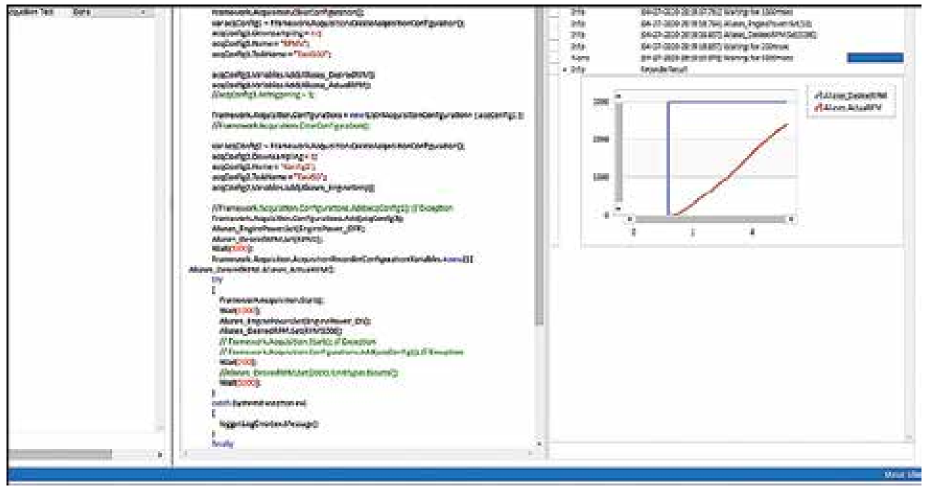
1. Supporting the ASAM XIL standard enables independent operation of testing equipment (e.g. combined use of NI, dSPACE and ETAS Hardware and Software can be controlled).
2. Integrated operation of software that does not support the ASAM XIL interface is possible (e.g. Matlab Simulink, IPG CarMaker, ETAS INCA, Vires VTD, etc.).
3. Common test cases secure testing reliability (Can be applied immediately to other testing equipment with mobilgene X Studio).

SITUATION

The Electronics Control Validation Team at Hyundai Autron has developed an in-house tool for application programming. The problem was that HILs system equipment manufacturers each have their proprietary system. There is not one standardized operating tool, but each company has its specific approach for each domain. Therefore, it is necessary to get familiar with each tool and prepare test case scenarios specific to each tool's purpose. ASAM XIL introduces the concept of a framework to run these tools even in heterogeneous tool environments without modifying the test case.

SUCCESS STRATEGY

One great feature of our automated evaluation tool (mobilgene X Studio) is the ability to perform vendor independent testing. To this end, the ASAM XIL API was implemented based on the IFramework interface. ASAM XIL API provides C# and Python interfaces. Own automated evaluation tools developed with the application program are designed to operate based on C# and use the ASAM XIL API version 2.1.0.



CHALLENGES

The HIL automation evaluation tool was developed based on the ASAM XIL framework API and applied to domain-specific verification. This way, it was ensured that a test case can be created with a single evaluation tool and an evaluation environment can be established that is not dependent on tools and equipment of a specific vendors. But once the test environment is built, changing or extending this environment is difficult. As each vendor uses his own, proprietary tool and test case format, expanding the test environment usually requires products of the same vendor. This makes it difficult to cope with the rapidly changing demands of the test environment. In addition, there is a probability that the method of developing tests will be uniform when relying on the technology of one specific vendor. Dependence on one particular vendor is also a major burden at company level.

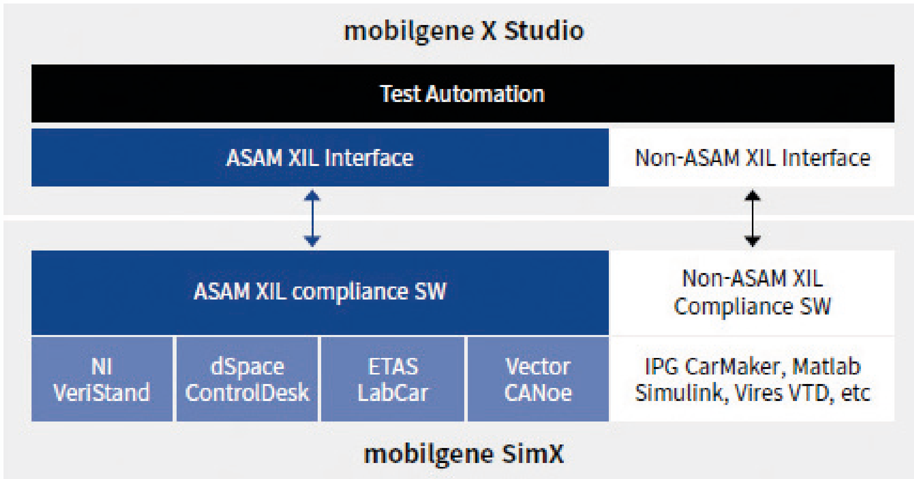
Own automated evaluation tools developed by an application program can solve these problems. The same applies to the test case: Test cases written with a proprietary technology complicates the change of the test environment. Depending on the test environment, all test cases may need to be migrated, and test authors must learn a new language and skills every time the environment changes. Therefore, as time passes and the number of test cases increases, it becomes more difficult to change the according environment. A self-developed automated evaluation tool solves this challenge by using C#, a general-purpose language that allows to perform tests on various tools or equipment without modifying the test case. The advantages of general-purpose languages, such as a thick user base and rich documents, will do the same for writing better tests.

BUSINESS BENEFITS

The ASAM XIL API cannot only be used in HIL tests, but also in MIL (Model in the loop) or SIL (Software in the loop) testing environments. So far, we have checked the self-developed test automation tool only in HIL equipment, but it can be expected that it will work just as well and provide the same advantages in MIL or SIL environments. Ultimately, the cost of maintaining and validating test cases can be reduced.

"We support ASAM XILbecause it enables vendor-independent operation of testing equipment. All, NI, dSPACE and ETAS Hardware and Software can be controlled."

BEOMSEOP KIM,
Team Leader,
Hyundai Autron



IAMTS – International Alliance for Mobility Testing and Standardization (IAMTS), AVL List GmbH

A Process for the Correlation of Virtual and Real Testing for the Validation of ADAS and AD Systems

Featured Standards:

ASAM OpenX

Author:

Dr. Tobias Düser
Work Group Lead at IAMTS and
Head of ADAS/AD Virtual Testing
Solutions at AVL List GmbH

SUMMARY

Challenge: Validation and approval of automated driving systems require the application of extensive virtual testing methods. One of the biggest challenges is the model and toolchain validation process in combination with what needs to be covered in the virtual world.

Solution: Within the International Alliance for Mobility Testing and Standardization (IAMTS) a reference process including best practices and methods for the correlation of the virtual and real world is in development.

Key benefits: The methods and processes consider global requirements from different regions to enable virtual testing for ADAS/AD validation and approval. They bring together the expertise of the different members, established approaches, best practices and existing standards from ASAM, SAE, ISO and many more.

SITUATION

A major challenge in the market launch of automated driving systems is validation. This is caused by the increasing complexity of the overall system in which the interaction between vehicle, humans (drivers, passengers and those outside the vehicle) and environment become more intertwined. Conventional on-road and proving ground tests are insufficient to assure meaningful coverage of test cases and scenarios. Virtual testing methods like Model-in-the-Loop, Software-in-the-Loop, Hardware-in-the-Loop, Human(Driver)-in-the-Loop and Vehicle-in-the-Loop will fill this gap. The more complex the system/ODD, the more relevant virtual testing becomes.

MOTIVATION

Using virtual testing for ADAS/AD validation and approval has many challenges. The most important topic is to show the required correlation between the real and the virtual world. This is especially true for ADAS/AD as it does not only include the vehicle dynamics model but also the environmental and sensor models. Virtual testing enables cost and effort reduction compared to on-road or proving ground testing. Depending on the configuration, virtual testing could also be executed much faster than real-time, be more easily automated, simulate complex scenarios with many actors, and be highly reproducible. On the other hand, setting up a virtual testing toolchain requires effort upfront. Therefore, it is important to only model the relevant systems and the relevant behavior for the dedicated use cases and scenarios. Building models that represent real behavior in the virtual world (e.g. for the vehicle, vehicle components or sensors) is only one part. You must also guarantee that all models are co-simulated synchronously and accurately without any numerical issues even though they are typically implemented in different simulation tools interfacing via different protocols and standards. In the area of ADAS/AD there are several different domains interacting. Vehicle dynamics simulation is using rather traditional approaches, simulating the environment and sensors have a high focus on computer graphics, raytracing etc. That's why most of the simulation toolchains consist of different tools. Connecting these tools requires coupling algorithms to find the best trade-off between execution speed and errors as well as standardized interfaces and protocols. The correlation must not only focus on the model itself but also on numerical and co-simulation topics.

SUCCESS STRATEGY

IAMTS is a global, membership-based association of organizations in the testing, standardization and certification of advanced mobility systems and services. It brings together testing consumers and providers on a global scale to develop a commonly accepted framework of test scenarios, validation and certification methods, and terminology. The development of a reference process with best practices and methods for the correlation of the virtual and real world is one of the key topics of IAMTS. A first delivery was the definition of a reference process including a step-by-step approach that helps to deal with the complex task of correlating the virtual and real world.

Before the virtual testing toolchain validation can be conducted, a detailed analysis of the ODD, the system itself and a detailed evaluation of the testing scenarios are required. Both provide essential input for setting up the requirements for the virtual testing toolchain with regard to model classes and fidelity levels. During the analysis and evaluation, standards like ASAM OpenTEST, ASAM OpenODD, ASAM OpenDRIVE® and ASAM OpenSCENARIO® will be core elements of the process. The virtual testing toolchain validation process is separated in four steps. This approach copes with the high complexity and the different domains which are modeled.

Step 1 validates the subsystems as standalone. This could be a brake system, a radar model, or artifacts of the environment like the lane marks.

Step 2 validates the passive vehicle system, meaning the vehicle dynamics in combination with the environment model (which mainly consists of the road and the road properties). There is no ADAS or AD function in this step.

Step 3 focuses on validating the sensor system using an integrated test of the sensor in a defined environment with static and dynamic objects.

Step 4 integrates all the models (vehicle, environment and sensors). To ensure a traceable process, sub steps are performed. Step 4.1 performs an evaluation based on a replay of recorded real-world data. Focus is on the raw data output of the sensor models in comparison to the real sensors.

Step 4.2 replays the same test but compares the output of the perception on object list level. ASAM OSI shall be used in this step as standard for the comparison.

Finally, in step 4.3 a fully closed-loop scenario is performed. The vehicle is driven in the virtual world by the ADAS or AD function and the results are compared to the real world.

While the correlation tests in step 1 to 3 are mostly open loop and not scenario based, step 4 focuses on scenarios. Those scenarios must be different to the final scenarios used for the validation or approval of the automated driving function. The description of the tests and scenarios which are used in the virtual testing toolchain validation will be described in ASAM OpenSCENARIO®, ASAM OpenDRIVE® and ASAM OpenCRG®.

CHALLENGES DURING THE PROJECT

Empowering virtual testing for validation and approval requires overcoming several challenges:

- reuse of existing models originally made for a different purpose
- the multitude of simulation tools on the market
- different requirements by regions that must be considered

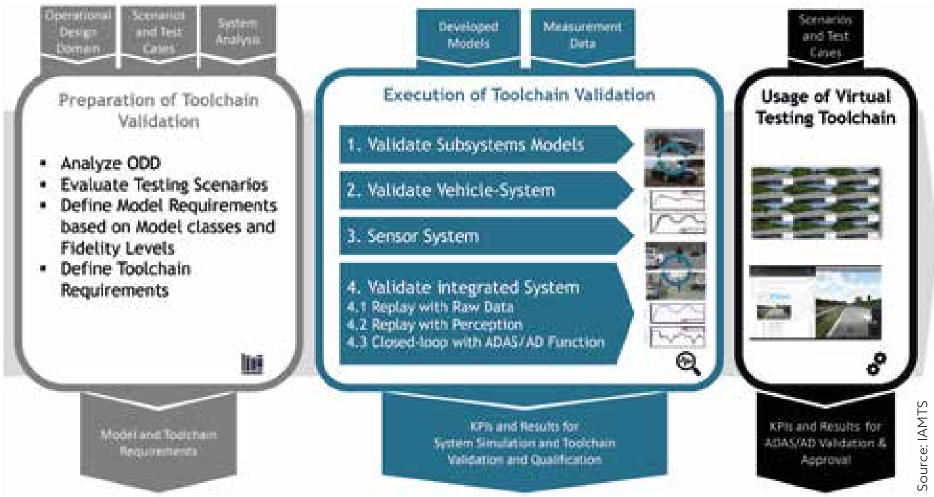
Beyond the correlation itself, a trade-off between cost increase for model build up and cost reduction in usage must be proven.

BUSINESS BENEFITS

The process, methods and best practices developed by IAMTS will not reinvent the wheel. They will instead bring established pieces together and fill existing gaps. IAMTS will enable vehicle manufacturers and suppliers to save costs and time, proving ground providers to increase or improve their virtual testing toolchain validation offerings and regulatory bodies and authorities to integrate virtual testing approaches.

"We chose the ASAM OpenX standards as one important pillar of our process because they provide a holistic approach supporting the abstraction and formalized description of important bricks of an ADAS/AD virtual testing toolchain."

DR. TOBIAS DÜSER,
Work Group Lead at IAMTS and
Head of ADAS/AD Virtual Testing
Solutions at AVL List GmbH



IAMTS Reference Process for the correlation of the virtual and real world

Vicomtech

Harmonised European Solutions for Testing Automated Road Transport: the HEADSTART project and ASAM

Featured Standard:

ASAM OpenX

Author:

Dr. Oihana Otaegui,
Director Intelligent Transport
Systems & Engineering

"I feel fortunate to be a part of the HEADSTART project and the different working groups of the ASAM OpenX family, being able to contribute to such a crucial issue as the harmonization of validation methodologies for the future of the automotive sector."

DR. OIHANA OTAEGUI,
Director Intelligent Transpor
Systems & Engineering,
Vicomtech

SUMMARY

Connected and Automated Driving (CAD) is foreseen to be one of the major technological challenges in the coming years. However, the increased complexity to validate emerging technologies implemented in CAD vehicles is one of the biggest barriers for its market introduction.

The development and introduction of CAD vehicles (SAE-L3 and above) into European roads implies a huge technological, regulatory and ethical challenge, considering the requirements on system performance and reliability. It is often said current SAE-L2 ADAS vehicles statistically assist drivers to drive 75 million km without any accident. Therefore, SAE-L3-4-5 CAD need to reach such accident-free distances driving autonomously, avoiding and controlling any critical situation, which necessarily includes a tremendously variable range of road and driving scenarios. Beyond safety, comfort and eco-driving need to be considered as well as Key Performance Indicators (KPI) of CAD vehicles.

The questions are:

- How to validate a SAE-L3-4-5 vehicle will drive safely?
- Under which circumstances the vehicle can continue to drive safely?
- Can simulation be used (along with real data) to validate CAD?
- Are pass/fail criteria still valid for AI-based (non-deterministic) CAD functions?

APPLICATION STORY

In Europe, any automation technology is subject to the strictest validation rules of the world, which mandate a thorough examination of the response of CAD vehicles under all possible road circumstances. There is still a lack of a common and consolidated European regulatory framework to provide a suitable environment for large-scale introduction of automated vehicles. As a consequence, SAE-L3-5 testing methodologies remain as an unsolved technological, organisational, economical challenge.

The starting point is to follow up SAE-L2 evaluation approaches, which define scenarios to be tested, either via collecting and labelling vast volumes of sensorial data from instrumented vehicles (with an unprecedented data management/processing cost) or creating (not-so) realistic simulations and then evaluate the performance of the system under test in controlled environments.

Initial findings in the sector unveil unaffordable figures. For testing a SAE-L3 vehicle, an automaker may need to record billions of km, which is not only unfeasible in terms of cost (data storage, transmission, processing, labelling), but also inefficient, as most of the driving situations will be repetitive (critical driving situations are rare and infrequent). Consequently, all eyes are on simulation and scenario-based testing, and the expectation is that only 5% of testing is carried out against real data, while 95% is run on virtual worlds (including simulated models of sensors, traffic participants and actions). However, other challenges immediately arise: How to orchestrate millions of simulation jobs? How to combine effectively models from different suppliers? How to guarantee realism of the simulated scenario? How to know if more tests are necessary? How to create testing and validation methodologies that are independent of the function, manufacturer and user?
A scenario-based methodology is necessary. The intelligent cross-linking of all test instances such as simulation, proving ground and real-world field tests is considered the only possible approach to address CAD validation . Some of the lighthouse initiatives in Europe such as PEGASUS, ENABLE-S3 and MOOVE, identified the main challenges to make this approach feasible. Novel perspectives need now to consider also the impact of Key Enabling Technologies (KET), such as cybersecurity, EGNSS (European Global Navigation Satellite Systems), and communication, in the testing and validation process.

The main challenges to overcome:

- Integration of positioning, communications, and cyber-security in CAD test scenarios
- Comprehensive procedure for the allocation of test cases per testing platform (Virtual, XiL, Proving Ground, Field Testing)
- Harmonised, open result compilation and analysis

The HEADSTART project aims to define testing and validation procedures of CAD functions including its KETs (communication, cyber-security, positioning) for all test methods to validate safety and security performance according to the needs of key user groups (technology developers, consumer testing and type approval).

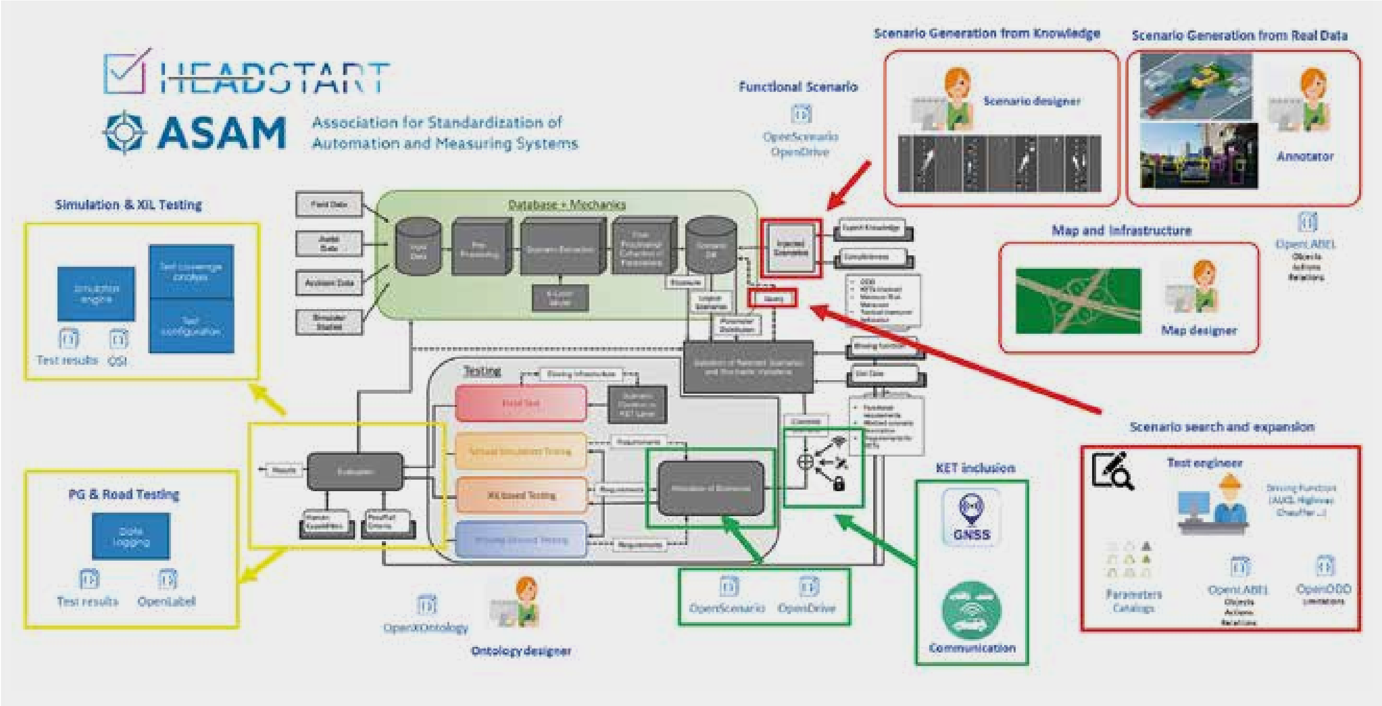
HEADSTART members participate also in various ASAM standard development projects (ASAM OpenSCENARIO 1.1-2.0, ASAM OpenXOntology, ASAM OpenLABEL) and ideation projects (ASAM Test Study Group). The goal of HEADSTART is to propose harmonization procedures where standards necessarily play a major role. This alliance is already established to tackle the following points (see Figure):

1) Unambiguous and cross-domain concept definitions – ASAM OpenXOntology
2) Definition of Operational Design Domain (ODD) of CAD functions - ASAM OpenODD
3) Definition of test methodologies, including scenario-based testing to foster the utilization of simulation (and mixed) capabilities – ASAM OpenSCENARIO, ASAM OpenDRIVE, ASAM OpenCRG, ASAM OSI and ASAM OpenLABEL
4) Harmonization of test results – Ongoing ASAM Testing Study Group

Several challenges await ahead:

- Computational requirements for mixed validation will grow at least linearly with the growth of tests needed to validate SAE-L3+ functions. Real data management, execution of tests on even larger clusters, simulation of components and models using AI (and thus GPU-enabled machines) are costs that need to be optimized.
- Connected and cooperative driving need to be valid worldwide. Operational Design Domain definitions need to be consistent, clear and extendable to all countries where CAD vehicles may drive.
- The ontologies under construction in ASAM OpenXOntology need to coordinate multiple heterogeneous domains, many of them with rock-solid definitions, often non-compatible (contradictory, partially overlapping) with similar concepts in other domains. The titanic effort can only be solved with participation and arduous negotiation from stakeholders and scholars from all these domains.

The solution proposed by ASAM is to have an entire set of standards under the same flag, the ASAM OpenX simulation family, which span domains as varied, but at the same time as aligned, as labelling, scenario description, HD maps, simulation interfacing, and test result management. This approach will guarantee simplified toolchains, focus on functionality, shorter development times and enable testing of even more complex scenarios. All of this is necessary for the effective and validated development of SAE-L3+ Connected and Autonomous Driving.



HEADSTART methodology and the ASAM OpenX simulation standards.

Source: HEADSTART (project - https://www.headstart-project.eu/)

KIsSME

Early addressing of ASAM standards in „KIsSME", a BMWi-funded research project

Cooperation project „KIsSME": Artificial Intelligence (AI) for the selective near real-time recording of scenario- and maneuver data during the testing of highly-automated vehicles.

Featured Standard:
ASAM OpenX

Author:
Armin Rupalla,
MoB Telematics & Ideation, ASAM e.V.
CEO, RA Consulting GmbH

Funded by Federal Ministry for Economic Affairs and Energy, based on a resolution of the German Bundestag

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

SUMMARY

The activities of ASAM (Association for Standardization of Automation and Measuring Systems), in part, consist of identifying standardization potential at an early stage and transcribing this potential into a standardization initiative, in case of market interest. For this purpose, ASAM has established an ‚ideation process' which can be initiated by individual companies as well as by other organizations or projects.

On Nov 20 2019, the Federal Ministry for Economic Affairs and Energy (BMWi) of the Federal Republic of Germany published a call for papers for the promotion of application-oriented research- and development projects in the field of „Artificial Intelligence as the Key Technology for the Vehicle of the Future". The ASAM Board of Directors has decided to support this federal initiative. The project will be jointly carried out by the ASAM member companies, AVL, Bosch, RA Consulting, LiangDao, Mindmotiv, The Research Center for Information Technology (FZI) and The Karlsruhe Institute of Technology (KIT), as well as by the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach Institute (FhG EMI). ASAM and e-mobil BW will be participating in the project as associated partners.

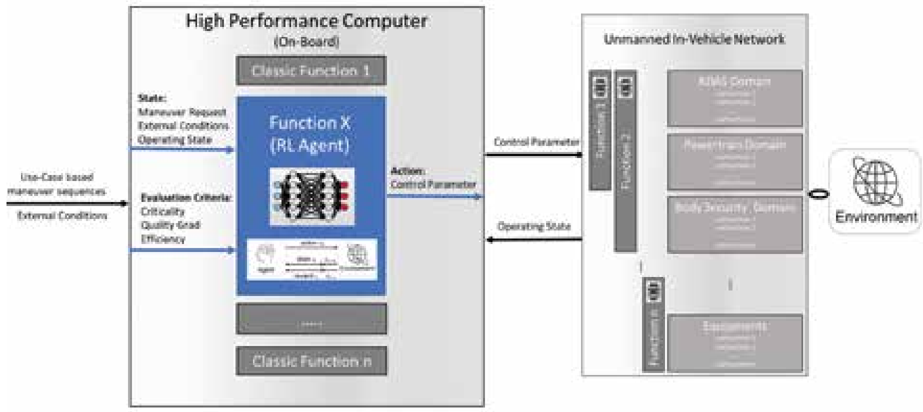
The participation of ASAM in a research project makes it possible to take into account current and important interim results of the ASAM standardizations in the project-relevant fields, in this case, for example, the standardizations for scenario description, simulation, and measurement and calibration. Furthermore, the project partners and ASAM can check the results for their suitability for standardization, and thus, where necessary, jointly submit new standardization initiatives to ASAM.

APPLICATION STORY

The functional safe-guarding of highly-automated vehicles is based on maneuver-based testing, and on statistical verification on the basis of enormous amounts of real-time data. In order to reduce the necessary amount of data, it is important, already during the driving tests, to capture only relevant and critical driving situations. Therefore, in the joint project „KIsSME", AI-based algorithms should be developed, with the aid of which On-Board Systems are able to detect relevant and critical scenarios in real-time and to selectively capture raw data and scenario descriptions for that purpose. These AI-based algorithms should be capable of learning, and therefore continuously improve the detection of critical situations and the associated relevant data. In this manner, the information density of the data used for the development and testing of Level 4-5 autonomous driving systems is increased, whereas the necessary data volumes and efforts for data protection are significantly reduced.

SUCCESS STRATEGY

In addition to the practice of event-based recording, as is conventional nowadays, in the future, procedures which independently trigger and mark recordings with the aid of AI will become particularly relevant. During the driving operation, it should be decided whether data relate to events that are relevant, sub-critical or even critical. These data should be extracted and subsequently incorporated in order to improve or validate the system. In this respect, the „KIsSME" project should investigate evaluation procedures and criteria in order to recognize scenarios or to identify significant deviations, during operation, using machine-learning methods.
The AI methods which are applied or further developed in the project should not only be used for intelligent scenario recognition in real-time On-Board, but should also mark those data obtained from test drives, which should be used for further improving the AI models (cf. also „Black Box" function in case of accidents or near-accidents).



Source: Project description „KIsSME", 2020

Variant of an agent-based architecture concept for the On-Board System (OBS).

Data can also support the planning and execution of vehicle tests in a targeted manner, insofar as only relevant data is provided. This directly contributes to an improved environment detection, environment interpretation, and maneuver planning for the testing of HAD/AD systems.

Automated driving in an urban environment places high demands, in particular on approaches for predicting the movement of other traffic participants. Classic model-based approaches often evaluate situations only in an exemplary and simplified manner. A conceptual approach to evaluation, in which the observation of motion paths of other traffic participants in the vehicle environment is automatically compared to the applied AI models, and in which subsequently a selection from the data (prediction deviation) is carried out, has not been available so far. For that purpose, multi-modal, interaction-based prediction procedures would need to be implemented in the project and extended to the application in the test vehicle.

In this context, decisive situations are those in which the system was unable to detect a critical situation at an early stage. If a driving scenario corresponds to a critical test scenario, it should automatically be marked accordingly for the post-analysis of the data, and furthermore, sensor data as well as ASAM OpenX-compliant scenario data should be extracted. At the same time, new test scenarios, which have not yet been modeled, should be learned on the basis of the observed data (unexampled events), for example with the aid of anomaly detection.

In the long term, the validation of driving functions will require the development of new methods and procedures for the testing in the field, and ultimately also for the homologation. In the project, novel AI methods for substantiating the extent of coverage of relevant, critical and sub-critical situations during testing - and thus for the systemic ensuring of the functionality and functional safety - of HAD/AD vehicle systems will be researched, tested, and – ideally – validated. The developed methods should be evaluated in an application-oriented manner by using different automated vehicle systems (vehicle, people mover, light-duty truck, urban utility vehicle) in heterogeneous urban real-world operation.

Source: Project description „KIsSME", 2020

Different automated vehicle systems used in an urban environment.

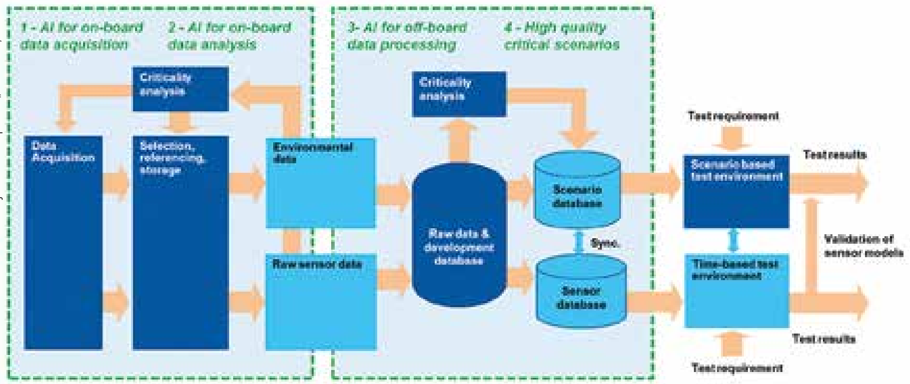
BUSINESS BENEFITS

The core of this BMWi-funded program is the integration of suitable AI technologies into the vehicle - both for applications of automated driving and in the field of other vehicle technologies. In this context, the focus lies on the applications in simulation, development, production and operation, and less on the basic development of the actual procedures. Application-related approaches - each originating from the vehicle - should be demonstrated in a prototypical manner. This would promote projects with a higher technology-readiness level (TRL), in which the development status is closer to a potential and desired exploitation by the project partners.

ASAM e.V. will be involved in the preparatory activities, both during the project and in the subsequent exploitation phase. In this manner, the early incorporation of established ASAM standards in the developed processes becomes possible, and, where applicable, an early identification of necessary standardization can be implemented in the ASAM environment. The project was approved in December 2020, with a 3-year term (2021 to 2023), and with total project costs of nearly EUR 10 million.

"Our participation in the KIsSME project – together with several ASAM members – gives ASAM the unique chance to identify at the earliest possible point in time important topics for standardization which are needed for successful ADAS/AV development. It also helps to raise the awareness for standardization among the research teams during the pre-development process."

DR. KLAUS ESTENFELD,
Managing Director, ASAM e.V.



Source: Project description „KIsSME", 2020

Project objectives 1 to 4 depicted in the data flow for identifying critical driving scenarios.

CATARC

ASAM OpenX: Best Practice for Simulation

Featured Standard:

ASAM OpenX

Author:

Bolin Zhou, Senior Technical Director,
Automotive Data of China (Tianjin) Co., Ltd

SUMMARY

The development of Automated driving systems and functions require a tremendous amount of testing. The function oriented and data driven approaches made a huge leap forward in the field and as a major market for the automotive industry, China is also evolving as a partner. One big advantage of ASAM OpenX is that it enables a data flow within scenario-based testing without boarder. Any company in any country can benefit from simulation testing with a free standard-suite focusing on simulation and beyond. Automotive Data of China (CATARC-ADC), subsidiary of China Automotive Technology and Research Center Co., Ltd. (CATARC), the largest automotive third-party institute in China, has been participating in the ASAM OpenX projects since 2018. The complexity of scenarios across the globe with their divers road users and wide-ranging parameters create the need for powerful and broadly-applied standards in the future.

DESCRIPTION OF THE SITUATION

We at CATARC-ADC cooperate closely with the simulation team at CATARC. Together, we hold more than 500k kilometers of open road driving data, CIDAS (China In-Depth Accident Study) data and many other scenario data from China as well as many spinoffs scenario databases providing analysis on typical driving behavior. We deliver analysis for many OEMs including Ford, Nissan, SAIC and many others.

By analysing those open road driving data, we could get some key figures on the behaviors, manners of the vehicle and driver, but to extend and to create an "useful" data, applications and implementations are the key. This is well simulation brings out the true power of those data. The extension of those "natural data" to more complicated and more convoluted scenario will match the future of ADV testing.

ASAM OpenX describes a family of cohesive standards around simulation, that provide a perfect framework for simulation applications. They support the data and work flow in the simulation process. Advantages of applying the standards include:

1. Data sharing and comparison capabilities;
2. Validation and analytical studies;
3. Common usage and tool joint development;
4. Corner cases and specific testing capabilities;
5. High-level scenario exchange and cross references.

ASAM OpenX creates a scenario-based testing workflow that can be shared, compared and tested, that can broaden our knowledge on simulation and create more "posterior knowledge" after testing. The standards ASAM OpenDRIVE, ASAM OpenCRG and ASAM OpenSCENARIO already support the process but there is still a lot to be done: Further projects are already underway and will complement the OpenX family soon.

CHALLENGE AND MOTIVATION OF ASAM OpenX

The challenges are three-fold:

1. High-level automated driving systems cannot be tested simply by milage based testing. The scenario supporting the AD system is a "long tailed one": most of the scenarios cannot be covered by the most comment scenarios. The quality of the test cases triumphed the quantity of the scenario. A well-thought out procedure and a well-organized process are essential. A common knowledge base in simulation will quickly enable a foundation for this process.

For each part of the process, a standardized way of data calculation, data processing and data interpretation are crucial. To achieve such testing procedure, a probabilistic geometric modelling method is required, as well as a back-end tool for verification, debugging, and synthesis of the automated driving system under test.

2. High-level automated driving systems should be tested worldwide and fulfil varieties of cases and constraints. This means that automated driving functions should be tested against a common set of scenarios. A common approach to determine which test sets are necessary, is using the Operational Design Domain (ODD) as a basis. Here, a formal scenario specified language and ontology are useful, all of which will be created as part of the ASAM OpenX activities.

3. Validation of the system, especially in simulation testing, should have a great advantage compared to real-world testing. If the real world situation cannot be replicated or mimicked in simulation, the whole process loses its value. ASAM OpenX aims to compare simulation and real-world testing data quantitatively and qualitatively for a test scenario that has been formally specified and implemented in both simulation and real-world testing. Once this is verified, the ASAM OpenX standards can release their full potential by enabling fast, cost-effective and accurate testing. ASAM OpenX is able to provide the framework for this process and enriches the power of scenario-based testing, ODD coverage and high-fidelity testing.

SUCCESS STRATEGY

Facing the three major challenges, few strategies toward success emerge:

Both milage-based and coverage-based testing should be supported: Pure milage based testing also has its merits: The results lead to a better validation of the project. ASAM standards, that are currently still under development, like ASAM OpenLABEL, are well matching with all the state-of-the-art methods tackling the "milage-based testing". A consensus framework within the working project is the corner stone for such standard. On the other hand, by setting up a good workflow and testing criteria, which ASAM is spending many times on such topic, will help to deliver smart and automated workflow for coverage-based testing procedure.

Involving as many stakeholders as possible: ASAM projects consist of experts from ASAM member companies. They do not only come from different parts of the world, but they also bring in their different sectors of industries. The different backgrounds help the project to consider a large number of requirements which is critical for the success and acceptance of the standards later on. In China, CATARC and ASAM have established C-ASAM, a work group dedicated for ASAM activities in China, to involve more Chinese participants in the standardization process.

Implementation is key: ASAM OpenX standards are free of charge. This helps to promote the standards, broaden their user base. and support the long chain in simulation testing implementations. This requires rigorous use case study, workflow variant, harmonization with multiple standards and fulfilling the gaps between each piece of the workflow.

CHALLENGE DURING THE PROJECT

Working together always brings challenges. Be it the time difference when companies from all over the world are working together or conflicts of interest that need to be resolved. Given the urgent need for standards in the simulation domain, all these difficulties have been solved well so far.

BUSINESS BENEFITS

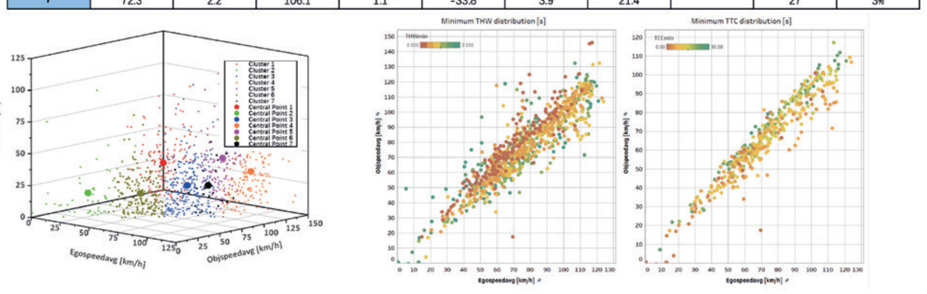
In the world of data, the more it can enrich, the more valuable it is. OpenX standards will eventually smoothen the workflow for simulation, create the ultimate data cost saving and simulation setup time saving, and provides flexibility for scenario creation. All in all, this will expedite the process and paves the way for more beneficiaries.

"We are looking forward to ASAM based solutions. Although it requires a great amount of input at the start, it will eventually pay off with great benefits."

DR. JISHUN GUO,
Director of AD Development,
GAC group

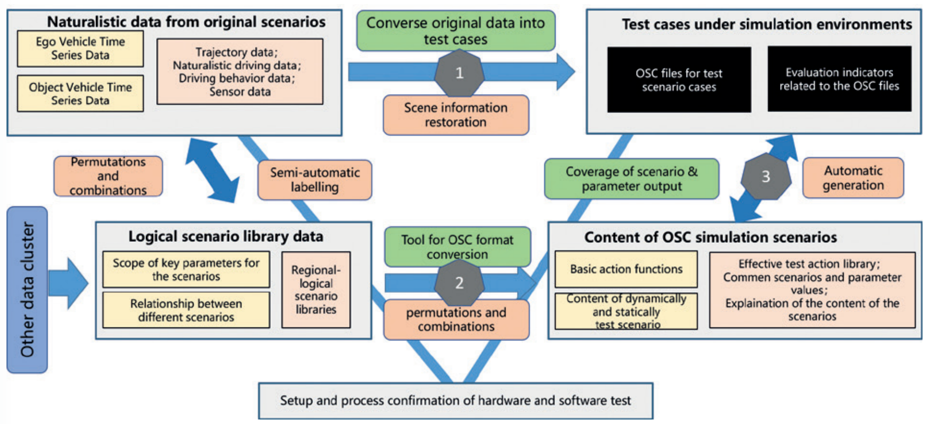
➤ Cluster central points showed as below.

Cluster No.	Egospeedavg [km/h]	ObjAccmax_x [m/s2]	Objspeedavg [km/h]	minTHW [s]	speed_diff [km/h]	Duration [s]	startPox1 [m]	minTTC [s]	Cluster number	Scene coverage [%]
1	68.3	2	60.4	1.7	7.9	6.3	44.9	13.2	147	15%
2	27.5	4.3	28.2	2.6	-0.7	7.3	19.8	17.2	51	5%
3	74.5	1.8	79.2	1.2	-4.7	6.1	25.5	24.3	242	25%
4	106.1	1.4	109.7	1.2	-3.6	5.7	37.1	29	183	19%
5	97.6	1.6	88.7	1.3	8.9	5.7	49.5	15.6	146	15%
6	51.8	2.3	56	1.3	-4.2	7	18.9	17.1	187	19%
7	72.3	2.2	106.1	1.1	-33.8	3.9	21.4		27	3%



Analysis based on the open road driving data for some major global OEM

Source: Automotive Data of China (Tianjin) Co., Ltd



Source: Automotive Data of China (Tianjin) Co., Ltd

"With the help of the ASAM OpenX projects, the data in the simulation field can be exchanged without border."

BOLIN ZHOU,
OpenSCENARIO 1.x Project Lead,
Automotive Data of China

MEMBERS

ASAM thrives on the collaboration of its members. Since the OpenX standards were transferred to ASAM, the number of members has doubled. These members not only bring additional expertise to standards development, but also expand the user base of the standards. Major tools on the market already rely on the use of ASAM OpenX standards.

ASAM MEMBERS

OEMs

Arrival Ltd.

AUDI AG

BMW AG

Daimler AG

Deere & Company

e.GO MOOVE GmbH

Ford Motor Company

General Motors Company

Hino Motors, Ltd.

Honda Motor Co., Ltd.

MAN Truck & Bus AG

Mazda Motor Corporation

Nissan Motor Co., Ltd.

Opel Automobile GmbH

Porsche AG

PSA PEUGEOT CITROËN Automobiles

Rimac Automobili d.o.o.

SAIC Motor Corporation Ltd., Dept. A

SAIC Motor Corporation Ltd., Dept. B

SEAT, S.A.

Škoda Auto a.s.

Subaru Corporation

Toyota Motor Corporation

VOLKSWAGEN AG

Volvo Cars Corporation

Volvo Technology AB

Yamaha Motor Co. LTD.

TIER-1 SUPPLIERS

ADVICS Co., Ltd.

AISIN SEIKI Co. Ltd.

Alps Alpine Co., Ltd.

APTIV

BorgWarner France

Continental AG

Cummins Inc.

Denso Corporation

DJI Systems Co. Ltd.

Hexagon Manufacturing Intelligence

Hitachi Automotive Systems Ltd.

Huawei Technologies Co. Ltd.

Keihin Corporation

Marquardt GmbH

MOTORENFABRIK HATZ GmbH & Co.KG

MTU Friedrichshafen GmbH

NIRA

NVIDIA Corporation

Robert Bosch GmbH

Sony Semiconductor Solutions Corporation

Thyssenkrupp Components Technology Hungary Kft.

Toyota Technical Development Corporation

Unity Technologies ApS

Veoneer Germany GmbH

Viessmann Elektronik GmbH

ZF Friedrichshafen AG

TOOL VENDORS

12th Wonder LLC	2D Debus & Diebold Meßsysteme GmbH	3D Mapping Solutions GmbH	51VR High Technology Co., Ltd.	A&D Company, Limited	AB Dynamics Ltd.
Accurate Technologies Inc	ACTIA I+ME GmbH	Advanced Data Controls Corp.	AED Engineering GmbH	AImotive Kft.	AIP GmbH & Co. KG
AKKA GmbH & Co. KGaA	ALES S.R.L. (Advanced Laboratory on Embedded Systems)	Aliaro AB	Alliance Automotive Research & Development (Shanghai) Co., Ltd	Alpha Drive Inc.	Altran Deutschland S.A.S. & Co. KG
Amazon	AMIQ EDA srl	AMIUM GmbH	Annecy Electronique S.A.S	Annotell AB	ANSYS, Inc.
Apicom S.p.A.	Apollo Intelligent Technology (Beijing) Co., Ltd.	Applied Intuition Inc.	APTJ Co., Ltd.	ArcCore AB	Autocom Diagnostic Partner AB
Automotive Artificial Intelligence (AAI) GmbH	Automotive Data of China (Tianjin) Co., Ltd	Avin Systems	AVL LIST GMBH	BeamNG GmbH	BETA CAE Systems S.A.
b-plus GmbH	Brüel & Kjaer Sound and Vibration A/S	BTC Embedded Systems AG	Caeri Science and Technology Co. Ltd.	CAETEC	CATS CO. LTD.
Change Vision, Inc.	CMORE Automotive GmbH	Cognata Ltd.	Concurrent HPS Europe S.A.	Cruden B.V.	CSM GmbH
Dassault Systèmes Simulia Corp.	Dataloop	Deepen AI	Deloitte Tohmatsu consulting LLC	Derive Systems	Dewesoft d.o.o

Digitalwerk GmbH	DSA – Daten- und Systemtechnik GmbH	DSO Infomation Technology (Shanghai) Co	dSPACE GmbH	DTS INSIGHT Corporation	DXC Technology Japan, Ltd.
Dynamometer Services Group Ltd.	E.S.R. Labs GmbH	Edge Case Research	eGlue Technologies Srl	Electrobit Automotive GmbH	embeddeers GmbH
emotive GmbH & Co. KG	ESI Group	eSOL Co.Ltd.	e-SYNC Co. Ltd.	ETAS GmbH	FDTech GmbH
FEV SA	FEV Software and Testing Solutions GmbH	Fiedler MPS – Günter Reinhard Fiedler	Five AI	Forecast Data Technology Co., Ltd.	Foretellix Ltd.
Futavis GmbH	GAFS Corporation	Gailogic Corporation	GAIO TECHNOLOGY	Gangolf Feiter-Concepts & Services Consulting	General Engine Management Systems Ltd. (GEMS)
GIT Co., Ltd.	GLIWA GmbH embedded systems	GOD mbH	GRYFTEC Embedded Systems Sp. z o.o.	HBK-Hottinger, Brüel & Kjaer	HEAD acoustics GmbH
HGL Dynamics Ltd.	HighQSoft GmbH	HIOKI E.E. CORPORATION	HMS Technology Center Ravensburg GmbH	Hongke Technology Co., Ltd.	HORIBA, Ltd.
HORIBA FuelCon GmbH	Hulinks Inc.	Hyundai Autron	Iasys Technology Solutions Private Limited	IAV GmbH	I-Chin Motor Technology Co., Ltd.
imbus AG	imc Meßsysteme GmbH	Incenda AI GmbH	INCHRON AG	Influx Technology Ltd.	INTEMPORA S.A.
Intrepid Control Systems, Inc.	IP Camp Kft.	IPETRONIK GmbH & Co. KG	IPG Automotive GmbH	iSyst Intelligente Systeme GmbH	iSYSTEM AG

itemis AG
K&S GmbH Projektmanagement
Karakun AG
Keisokugiken Corporation
Keysight Technologies Deutschland GmbH
Kistler Chemnitz GmbH
Kithara Software GmbH
Kontrol GmbH
KPIT Technologies GmbH
Kratzer Automation AG
Kristl, Seibt & Co GmbH
Kvaser AB
Lauterbach GmbH
LiangDao GmbH
Lipowsky Industrie-Elektronik GmbH
Luxoft GmbH
The MathWorks Inc.
measX GmbH & Co. KG
Mecalc Technologies Inc.
Mechanical Simulation Corporation
Meidensha Corporation
Micro Technology Co., Ltd
MicroNova AG
Mitsubishi Precision Co., Ltd.
monoDrive
MORAI Inc.
MOTEON GmbH
MP bvba
Müller-BBM VibroAkustik Systeme GmbH
National Instruments Corporation
NavInfo Co. Ltd.
NEXT LIMIT SL
Nexty Electronics Corporation
Nihon Unisys, Ltd.
NorCom Information Technology Gmbh & Co. KGaA
OnoSokki Co., Ltd.
OTSL Inc.
Parkopedia Limited
parson AG
Peak Solution GmbH
PEAK-System Technik GmbH
Peritec Corporation
Perpetuum Progress GmbH
Phantasma Labs GmbH
Pico Technology Limited
Piketec GmbH
Pilotd Automotive (Shanghai) Co., Ltd.
PLS Programmierbare Logik & Systeme GmbH
PMSF IT Consulting Pierre R. Mai
Polytec GmbH
PROSTEP AG
QTronic GmbH
Quint Safety GmbH
RA Consulting GmbH
rd-electronic gmbh
Rainfe Technology Ltd.
ReliaTec GmbH
Rototest International AB
Saimo Technology Co. Ltd.
Sapa Automotive Technology Co.Ltd.

Schleißheimer Soft- und Hardwareentwicklung GmbH
science +computing ag
SCSK Corporation
Sensmetry, UAB
SGE Ingenieur GmbH
SGS CyberMetrix, Inc.
Shanghai Motor Vehicle Inspektion Certification & Tech Innovation Center Co., Ltd
Sibros Technologies, Inc.
Siemens AG
Sierra CP Engineering Ltd.
Sky Technology Inc.
Smart Design Technology Co., Ltd.
SMART Testsolutions GmbH
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Softing Automotive Electronics GmbH
Sohatex GmbH
SOLIZE Engineering Corporation
Sontheim Industrie Elektronik GmbH
Speedgoat GmbH
SpringCloud Inc.
STAR ELECTRONICS GmbH & Co. KG
STIEGELE Datensysteme GmbH
Strong Plus Technology GmbH
Symphony

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Synopsys GmbH

Synostik GmbH

Systemite AB

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Technica Engineering GmbH

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Techways Co., Ltd.

Tencent Dadi Tongtu (Beijing) Technology Co. Ltd.

Tenergy CO.LTD.

T-Engineering AB

TOYO Corporation

TraceTronic GmbH

TTTech Germany GmbH

TÜV SÜD AG

Typhoon HIL, Inc.

UATC LLC (UBER)

Ubiquitous AI Corporation

U-chain Vehicle Network Technology Co., Ltd.

UMAN Universal Media Access Networks GmbH

UniqueSec AB

Vayavya Labs Pvt Ltd.

Vector Informatik GmbH

Vibes Technology B.V.

ViGEM Gmbh

virtualcitySYSTEMS GmbH

VIRES Simulations-technologie GmbH

Visu-IT! GmbH

We4Data GmbH

Weber Electronic & Race Engineering GmbH & Co. KG

White Pine Software Technologies, LLC

X2E GmbH

XI-Works

Xylon d.o.o

Yokogawa Test & Measurement Corporation

Zuragon

ACADEMICS

Aristotle University

AstaZero

Automotive Solution Center for Simulation e.V. (ascs)

Beihang University

Computer Vision Center (CVC)

Connected Places Catapult

Czech Technical University Prague

Deutsches Zentrum für Luft- und Raumfahrt e.V. DLR

Driving Simulation Association

Fachhochschule Aachen

FH Braunschweig / Wolfenbüttel

FlandersMake vzw

Fraunhofer-Institut für Experimentelles Software Engineering (IESE)

Fraunhofer ITWM

Fraunhofer-Institut für Betriebsfestigkeit & Systemzuverlässigkeit

Fraunhofer-Institut für Kognitive Systeme IKS

Fraunhofer-Institut für Verkehrs- & Infrastruktur-systeme IVI, e.V

FZI Forschungszentrum Informatik

GFal e.V.

Hochschule für Angewandte Wissen-schaften Kempten

Hochschule Trier

Höchstleistungsrechen-zentrum Universität Stuttgart

HTW Dresden (FH) / ZAFT e. V.

IFKM – Karlsruher Institut für Kolbenmaschinen

Institute of Communica-tion & Computer Systems (ICCS)

IRT SYSTEMX

Istanbul Okan University

Japan Automotive Research Institute

Jiangnan Academics

JOANNEUM RESEARCH Forschungsgesellschaft mbH

JoongBu University

Korea Electronics Technology Institute

Mindmotiv GmbH

Mississippi State University Center for Advanced Vehicular Systems

Nagoya Academics

National Taiwan Ocean University

OFFIS e.V.

OSU Center for Automotive Research

Oxfordshire County Council

Physikalisch-Technische Bundesanstalt PTB

RISE Research Institutes of Sweden

RWTH Aachen Academics

School Judical Person Ikotokugakuen (KAIT)

School of Automotive Studies, Tongji University

Technische Hochschule Ingolstadt

Technische Hochschule Köln

Technische Universität Darmstadt

Tianjin Vocational Institute

TNO

Transportation Research Center Inc.

Tsinghua University Suzhou Automotive Research Institute

TU Braunschweig Institut für Regelungstechnik

TU Dresden, IAD – Institut für Automobiltechnik

Universität Stuttgart, Institut für Verbrennungs-motoren

University of Bath

University of Bologna

Vicomtech

Virtual Vehicle Research GmbH

VTI – Statens väg- och transportforsknings-institut (VTI)

VTT LLC

WMG University of Warwick

Xihua University

PRODUCT OVERVIEW

Although the ASAM OpenX standards are relatively new, there are already many companies whose tools and services support ASAM simulation standards. Many more companies are in the process of implementing ASAM standards.

On this page you will find an overview of the current ASAM OpenX tool landscape. The information below is based on the member profiles on the ASAM website. ASAM assumes no liability for the correctness or completeness of this information. For more information on the products:

www.asam.net/members/product-directory/

Company	Product	Desription	ASAM OpenDRIVE®	ASAM OpenCRG®	ASAM OpenSCENARIO®	ASAM OSI®	ASAM MDF	ASAM XIL	ASAM ODS
3D Mapping Solutions GmbH	Ultra HD Maps	High-resolution identical digital twin of roads	x						
	Digital road surface models	High-resolution road surface models		x					
AMIQ EDA srl	DVT IDE for OpenScenarioe/SDL/DSL	Integrated development environment (IDE)			x				
	Quality assurance/ Verification services for autonomous	Consulting services			x				
Ansys, Inc.	Ansys VRXPERIENCE Driving Simulator powered by SCANeR™	Simulator	x			x			
Applied Intuition Inc.	Simian	Autonomous vehicle simulation software	x	x					
Automotive Artificial Intelligence (AAI) GmbH	AAI Scenario Cloning & Extraction	Digitalisation and analysis service	x		x	x			
	AAI Intelligent Traffic	Software module	x		x	x			
	AAI Sensor Simulation	Service to create sensor models & 3D assets				x			
	AAI ReplicaR	Simulation platform	x		x	x			
Automotive Data of China (Tianjin) Co., Ltd	ADChauffeur	Scenario generator	x		x	x			
Change Vision Inc.	Astah	Modeling tool			x				
Cognata Ltd.	Cognata simulation platform	Cognata simulation platform	x		x				
	Synthetic Datasets	Synthetic datasets	x		x				
CRUDEN B.V.	Panthera Software Suite	Simulation software	x	x					
dSPACE GmbH	Automotive Simulation Models (ASM)	Real-time simulation models	x		x	x			
	ModelDesk	Graphical user interface	x	x	x	x			
	Scenario Generation Service	Service to generate simulation scenarios	x		x	x			
Five	The Five Platform	Automated driving system develop. platform	x		x	x			
Forecast Data Technology Co., Ltd.	Cognata	Simulation platform	x		x				
Foretellix Ltd.	Foretify™	Verification environment	x		x				
Hongke Technology Co., Ltd.	Simulation tool	Building scenarios. Performing tests.			x				
JOANNEUM RESEARCH Forschungsgesellschaft mbH	Highly Automated Driving Laboratory		x	x	x				
	UHD Mapping, UHD Maps, Mobile Mapping		x	x					
IPG Automotive GmbH	CarMaker	Open integration and test platform	x	x	x		x	x	
	MotorcycleMaker	Open integration and test platform	x	x	x		x	x	
	TruckMaker		x	x	x		x	x	
PMSF IT Consulting Pierre R. Mai	PMSF FMI Bench	PC-based simul. integration environment				x			
	PMSF RFMI Server	Simulation host				x			
	PMSF OSI3Test Framework	Python framework				x			
Unity Technologies ApS	Simulation	Simulation platform	x		x			x	
Vector Informatik GmbH	DYNA4	Open simulation environment	x	x			x		
VIRES Simulationstechnologie GmbH	Road Designer (ROD)	Static content creation tool			x				
	Virtual Test Drive (VTD)	Simulation software	x	x	x	x			
	VTD Scale	Cloud-based simulation service	x	x	x				
Weber Electronic & Race Engineering GmbH & Co KG	Data Analysis a. Statistics World Wide					x	x		x
Open source project: https://github.com/esmini/esmini	Esimini	Basic OpenSCENARIO player			x				
Open source project: https://github.com/pyoscx/pyoscx	Pyoscx	Python Wrapper for OpenSCENARIO V1.0.0			x				
Open source project: https://github.com/RA-Consulting-GmbH/openscenario.api.test	OpenSCENARIO 1.0 API + Checker – Beta version	API & Checker			x				
CARLA open source project: https://github.com/carla-simulator/carla	CARLA simulator	Simulator			x				

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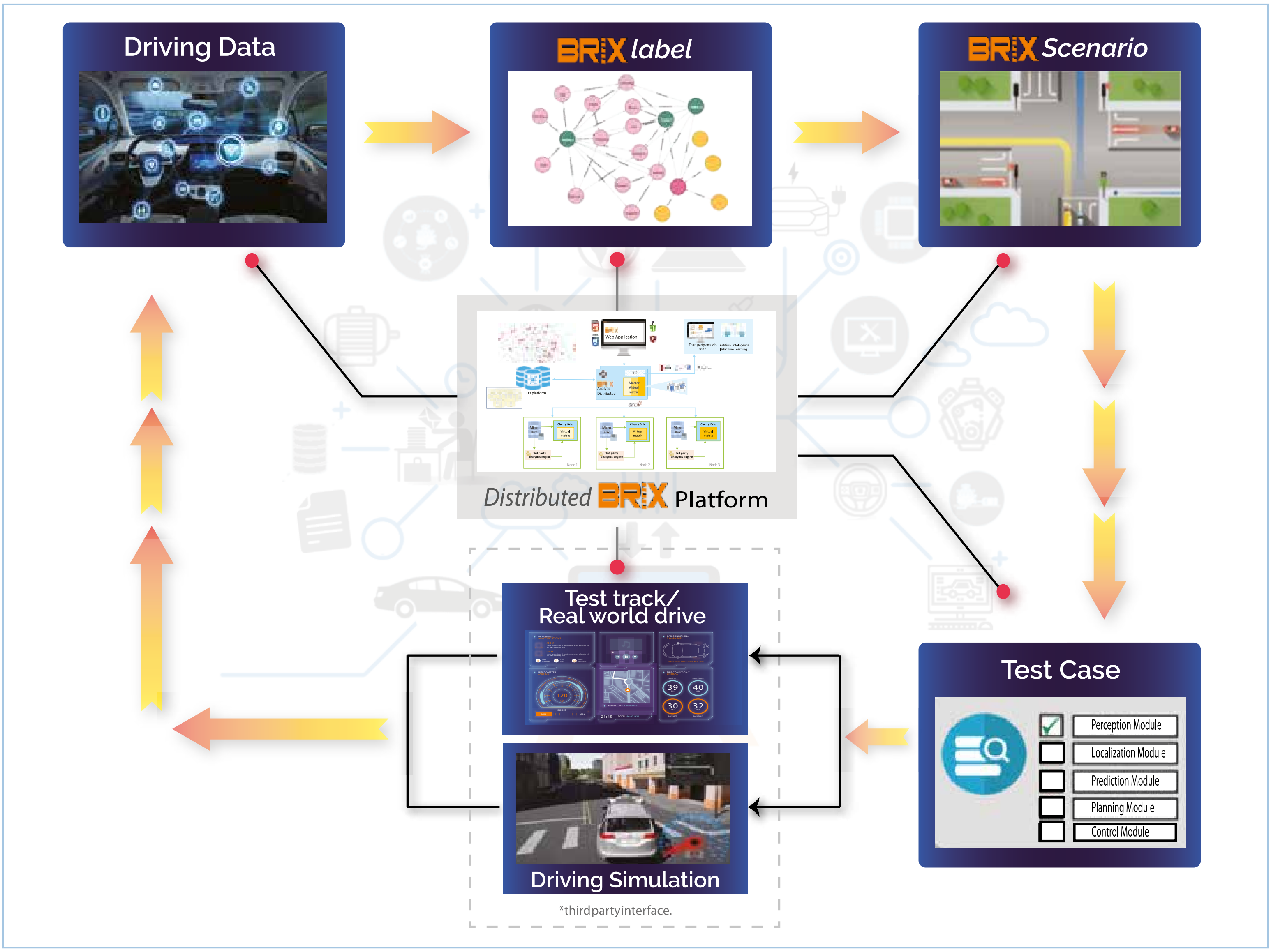

Other solutions

- **BRIX lite** – Test Data Management
- **BRIX lab** – Facility Management & Lab Monitoring System
- **BRIX PVM** – Product Validation Management
- **BRIX Distributed** – For Big Data, Telematics & Autonomous Driving
- **Orbit** – Test Automation Platform

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