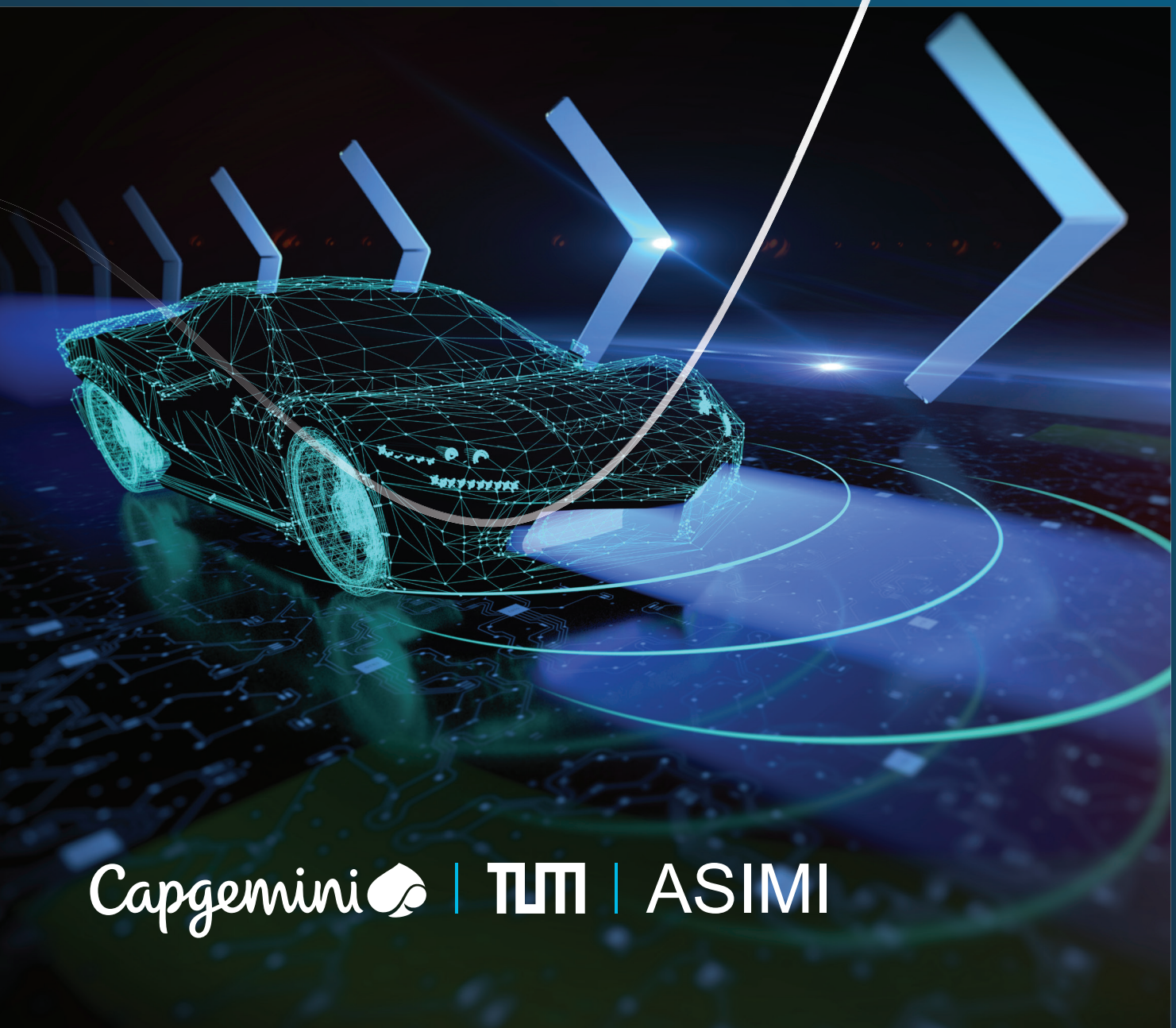
# Enabling *Digital Homologation* with Advanced AD Simulation Ecosystems

Analysis of the AV Simulation Ecosystem



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# Executive Summary


This white paper explores how advanced simulation for validating Advanced Driver Assistance Systems (ADAS) and Automated Driving (AD) systems can significantly reduce the dependency on traditional testing methods which are highly complex, extremely expensive, and time-intensive with single-function validations that require extensive real-world driving in the range of millions of kilometres. Advanced simulation platforms aim for a faster, cost-efficient alternative, reducing reliance on physical testing while ensuring regulatory compliance.

With the rise of complex driving environments, digital homologation is emerging as a faster, more cost-effective, and efficient solution compared to the time-consuming and expensive conventional homologation approaches.

To gain a deeper understanding of how advanced simulation technologies are shaping this shift, we conducted interviews and live Demos with key industry players. These included hyperscalers, tool providers, emerging innovators, and Tier 1 suppliers, all of whom are playing pivotal roles in the advancement of ADAS/AD validation. Please read through to discover our findings.

# 01. Introduction

This study examines the critical role of advanced simulation platforms in the development and homologation of Advanced Driver Assistance Systems (ADAS) and Automated Driving (AD) technologies. It provides key stakeholders with insights into the strategic advantages of digital homologation in accelerating innovation and maintaining a competitive edge in the automotive sector.

Today's simulation platforms enable rapid prototyping and iteration, significantly reducing time-to-market. By supporting scalable testing across diverse conditions, these platforms enhance product quality, ensuring reliability and safety in autonomous driving. They also address legal and homologation challenges for automotive OEMs, making them essential for ADAS and AD development, particularly for Level 3+ autonomous driving systems.

AV simulation and evaluation frameworks typically consist of two key components: high-fidelity environments for complex closed-loop scenarios and scalable, scenario-based testing. This study explores how various industry players utilize these frameworks and verification and validation (V&V) processes to tackle the complexities of AD development and gain a competitive advantage. It also provides a comprehensive overview of the key players in the simulation platform ecosystem and how they differentiate themselves.

We categorize and present the results in a system of common categories for easy access and comparison. This includes a detailed breakdown of simulation software, hardware, data analytics tools, and digital twins, evaluating their potential for time and cost savings, and their alignment with international standards and regulatory compliance. We also assess the architectural readiness for standardized digital homologation in the future.

The study further examines the role of analytics in forming safety arguments and integrating performance metrics. Of particular importance is the automation of scenario generation, using both algorithm-defined and real-world data-driven scenarios, traffic models, and standards-compliant AV testing environments. The importance of diverse maps, Operational Design Domains (ODDs), and navigation data standards for effective simulation is also emphasized.

Finally, the study reviews performance metrics such as runtime and hardware utilization, evaluates integration techniques for systems under test, and assesses the maturity and readiness of these platforms for extensive testing and complex system integrations.

The study focuses on companies from various industry segments, each bringing distinct technical expertise and focus. Chip manufacturers provide the essential hardware that powers complex computations, while hyperscalers offer the computational scale needed for large-scale simulations and safety assessments. Newcomers introduce innovative technologies, particularly in scenario generation and simulation, while Tier 1 suppliers collaborate closely with OEMs to ensure components meet regulatory and performance standards. Tool providers offer specialized solutions that enhance design and testing processes, making them indispensable for tailored, high-precision support.

This study aims to guide readers through the technological landscape of simulation, providing insights into key technologies and the leading players driving progress in ADAS and AD development.

We extend our sincere thanks to all participants for their valuable input and time spent contributing to this study.

**Disclaimer: The information and comparative analysis presented in this study are based solely on claims made by platform providers. We have not independently tested or verified the functionality, quality, or accuracy of the capabilities or claims. All insights were gathered through personal interviews with one or more representatives from each automotive OEM, supplier, or toolmaker.**



# 02. Objectives and Hypothesis

As the automotive industry accelerates toward an autonomous future, the significance of ADAS/AD digital homologation platforms continues to grow. This study aims to achieve multiple objectives, offering a comprehensive exploration of key aspects while providing readers with an insightful overview of this rapidly evolving landscape.

## Market landscape and strategic insights

We conduct an in-depth market analysis of existing ADAS/AD simulation platforms, tools and additional services, exploring their key features and functionalities. By doing so, we aim to provide stakeholders with an understanding of the current market and individual company offers. By examining their impact on cost savings, development speed and regulatory compliance, we generate insights on their strategic importance.

## Alignment with OEM Requirements

Meeting the complex demands of AD development, including safety, reliability, and compliance, OEMs combine existing V&V practices with simulation platforms. Our study examines this ecosystem, focusing on rapid prototyping, established technology trends, and adherence to regulations.

## Simulation platforms significantly reduce reliance on real-world testing, leading to faster time-to-market for ADAS/AD systems

By integrating simulation platforms into the V&V process, automotive manufacturers can create virtual environments that mimic real-world driving conditions. These platforms allow for extensive testing without having to physically deploy vehicles on the road. Hereby, the cost of conducting test cycles is significantly reduced, while simultaneously accelerating their execution-time and frequency. Overall, this results in development cost being reduced as errors are identified earlier and a shortened time-to-market.

## Effective AV simulation solutions enhance product quality by replicating diverse driving conditions and real-world variables

Simulation platforms provide a controlled environment where developers can test ADAS/AD algorithms under different scenarios (e.g., adverse weather, complex traffic, emergency situations). Through accurate replications of real-world conditions, the robustness of the function is increased. The significance of introducing variation while maintaining high fidelity cannot be overstated, as it enables rigorous safety argumentation, which is critical in the safety-critical automotive sector. As system representation becomes more complex, computational demands inevitably increase. This study explores how individual companies address and manage this growing challenge.

## Market leaders in the domain of simulation platforms differentiate themselves through unique features and capabilities

The ADAS/AD simulation market is competitive, with several players offering solutions. To maintain a competitive edge, these players must provide unique features (e.g., high-fidelity sensor models, efficient scenario generation, seamless integration within the DevOps environment). Our study seeks to identify the key unique selling points of each player, and which services are the best fit for which solution.

# 03. Key Player Selection Criteria

Simulation technologies are pivotal in advancing the development, testing, and validation of automotive systems. However, they do not represent a singular technology but rather a sophisticated interplay of multiple sub-technologies, services, and requirements. For automotive manufacturers and technology integrators, selecting the right key partners or technologies is critical. A comprehensive breakdown is essential to ensure the best fit and maximum benefit. Several key criteria have been meticulously considered to ensure alignment with both technical and strategic goals.

## Technical Capabilities and Scalability

When evaluating key players in the field of simulation technologies for ADAS, several technical capabilities are crucial, especially regarding digital twins. A high technical proficiency ensures that the digital twin can accurately replicate and predict the behavior of ADAS systems, providing a reliable platform for development, testing, and validation.  the foremost consideration is the technical capabilities of their solutions. High technical proficiency ensures that the digital twin can accurately replicate and predict the behavior of ADAS systems, providing a reliable platform for development, testing, and validation. Critical aspects of technical capabilities include simulation accuracy, sensor integration, scenario modeling, and real-time performance. As ADAS complexity grows, scalability becomes a further vital criterion. Solutions should manage large datasets and  support real-time performance testing by leveraging advanced computing resources such as edge computing and cloud services.

## Innovation and AI Integration

Innovation and the integration of artificial intelligence (AI) play a pivotal role in AD/ADAS development by automating scenario generation and parameter variation, reducing the dependency on costly and time-consuming real-world testing. AI enables the creation of diverse driving scenarios, including rare edge cases, and simulates varying conditions such as weather, traffic, and sensor performance. This enhances the robustness and safety of AD/ADAS systems, allowing OEMs to test and validate their systems more efficiently. Suppliers offering AI-driven simulation platforms enable OEMs to accelerate development, optimize testing resources, and meet stringent safety standards with greater accuracy.

## Tool Customization and Ecosystem Integration

Ease of use and customization are critical criteria for simulation solutions. These factors ensure accessibility to a wide range of users and allow tailoring to meet specific needs and requirements. This includes user interface design, flexibility, and adaptability to various applications and workflows, facilitating efficient and effective use across diverse contexts.

## Solution Availability

The availability of the solution/tool ensures that the provided solutions/services are readily accessible when needed, thereby minimizing downtime, and maximizing productivity for the integration with the client. The more reliable the solution, the higher the customer satisfaction and the overall product's quality. Solution availability is regarded as an integral part of any player who seeks market acceptance.

# 04. Research and Comparison Criteria

To effectively cover the technological landscape and compare key players in the simulation field for Advanced Driver Assistance Systems (ADAS), a comprehensive set of criteria has been established. These criteria ensure a holistic evaluation of each company's capabilities, tools, and solutions. The comparative aspects are divided into several categories, each focusing on different facets of simulation technology.

## Platform

The platform criterion is essential when evaluating key players. It encompasses the overall structure and functionalities of the software tools and services provided by the companies, ensuring they meet necessary standards and integrate seamlessly into the development workflow. Key aspects include workflow management, which ensures test management, scenario management, and data management comply with ISO 34502 standards, providing a structured and standardized approach to testing ADAS systems. The platform should also support robust analytics capabilities to develop and validate safety arguments, crucial for ensuring the safety and reliability of ADAS systems and ensure adherence to ISO 26262 for functional safety in automotive systems. Additionally, it should provide tools for calculating and evaluating Key Performance Indicators (KPIs) effectively, facilitating the assessment of performance and progress in ADAS development. Integration into Continuous Integration (CI), Continuous Delivery (CD), and Continuous Testing (CT) pipelines is vital, supporting automated testing and deployment, and ensuring the platform can be seamlessly integrated into modern software development workflows.

## Scenario Generation

The scenario generation criterion focuses on the platform's ability to create and manage diverse testing scenarios. Key aspects include support for user-defined scenarios, automatic generation of function-based scenarios, and the use of real-world data for realistic simulations. The platform should also incorporate artificial traffic models and be compatible with industry standards like PSV, ODR, and OSI. Additionally, it should provide a comprehensive database for storing scenarios and cover a wide range of driving situations to ensure extensive testing capabilities. Here emerging technologies in the field of Generative AI are promising and from particular interest as to hand generate the complete scenario space is simply not possible.

## Maps and ODDs

The maps and operational design domains (ODDs) criterion are vital for evaluating key players in the digital twin field for ADAS. It focuses on the platform's mapping capabilities and its support for various operational scenarios. Key aspects include extensive map coverage, function-based ODDs, and route-based maps. The platform should support automation in map usage and updates, provide specific maps for parking simulations, and be compatible with Navigation Data Standard (NDS) maps.

## Infrastructure

The next aspect that is considered when evaluating each company is the infrastructure. It focuses on the underlying support systems and tools provided by the platform. Key aspects include offering cloud-native services and on-premises solutions, as well as tools for data editing, visualization, and other tasks. The platform should allow local usage on development machines, including debugging features like breakpoints and code stepping. While hard to evaluate as an external source, especially the ease of integration and combination of external company software with the provided services is essential for a sophisticated Infrastructure.

## X in the Loop

"X in the Loop" assesses the platform's ability to integrate and test various components in simulated environments. Key aspects include support for Software in the Loop (SiL), Module/Model in the Loop (MiL), Hardware in the Loop (HiL), and Vehicle in the Loop (ViL). These capabilities ensure comprehensive testing and validation of ADAS systems at different stages of development, providing robust and reliable integration of both software and hardware components.

## Environment

The environment in which the development of Advanced Driver Assistance Systems (ADAS) operate is a critical criterion for comparing key players in the field. This criterion emphasizes the importance of adhering to open standards, operating system compatibility, and toolchain flexibility. Key aspects include the use of OpenX Standards – which has established itself as an industry trend, compatibility with both Linux and Windows operating systems, and the provision of open interfaces through tool-external APIs.

Additionally, the toolchain's modularity is vital for seamlessly integrating various components. The environment should support configurable sensor models, including radar, lidar, and cameras, and allow their connection to the device under test (DUT) in both Hardware-in-the-Loop (HIL) and Software-in-the-Loop (SIL) configurations. Furthermore, it should enable the integration of third-party sensor and vehicle models, support various automotive bus simulations like Ethernet, CAN, and FlexRay, and meet specific datacenter requirements. High levels of automation and scalability in the system are also essential for ensuring efficient and effective development and testing processes.

## Parameter Variation

Parameter variation is crucial for evaluating the capabilities of virtual testing platforms for ADAS. It focuses on the platform's ability to handle extensive computational tasks and the flexibility of its algorithms for sampling and data processing, covering a broad evaluation space. Key elements include support for parallel computing, which allows for efficient execution of multiple simulations simultaneously, and sophisticated orchestration capabilities to manage these tasks. The platform should employ advanced sampling algorithms to effectively explore a wide range of parameter variations and scenarios.

## Performance

The efficiency and speed of the platform in executing simulations and processing data are significant factors when comparing platforms. Key performance indicators include the real-time factor, which measures the ability of the platform to perform simulations in real-time or faster. Here methods such as parallelization or adaptable search-space algorithms can be implemented to handle the increasing computational demand of a sophisticated parameter variation. Visualization capabilities are also important, as they allow users to view and interpret simulation results effectively and make them human interpretable. The platform should support integration with third-party visualization tools, such as Foxglove, to enhance data representation. Additionally, the utilization of GPUs and the requirements for CPU and RAM resources are critical for ensuring smooth and fast simulations. The platform should also support data replay and data-driven development, enabling users to analyze past simulations and continually improve system performance.

## Integration

This element focuses on the platform's ability to seamlessly integrate with various system components and external interfaces. Key elements include methods and interfaces for System-under-Test (SuT) integration, ensuring that different systems and modules can be tested cohesively. The platform should support the integration of Instruction Set Simulations (ISS) and processors, enabling detailed and accurate testing of hardware components. Additionally, it should support various levels of Virtual Electronic Control Units (V-ECUs), facilitating comprehensive testing of electronic systems. The ability to integrate multiple SuTs and manage their communication is also crucial for ensuring that complex systems can be tested in a coordinated manner.

## Maturity and Availability

A mature platform will have extensive capabilities to handle continuous testing over extended periods, ensuring robustness and reliability of ADAS functionalities. Availability refers to the platform's accessibility and operational readiness, including support for varied testing needs and scalability. Companies offering platforms with advanced maturity and high availability in endurance testing demonstrate their commitment to providing stable, effective tools for developing and validating ADAS systems under demanding conditions. Previous or existing demonstrative integration of tools with OEMs or Tier 1 Suppliers is a strong indicator to a potential successful integration with a potential new technological stack.

The comparison of platforms based on these key factors enables stakeholders to select solutions that align with their testing and development needs, acting as the missing piece to complete their toolchain. These criteria have been meticulously gathered through ongoing discussions with OEMs, providing insight into the critical technological requirements they prioritize. Each criterion outlined offers a multi-faceted perspective for analysis, offering both a high-level overview and deeper insights. In the figure below (Figure 1), the sub-criteria are detailed and visually represented. For a comprehensive evaluation, the accompanying Excel file in the study provides an in-depth breakdown of these sub-criteria, offering further clarity and understanding.

# 04. Research and Comparison Criteria


Figure 1: Each of the presented comparison criteria is further subdivided into specific technical aspects that must be carefully considered to ensure a comprehensive and thorough analysis.

# 05. Methodology, Structure and Process

In this study, we explored two key dimensions: the technologies essential to the digital homologation process, which served as the foundation for our research and comparison criteria, and the industry segments and companies that excel in these areas.

Our information was gathered from publicly available sources and compiled into a detailed table (see attachments), focusing on the highlights and specialties of each provider's services.

We selected standout companies from each industry segment and requested interviews to gain deeper insights. These included AWS as a hyperscaler, dSPACE and Ansys as tool providers, AAI as an newcomers, and Bosch as a Tier 1 supplier. Each company contributed to their segment of the table, and individual interviews were conducted where they provided live demonstrations of their technologies. Following the demos, we engaged in a Q&A session to further explore what makes each company unique. See page 20 and 21 for the list of the interviewed players. In the appendix there is a complete list of all key market players.

Through this process, we refined and extended the key differentiators on two levels, providing readers with a concise overview of the individual strengths of each company. This comprehensive analysis will also be presented at ELIV 2024.

We would like to stress again, the information and comparative analysis presented in this study are based solely on claims made by providers. We have not independently tested or verified the functionality, quality, or accuracy of the capabilities or claims. All insights were gathered through personal interviews with one or more representatives from each automotive OEM, supplier, or toolmaker or publicly made information.



# 06. Review of Providers

## 6.1 Examined Providers

This section offers an overview of the leading providers within the ADAS/AD ecosystem, organized into distinct segments according to their roles and contributions. Each segment emphasizes the providers' unique capabilities and innovations, showcasing their impact on the industry and relevancy in the complete digital homologation technology chain. Some OEMs already have comprehensive solutions in place, integrating the building blocks from simulation companies. Others only have partial solutions that still need to be fully incorporated into the overall digital homologation ecosystem. Meanwhile, there are OEMs that currently have no solutions at all and are unable to serve the market.

### 6.1.1 Tool Providers (Traditional)

The tool provider cluster is composed of well-established businesses known for their expertise in specialized areas. These organizations offer advanced tools and solutions that support the design, simulation, and testing of ADAS/AD systems, working in close collaboration with OEMs and Tier 1 suppliers. While their expertise may be focused on specific areas, they may excel in delivering specialized services, making them invaluable partners for companies seeking tailored, cutting-edge solutions.

#### Ansys

Ansys is a US-based engineering simulation software provider with over 50 years of experience. Their diverse product portfolio includes tools for structural analysis, fluid dynamics, electromagnetic fields, optics and more. In January 2024, it was announced that Synopsys would acquire Ansys. Within the autonomous vehicles sector, Ansys supports safety by design and validation, simulating ADAS/AD while complying with ISO26262 and AUTOSAR standards. With years of experience in the industry, Ansys has established themselves as go-to partners and the gold standard in safety and SOTIF (Safety of the Intended Functionality). Their expertise lies in utilizing high-fidelity physics simulations, which are essential for achieving accurate sensor realism. In scenario testing, they offer extensive parameter exploration and fidelity optimization to ensure comprehensive coverage of the required representation space, all within feasible timescales. This is further enhanced by large-scale parallelization, enabling thorough testing without compromising on speed. Their entire platform is based on a model-driven approach, allowing seamless integration and collaboration with external partners through adaptable, complex system models. Demonstrating a strong commitment to collaborative development, these providers have already delivered successful, industry-ready projects in cooperation with multiple OEMs and Tier 1 suppliers, including notable collaborations with BMW. Ansys covers the Safety by Design to Safety by V&V with different tools with APIs. Main tools they offer are: Medini (Safety analysis), DSM (Digital Safety Management based on MBSE system architecture), AVxcelerate (scenario based testing) and Tool suites (HFSS, SPEOS, Zemax) for Sensor development.

#### dSPACE

dSPACE was founded in 1988 as a spin-off from the University of Paderborn, Germany. The company is an innovation leader in simulation and validation technology. Their solutions include data logging, annotation, replay, sensor simulation, and scenario-based testing for safe autonomous driving. With a long-established position in the market and deep integration within the automotive sector, dSPACE has solidified its reputation as the gold standard for verification and validation. Particularly in the area of X-in-the-Loop, they not only support a wide range of interfaces but also have own integration with tools like Aurelion. They offer a wide Range of Scenarios in multiple Standarts like NCAP, CCRb, CCRm CCRs, LSS, VRU with their additional Variants.

### 6.1.2 Tool Providers (Newcomers)

Newcomers are organizations that have been founded recently or employ novel technologies, such as AI, to advance their simulation platforms. These companies introduce fresh perspectives and innovative approaches to the automotive industry. These innovations are particularly evident in the fields of map extraction and scenario generation, which are essential for accurately simulating the challenges a function will encounter when deployed in real-world driving conditions. Companies in this space are focused on overcoming critical hurdles, such as generating a diverse range of novel scenarios while maintaining high-fidelity representations.

### aiMotive (aiSim / owned by Stellantis)

aiMotive is a Hungarian-based company specializing in automotive technology. Acquired by Stellantis in 2022, aiMotive offers the three key products aiSim, aiWare and aiData. aiSim is a dynamic virtual environment that is inspired by aviation industry testing practices. It utilises 3D data for testing and evaluation, indicating a commitment to innovative approaches in ADAS/AD testing. aiWare is purpose-built AI acceleration IP, addressing the automotive industry's need for specialized hardware for AI tasks.
The third offering, aiData launched in 2022, providing sophisticated data processing tools for AD development.

### Applied Intuition

Applied Intuition is an ADAS/AD tooling provider, headquartered in Silicon Valley. Their software solution supports automakers, Tier 1 suppliers and companies spanning across different sectors. By offering a comprehensive environment for simulation, development, and validation of ADAS/AD-systems, Applied Intuition has a strong focus on safety functionality. Beyond the automotive industry, Applied Intuition's mission extends to everything that moves, including construction equipment, trucks, and military vehicles.

### Automotive Artificial Intelligence (AAI)

AAI, a Germany-based company, was founded in 2017 with a mission to provide safer and faster development of highly automated driving. AAI's approach is centred around a comprehensive virtual environment that enables early, efficient, and secure testing for ADAS/AD. Dynamically generating traffic scenarios from high-definition maps and emphasizing a holistic synthetic world, allows AAI to create diverse and realistic testing environment for ADAS/AD development. They accomplish this by building their scenario portfolio on real-world driving data and sensor recordings, which are then enhanced with synthetic data to expand coverage and complexity. This approach allows for a highly accurate but information rich simulation environment. AAI is a relatively new player in the market but has shown remarkable growth and rapid development in recent years. While they have not yet implemented their technologies with OEMs or Tier 1 suppliers, their services in scenario management, data management, test methodology, and scenario generation are already TÜV certified. These certifications highlight their commitment to quality and differentiates them from other competitors. Additionally, they offer an end-to-end platform with one cohesive GUI Interface that is still modular and can support an external adaptable toolchain.

### Cognata

The large-scale simulation platform provider Cognata is headquartered in Israel. Their platform is offered to users across various industries, including construction, mining, defense, agriculture and autonomous vehicles. Cognata's platform provides a robust environment for safety testing, performance assessment, and validation of autonomous systems. OEMs benefit from Cognata's focus on compliance with safety regulations, ensuring the development of reliable ADAS/AD solutions.

### MORAI

MORAI, a South Korean technology company founded in 2018, specializes in simulation platforms that verify the safety and reliability of autonomous vehicles along each step of the vehicle development process. Their suite of autonomous driving simulation solutions includes core simulation engines, making them a key player in the self-driving industry.

The company was established by former researchers from the Korea Advanced Institute of Science and Technology (KAIST), leveraging their expertise in autonomous systems and simulation technology.

## 6.1.3 Tier 1 Supplier

Tier 1 suppliers are essential to the automotive industry, particularly in developing advanced technologies like autonomous driving. They provide critical components and systems directly to OEMs, and their close collaboration is key to ensuring the safety and performance of these technologies.

As the industry embraces digitalization, Tier 1 suppliers become even more vital in digital homologation ecosystems. They develop core components—such as sensors and software—that must be tested in close cooperation with OEMs. This joint testing is crucial to ensure components meet both performance requirements and regulatory standards before integration into final vehicle designs.

In a digital homologation setup, real-time data sharing, simulation, and collaborative testing accelerate validation, making processes more efficient and helping meet global regulations. As autonomous technology advances, the coordinated efforts of Tier 1 suppliers and OEMs will become even more critical, cementing the suppliers' role in the future of vehicle development.

### Bosch

Founded in 1886, the Bosch Group is a leading global supplier of technology and services and with Bosch Mobility one of the leading mobility suppliers. Bosch is developing the connected and automated mobility of the future. To this end, the company has in-depth know-how in electronics and software.
Bosch is a technology leader in the field of driver assistance, that laid the foundation for all stages of automation at an early stage with driver assistance systems and the associated sensor technology. To make driving safer and more relaxed, Bosch is focusing on the development of driver assistance and automated systems for private vehicles (SAE Level 1-3) and is pursuing a sequential development approach in this field.
Bosch offers its customers a comprehensive portfolio of solutions for ADAS in the field of driver assistance and automated driving, from hardware in the form of reliable exterior and interior sensors, vehicle computers, and control units to software-based driver assistance functions and cloud solutions for optimizing onboard functions. In the field of testing and simulation for automated driving functions Bosch established a set of qualified tools that can scale to different complexity levels. The deep system knowledge across all vehicle domains as well as access to sensor data from various sensor modalities is a unique advantage Bosch brings into the field.

## 6.1.4 Chip Manufacturers

Chip manufacturers provide the hardware that powers ADAS/AD capabilities. They design and produce the silicon, that allows for the complex computations required.

### Nvidia

Nvidia, founded in 1993, is a pioneering US-based technology company specializing in graphics processing units (GPUs) and artificial intelligence (AI). While Nvidia is best known for its leadership in high-performance GPUs, it has also developed dedicated platforms for advanced driver-assistance systems (ADAS) and autonomous driving (AD). Nvidia's DRIVE SIM platform offers a comprehensive suite of hardware and software solutions, specifically designed to support the development and deployment of autonomous vehicles. Access to the DRIVE SIM Platform is currently limited to existing Nvidia Partners.

### Qualcomm

Founded in 1985, Qualcomm is an American company, specializing in semiconductors, software and services related to wireless technology. Within ADAS/AD development, Qualcomm offers the Snapdragon Ride Platform. The platform is designed to support the evolution of software-defined vehicles and includes foundational elements, including advanced process nodes, vehicle control and data and cloud services. Developers benefit from AI-based applications and tools, enabling the creation of safer end-to-end solutions. The platform further offers a range of SoCs that are optimized for ADAS & Cockpit integrations. Qualcomm works directly with their costumers together and adapts their solutions to their client needs,. They do not currently offer any toolchains or services to the broad market.

## 6.1.5 Hyperscalers

Hyperscalers are major cloud service providers that offer vast computational power and advanced technologies to support a wide range of industries. In the context of safety-critical ADAS/AD systems, these providers play a pivotal role by enabling the extensive simulation capabilities required for comprehensive safety assessments. With their ability to facilitate large-scale parallelization and integrate complex, multi modular verification and validation processes, hyperscalers are indispensable for advancing the rigorous and computational demanding testing environments needed in autonomous driving technologies. It's important to note again that while these providers don't offer digital homologation directly but supply essential technologies.

### Amazon Web Services (AWS)

AWS, founded in 2006, is a leading US-based cloud technology provider. While AWS does not specialize in dedicated ADAS/AD simulation platforms, it excels in purpose-built cloud capabilities and leverages Gen-AI-powered platforms. These technical capabilities enable AWS to support a wide range of solutions, ranging from software-defined vehicles to connected mobility and autonomous driving. Their extensive range of services has positioned AWS as an essential partner in the automotive industry. This is evident through their numerous successful collaborations with OEMs and Tier 1 suppliers, both past and ongoing. These partnerships highlight their adaptability to the evolving ADAS/AD technology stack, as well as the maturity and reliability of their solutions.

### Microsoft Azure

Microsoft Azure, launched in 2010, is a leading US-based cloud computing platform that offers a comprehensive suite of services and solutions. While Azure is not exclusively focused on ADAS/AD simulation, it provides a wide array of purpose-built cloud capabilities, including advanced AI, machine learning, and data analytics tools. These features enable Azure to support various automotive solutions, from software-defined vehicles to connected mobility and autonomous driving.

## 6.2 Results of this study

Compiling the results of this study, we look into the five dimensions introduced earlier.

### Platform

Initially, the platforms were analyzed, focusing on various workflow management areas such as test management, scenario management, data management or Integration into CI/CD pipeline. Most of the providers have robust test, scenario and data management features embedded. Furthermore, compliance guidelines for safety according to the ISO26262 is prevalent across most providers in this study. Most businesses provide a solution which is integrable into CI/CD/CT pipelines. Notable, AAI excels in safety complience in their Platform, they provide scenario managment technologies according to ISO34502. Additionally they have achieved TÜV Certification for their Products in Scenario Management, Data Management, Test Methodology, and Scenario Generation. Furthermore, dSPACE stands out with an extensive test management. AWS is limited by offering only the Cloud aspects of the Platform but has proven itself to be a reliable Partner through extensive past and current cooperations. Ansys and Bosch provide multiple tools in the workflow, bit they are accessible with open APIs. Bosch's advanced tools used in series projects have earned ISO26262 certification, with significant experience qualifying new tools as they are developed

### Scenario Generation

Most of the examined providers offer user-defined scenario simulations with varying levels of customization. Further, all providers offer function-based and automatic scenario generation and leveraging real-world data from training drives is common. However, some providers differentiate through the depth and diversity of their training dataset. Most providers adhere to industry standards (such as PSV, ODR, and OSI) in their scenario generation processes. ASAM has been strongly established as industry trend for Scenario descriptions and has been integrated by nearly all companies.

AAI has shown extensive capabilities and milestones for each scenario within this segment, integrating new AI methods to adaptably extend the scenario and representation of information.

### Maps & ODDs

The criterion of Maps & ODDs investigates multiple aspects, including coverage, function-based ODDs, route-based maps, automation, maps for parking simulation, and NDS support. AAI stands out, having shown impressive advancements in the area of automation, route-based maps, function-based ODDs etc., which underlines their functional capabilities in simulation and automation areas.

### Infrastructure

On the infrastructure level all providers have solutions based on cloud native services. Additionally, some providers have on premises resources for simulation engines for testing purposes, which continues to be a the industry trend. Many providers are using different tools for editing, data analysis or visualization purposes. However, AAI stands out with their diverse set of different tools for editing and visualization purposes. Ansys has shown high capabilities to modularize their toolchain and adapt it quickly to external needs and software modules, while maintaining a cohesive configurable interface.

### X in the loop

Most providers offer embedded software, hardware and module in the loop. dSPACE hereby has shown extensive capabilities in software, module, hardware and vehicle in the loop, standing out in the overall results of this analysis. They are able integrating their own experience in Hardware and Software development to tailor their toolchain to requirements and industry standards.

### Environment

The environment considers system compatibility, sensor and vehicle models, automotive buses, special datacenter components, and scalability. Within this domain, data availability is limited, with dSPACE being the only provider offering comprehensive insights. Most providers offer configurable sensor models and support for camera and lidar. Additionally, some companies, including aiMotive, MorAI, dSPACE, Ansys, and Bosch, offer a wider range of sensors such as radar, ultrasonic, GPS, IMU, and thermal cameras. Furthermore, most providers allow for the integration of third-party sensor and vehicle models. Taking the limited data availability into consideration, dSPACE shows strong capabilities in the number of different type of sensors being available (e.g., radar, lidar, cameras) and offers robust sensor connections to the device under test environment (HIL and SIL).

### Parameter Variation

Regarding parameter variation, most of the providers have integrated advanced simulation options based on a high degree of parameter variation. Cognata stands out as they integrate sampling algorithms to increase the degree of parameter variation.  Ansys has shown an already capable and extensive Scenario perturbation module, necessary for generating high fidelity but representative scenarios.

### Performance

Many providers offer real-time factors with high-fidelity cameras or sensor simulation to collect real-time data. Only a handful of providers have visualization tools embedded in their systems. For instance, dSPACE offers different 3D tools for visualizing purposes and Ansys operates a self-developed / self-deployed visualization tool. Ensuring the deployment of real-time factors like sensors or cameras, demands the usage of GPUs. Most of the providers have GPUs in deployment to ensure real time data processing. A performance highlight is the data replay and data-driven development of dSPACE, being the sole provider having embedded a sophisticated solution for data replay. Overall, most of the players have established extensive capabilities to ensure a high degree of scalability and performance. Most of the investigated providers create their own synthetic maps with a few players, such as MorAI differentiating themselves by including digital twins or global coverage across different continents, like AAI. An additional differentiating factor is the variety offered within function-based ODDs, with dSPACE and AAI showcasing compelling offerings. dSPACE further distinguishes itself by providing real-time data-driven maps. Conversely, a significant number of players do not offer route-based maps. In the development and validation process, the majority companies leverage automation to enhance efficiency and reliability. Additionally, maps for parking simulations, a critical aspect for urban mobility, are incorporated by most actors. Furthermore, it is assumed that most providers offer NDS-support. Ansys and dSPACE showed high capabilities in optimizing their simulation cases by high scale cloud-based parallelization, which is necessary for a thorough exploration of the verification space while maintaining reasonable testing intervals.

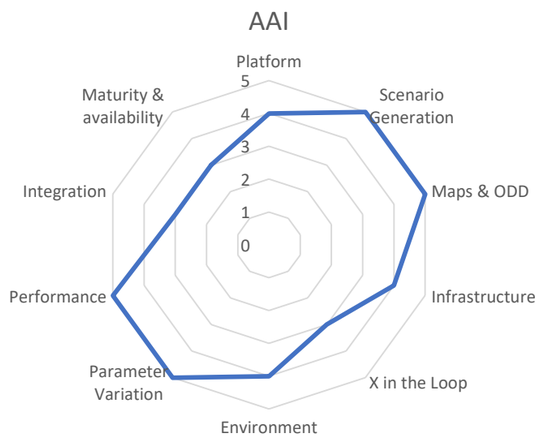
### Integration

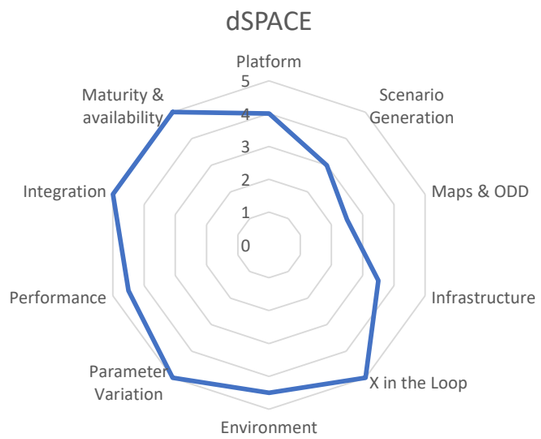
The integration dimension examines criteria such as homologation, methods and interfaces for integrating the system-under-test (SuT), and the integration of instruction set simulation and processors. Additionally, it evaluates the supported levels of V-ECUs and the communication and integration of multiple SuTs. Except for MorAI, where no information was accessible, all providers offer homologation processes, with dSPACE highlighting its ISO 26262 certified toolchain. Furthermore, only AAI and dSPACE provided information on supporting the integration and communication of multiple SuT. Cloud services are integrated by nearly all the providers we examined. It is important to differentiate of the product the companies offer are not only cloud compatible, but also run locally or offer hybrid approach.

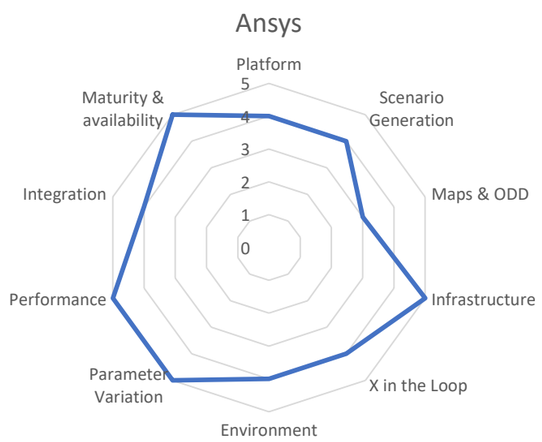
### Maturity & Availability

The solution availability of the investigated providers was assessed based on their maturity and availability, and the provision of endurance testing. Most providers, including AAI, aiMotive, dSPACE, and Ansys, offer endurance testing, demonstrating their capability to support robust and reliable ADAS functionalities. Additionally we investigated past and current implementations in the market, as it is important to differentiate in maturity between products that are "ready to use" and are already "in use". dSPACE, AWS and Ansys need to be highlighted, as they have shown the most impressive maturity and availability in this analysis, already having existing cooperation and technical integration with OEMs and Tier1 suppliers today in the market.

# 07. Key Differentiators



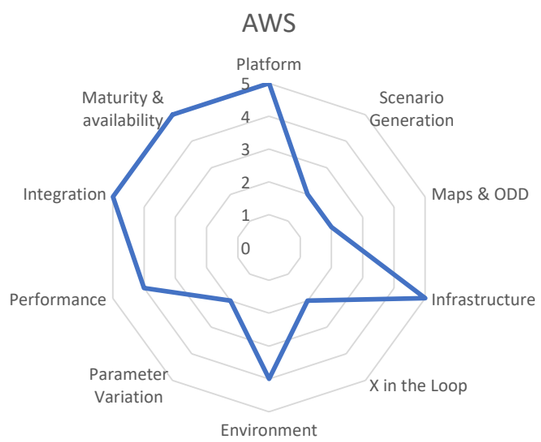




Figure 2: Plots only based on interviewed companies

# 07. Key Differentiators

| CRITERIA | AAI | ANSYS | AWS | dSpace |
|---|---|---|---|---|
| **Platform** | Workflow in one Tool with APIs and one GUI. | Workflow in different tools with open APIs. | Workflow in different tools with open partner APIs. | Workflow in different tools with APIs. |
| **Traffic Scenarios** | Customized scenario with AI-Driven Traffic Models. | Customized scenario portfolio with support of AI/ML traffic. | Via partner | Customized scenario portfolio and 3rd Party AI capability. |
| **Maps & Odds** | Real-world and synthetic map with ODDs coverage based on sensor data. | Real-world and synthetic map with ODDs coverage. | Via partner | Real-world and synthetic map coverage with ODDs coverage. |
| **Verification & Validation** | Camera and lidar - Parameter variation for scenarios and dynamic adaptability.<br>SiL ☑ MiL ☑ HiL ☐ ViL ☐ | Camera, lidar, and radar including physical models - Parameter variation for edge case scenarios with parallelization.<br>SiL ☑ MiL ☑ HiL ☑ ViL ☐ | Primarily Cloud – Rest of the Car systems integrated via partners.<br>SiL ☑ MiL ☐ HiL ☐ ViL ☐ | Camera, lidar, radar and Ultrasonic - Parameter variation algorithm for critical scenarios with parallelization.<br>SiL ☑ MiL ☑ HiL ☑ ViL ☑ |
| **Safety/Security Certification** | TÜV Certified<br>Compliance SOTIF and ISO 34502. | Compliance with ISO 26262 and other safety standards. | Shared responsibility model for safety compliance. | Compliance with SOTIF and ISO 26262 and certified for ASIL-D. |
| **Maturity and Availability** | Ready to use by customers. | Already in market products. | Ready to use by customers. | Already in market products. |

# 08. Conclusion

The study demonstrates that simulation platforms are indispensable in the development and homologation of ADAS and AD technologies. As the complexity of these systems increases, traditional testing methods are becoming insufficient. Traditional testing and validation through physical test drives are no longer sufficient—it's time-consuming and costly! Simulation frameworks offer faster, more cost-effective, and scalable solutions that significantly reduce the time-to-market for advanced driving systems. By automating scenario generation and integrating real-world and AI-driven traffic data, these platforms enable comprehensive testing that enhances the reliability and safety of ADAS/AD functions. In our analysis and discussions with companies, several outstanding solutions have emerged. The key was to identify the unique strengths of each, which are shaped by their histories, the technologies they've developed, and their current positioning in the market.

The leading players in this domain differentiate themselves through **advanced scenario generation, integration capabilities**, **and compliance with industry standards**. Their ability to offer **real-time, data-driven testing environments, high-performance computational tools**, and adaptable cloud-native infrastructures sets a new standard for OEMs aiming to stay competitive in the rapidly evolving automotive market.

**Digital homologation**, driven by these simulation platforms, not only ensures regulatory compliance but also supports innovation, reducing the overall development cost while improving safety and functionality. Thus enables:

- **Accelerated Development Cycles:** By integrating advanced simulation platforms, OEMs can drastically shorten development timelines through rapid prototyping and iteration, moving from traditional testing to faster digital homologation. It is especially important to integrate simulation in the early stages of development to identify weak spots and drive development in the right direction.
- **Cost Efficiency:** Simulation tools reduce reliance on real-world testing, leading to significant cost savings. With reduced physical testing and faster scenario generation, development costs can be minimized.
- **Regulatory Compliance:** Platforms offering digital homologation align with industry standards (ISO 26262, ISO 34502), helping OEMs meet regulatory requirements more efficiently and maintain high safety standards.
- **Scalability and Flexibility:** The ability to run diverse, complex scenarios in parallel ensures that OEMs can meet the growing demands of ADAS/AD systems, especially for Level 3+ autonomous driving, without the bottlenecks of traditional methods.
- **Competitive Advantage:** Leveraging state-of-the-art platforms enables OEMs to stay ahead of competitors by introducing innovative, well-validated systems faster and at lower costs, ensuring market leadership in the race for autonomous vehicles.



# 09. Key Take-Aways for OEMs

For OEMs, the shift towards digital homologation and simulation-driven development presents both challenges and opportunities. Here's what comes next:

### 1. Adoption of Full-Scale Digital Homologation:

OEMs must transition to fully embracing digital homologation to meet the increasing complexity and regulatory demands of ADAS and AD systems. This will require investments in high-fidelity simulation tools that enable real-world scenario replication at scale. As regulations evolve, OEMs will need to stay aligned with international standards, such as ISO 26262 and ISO 34502, ensuring that their Verification and Validation processes are robust and compliant.

### 2. Partnerships with Key Technology Providers:

Collaborations with leading simulation platform providers will become essential. OEMs will need to partner with companies that offer comprehensive solutions spanning scenario generation, cloud integration, and V&V (Verification and Validation) capabilities. Establishing strategic alliances with simulation leaders such as dSPACE, AAI, and other key players in the hyperscaler, chip, and function domains based on each one's key differentiators and power will enable OEMs to access cutting-edge technologies that streamline the development and validation processes for the SDV (software defined vehicle) era of an E2E vehicle/feature development to vehicle/feature homologation for the vehicle SOP and the frequent feature OTA updates.

### 3. Investing in AI and Data-Driven Testing:

Without AI and data analytics a sufficient and complete simulation is not possible. OEMs should integrate AI-driven scenario generation and data analytics into their simulation processes to enhance testing accuracy and identify edge cases that may not be captured in traditional tests. This approach can improve system robustness and accelerate the validation of ADAS and autonomous driving functions. Especially the newcomers have demonstrated their strength in utilizing AI, particularly Generative AI, to synthesize and enhance street layouts and map data. Their innovative use of these technologies is pushing the boundaries of what's possible in simulation, setting new standards for the industry.

### 4. Enhancing In-House Capabilities:

OEMs need to develop internal expertise in digital homologation and simulation technologies. Building in-house teams capable of managing and optimizing these platforms will be crucial for maintaining control over the development pipeline and ensuring that digital tools are fully leveraged to their potential.

### 5. Continuous Innovation and Agile Development:

The automotive landscape is evolving quickly, and OEMs must adopt agile development frameworks that allow for continuous updates and iterations. Simulation platforms integrated into CI/CD (Continuous Integration/Continuous Delivery) pipelines will enable ongoing improvements and quicker response to market demands or regulatory changes.

### 6. Focus on Cybersecurity and Data Integrity:

As OEMs increase their reliance on digital tools, ensuring data integrity and cybersecurity will become even more critical. Simulation platforms will generate and process massive amounts of data, which must be securely managed. OEMs will need to implement strict data governance and cybersecurity measures to protect intellectual property and ensure regulatory compliance.

### 7. Leveraging Cloud and Edge Computing:

To meet the growing computational demands of real-time, large-scale simulations, OEMs must embrace cloud-native infrastructures and edge computing solutions. These technologies will allow for scalable, high-performance simulations that can process data efficiently, even in complex ADAS/AD environments.

### 8. Standardisation:

A broad trend towards standardization is not yet visible, though such a shift would significantly accelerate market development and foster collaborative innovation. So far, only in the area of maps is a trend towards ASAM standards emerging. The time for full standardization has not yet arrived, as OEMs remain competitive and act independently in their approach.

By focusing on these areas, OEMs can position themselves at the forefront of automotive innovation, ensuring that they remain competitive and responsive to the evolving needs of the autonomous driving market.

| | | TOOL PROVIDER (TRADITIONAL) | | TOOL PROVIDER (NEWCOMER) | | | | |
|---|---|---|---|---|---|---|---|---|
| | *FULL NAME* | DSPACE | ANSYS | AUTOMOTIVE ARTIFICAL INTELLIGENCE | APPLIED INTUITION | COGNATA | MORAI | AIMOTIVE |
| | *COMMENTS* | BASED ON INTERVIEW | BASED ON INTERVIEW | BASED ON INTERVIEW | | | | SOLD TO STELLANTIS |
| **PLATFORM** | | | | | | | | |
| **WORKFLOW MANAGEMENT** | Test Management - ISO 34502 | dSPACE supports efficient automated testing of autonomous vehicles in accordance with **SOTIF, based on the ISO 26262 certified V&V and cloud-native platform SIMPHERA**. Test management is realized by a robust and easy organization of test cases within test suites that can be configured seperately to be executed on different test environments for example. Additionally **it is possible to link every test case to requirements**, that are typically handled within application lifecycle tools like Codebeamer or doors. This linkage of the test cases to the requirements then automatically links the respective results of the test cases to the same requirements in the ALM system. This ensures full tracebility from the requirements to the test case results and enables test coverage analysis. | Ansys AVxcelerate is a cloud native tool providing a major piece for the pervasive toolchain for Autonomous Vehicle software stack validation. Ansys AVxcelerate contains several applications to serve this goal. Thansk to API, and Ansys AVXcelerate enables connection to requirements tools (like Doors or Codebeamer) as well to MBSE Safety environment (like Ansys Medini and Dgitial Safety Manager) | AAI provides a highly advanced, reliable toolchain designed for comprehensive simulation and testing, focusing on seamless integration of test management and endurance testing capabilities. The AAI toolchain is TüV certified, adhering to the highest industry standards, ensuring both quality and reliability in every aspect of its operation.<br><br>This certification underscores our commitment to delivering a top-tier solution that supports traceability from requirements to test reports, facilitating collaborative development and full compliance across ADAS and automated driving validation projects. Our toolchain also enables the creation of digital twins using sensor data, allowing for the continuous validation of evolving scenarios. AAI remains at the cutting edge of automotive simulation technology, offering flexible solutions that adapt to the changing needs of the industry while ensuring adherence to the most stringent standards for automated driving systems. | Offers tools for simulation, development, and validation, likely including test management. | supports the lifecycle of AV testing, indicating robust test management. | express realistic movements within the virtual simulator environment | comprehensive environment for ADAS/AD validation, indicating robust test management. |
| | Scenario Management - ISO 34502 | SIMPHERA allows the management of driving scenarios for development and testing of autonomous vehicles. The use of tagging and parameter variations allows the mapping to related ODDs and broad test coverage. **dSPACE is able to offer a wide range of standard scenarios for the validation of automated driving functions and ADAS systems like NCAP or ALKS scenarios** for example. They can be organized in diffenrent projects or test suites to use them for the validation of different software stated and variants. | Ansys Avxcelerate offers a Logical Scenario Manager based on ASAM openScenario XML.<br>The tool enable to import logical scenario and define parameter space variations. | AAI offers a comprehensive simulated environment in full compliance with ISO 34502 standards, emphasizing strong capabilities in scenario management.<br><br>The AAI toolchain is TüV certified, not only for its overall simulation and testing capabilities but explicitly also for its scenario management features. This certification highlights AAI's ability to deliver high-quality, reusable, and customizable scenarios, enabling efficient and consistent validation across ADAS and automated driving systems. Our platform supports flexibility in scenario generation and management, ensuring robust solutions for Verification and Validation (V&V) processes. | Provides simulation and testing tools, indicating robust scenario management. | Offers a simulation platform that includes scenario management. | includes the core simulation engine | Offers ADAS Tutor for teaching drivers ADAS functionalities, suggesting scenario management capabilities. |
| | Data Management - ISO 34502 | dSPACE offers a data management tooling that allows management of large ADAS/AD datasets. **The tooling supports hybrid-cloud setups, i.e. a combination of on-premises and public cloud (e.g. AWS, MS Azure,...) data storage and compute**, for cost effective data handling. Furthermore it provides unique data-insight capabilities to index and tag the data (e.g. AI-based object- or scenario-detection). Appropriate interfaces to 3rd party tools, like Codebeamer, give further capabilities for traceability and ALMs. | All data manageed by Ansys Avxcelerate have unique ID and version. In that way, traceability and safety evidence are ensure. Avxcelerate can connect to Ansys Minerva which enable complete data management. | AAI provides a complete suite of data management solutions, extending beyond annotation services to excel in data curation, ensuring data quality and relevance for testing and validation purposes. Using certified methods under ISO 34502, AAI offers a structured, efficient, and scalable approach to handling vast data sets, crucial for the development of ADAS and automated driving systems. Our platform enables seamless integration of data annotation, curation, and management to support robust scenario management and real-time simulations | Re-simulate the identified real-world logs to understand your AV stack's performance and determine necessary adjustments | Powerful Python scripting capability | Data acquisition and annotation to then be able to simulate and generate reality-like scenarios | Focuses on handling complex data for ADAS/AD systems. AINotate |
| | Analytics - Safety Arguments | **SIMPHERA includes analytics features for safety argumentations, incl. Customizable KPI calculation and evaluation**. There are different options for result analysis. E.g., the user can directly look into calculated observers and KPIs in the validation part of single test cases. F**or more detailed result analysis, dedicated Apps within SIMPHERA are available.**<br>For the management of customers code like for example the functional code of the system under test, SIMPHERA offers a connection the GIT as the typical development and versioning system used in such applications. This allows our customers to track which simulation or test case execution was done with which version of their system under test. This allow to track if the system under test improves over the versions upto a possible version that is sufficient to be homologated. | Ansys Medini, Digital Safety Manager and Avxcelerate provide a complete analytics set of features in order to build and continuly update the Safety Case. | AAI delivers a comprehensive and user-friendly approach to analyzing data from simulated test runs or digital representations of physical test drives, using interactive dashboards. AAI offers full support for all NCAP catalogues, including the latest General Safety Regulation (GSR 2) standards for Intelligent Speed Assist (ISA), ensuring compliance with cutting-edge safety requirements. Our platform enables detailed analysis and reporting across all critical safety and performance metrics, making it an invaluable tool for the development and validation of ADAS and autonomous driving technologies. | Offers analysis for Euro NCAP tests, which may include safety arguments. NHTSA, ALKS | Provides a platform for safety testing and regulations, including analytics for safety arguments. | | Euro NCAP standards including ALKS, ACC, Lane Keeping and many additional AD functionalities |
| | Safety - ISO26262 compliant | **SIMPHERA and the underlying tools, like ASM (vehicle dynamics & traffic) and AURELION (3D & physics-based sensors), are certified for ISO-26262 for all ASIL by TÜV Süd Germany.**<br>The use of back-to-back tests for different versions of the system under test in different test environements like software-in-the-loop and hardware-in-the-loop within the dSPACE toolchain with SIMPHERA further improves the efficiency of the homologation process at our customers. Since dSPACE provides every single piece of the toolchain, we can make sure that this process is supported from the models, the simulation environment and the validation tools themseves. | Ansys solutions are ISO 26262 certified software with a certificated provided by TÜF SGS. Ansys solution implement the Safety by Design and Validation methodology with extensive support of NATM, ISO TS 5083,NHTSA, EURONCAP, UNECE standards. | AAI prioritizes safety and efficiency by fully supporting automatic export of requirements from systems like Doors or CodeBeamer using the ReqIF standard. Additionally, AAI offers a comprehensive view in Model-Based Engineering, leveraging SysML 2.0, which forms the foundation for ISO 26262 compliance.<br>This unique, holistic platform has integrated all chapters of ISO 26262 as Large Language Models (LLMs) directly within the toolchain. These models guide users through Functional Safety (FUSA) and Safety of the Intended Functionality (SOTIF) perspectives, creating an unparalleled efficiency boost of 100x in the development process. AAI also ensures compliance with TÜV certification, ISO 34502, and ISO 21448 standards, making it a leader in safety-critical systems engineering. | Focuses on safety functionality, suggesting compliance with safety standards. full test suite before merging changes or deploying a new stack version in the field to prevent regressions. certified 26262 | NHTSA and NCAP. support ADAS safety scenarios | Automotive safety integrity level D. provides safer and more reliable V&V process for autonomous system. | Likely compliant, given their focus on safety in ADAS/AD systems. world's first ISO26262 ASIL-D certified simulator tool. TÜV trusted |
| | KPI calulation and evaluation | SIMPHERA enables **custom KPI computation** and visualization on different aggregation levels of the test case hierarchy. **KPIs can be reused** between open and closed loop testing and on the different aggration levels. | Ansys Avxcelerate is provided with a framework that allow user to build their own KPI calculatio. UI enables analyzed of KPI report with customizable graph allows zooming on the situations with highest failure rate . The number of KPIs is not limited. | AAI brings extensive experience in defining and executing Key Performance Indicators (KPIs) for camera and LiDAR sensors, covering critical functionalities such as object detection, hazard recognition, lane detection, and traffic sign identification. AAI's KPIs are actively used by OEMs in their Series Production (SOP) projects across the European market, ensuring compliance with industry standards and delivering reliable analytics.<br>The platform supports comprehensive KPI calculations and assessments, while also enabling the seamless integration of third-party KPIs, making it a trusted tool for evaluating the performance of ADAS and automated driving systems. | Offers analytics that may include KPI calculation and evaluation. | Offers analytics that may include KPI calculation and evaluation. | | |
| | Integration into CI/CD/CT pipelines. | With our partnership with control and the digital loop that we demonstrated with partners like Microsoft, Telekom, the TÜV and others, we are able to automatically extract safety critical and regulatory KPIs from regulations. These KPIs and regulations are then automatically checked during each test execution to make sure, that the driving function is behaving within all valid regulation within its ODD. SIMPHERA can create a digital report that could be used from the authorities for a complete digital homologation process. | Ansys tools integrate with continuous integration, continuous delivery, and continuous testing pipelines.<br>Ansys tools enable to connect software CI/CD with MBSE environment using SysML v2 facilitating sharing and reuse. These pipelines can be on-prem or on AWS / Azure. | AAI provides a scalable testing solution designed to seamlessly integrate with continuous integration, continuous deployment, and continuous testing (CI/CD/CT) pipelines. With extensive pipelines already in place, AAI supports seamless connections with proprietary tools such as dSPACE and IPG, enabling a robust and flexible development environment. This allows for streamlined testing, faster feedback loops, and greater scalability in validating ADAS and automated driving systems. | Provides a large-scale testing solution that may integrate with CI/CD/CT pipelines. | Supports automated testing with Jenkins and Bamboo, indicating integration capabilities. | | Offers integration capabilities for continuous testing and development. complete CI/CD simulation pipeline |
| | Integration into the development enviroment | **SIMPHERA allows the integration and connection to local developer IDEs, like Visual Code**. Thus, function developer can stay in their existing development environment and use SIMPHERA as quality gate test pipelines before committing changes to the code. Debugging features with breakpoints and detailed code analysis is possible, as well. | Ansys Avxcelerate is coming with multi-levels of integration into customer development environment. Can be at system level (via MBSE approach) or at software level (via open closed-loop simulator, APIs, standard compliance…) | | | | | |

| | | TOOL PROVIDER (TRADITIONAL) | | TOOL PROVIDER (NEWCOMER) | | | | |
|---|---|---|---|---|---|---|---|---|
| | *FULL NAME* | **DSPACE** | **ANSYS** | **AUTOMOTIVE ARTIFICAL INTELLIGENCE** | **APPLIED INTUITION** | **COGNATA** | **MORAI** | **AIMOTIVE** |
| | *COMMENTS* | BASED ON INTERVIEW | BASED ON INTERVIEW | BASED ON INTERVIEW | | | | SOLD TO STELLANTIS |
| **SCENARIO GENERATION** | | | | | | | | |
| **SCENARIOS** | **User defined Scenarios** | Scenarios can be created by using the interactive scenario- and road-editors within **dSPACE ModelDesk**. These editors offer interactive methods to define roads (with all required details according to specification, like NCAP with detailed information about lanes, junctions, lane-markings, static objects, …) and scenarios. The behavior of the traffic participants in the scenario is user-defined by a sequence of actions. The tooling also allows a quick, interactive preview of the scenario while creation of the scenario. All scenario actions are fully reproducable and deterministic. | Ansys Avxcelerate came with already imported standard UNECE 157 ALKS scenario. User can import any scenario based on ASAM openScenario XML. | Users gain the capability to customize the 'scenery,' including **thousands of real-world highway and urban maps**, and adjust 'environment' settings to define 'dynamic effects' (static objects) for road users. This flexibility extends to **creating logical and concrete scenarios**, emphasizing our highly automated and efficient approach, setting us apart from other providers. | complex and diverse scenarios programmatically for synthetic simulation and re-simulation | Library of pre-built scenarios for common automated driving functions | Weather and illuminance controls and the auto-annotation function enable the automatic creation of user-specific datasets. | Supports user-defined scenarios in simulation. Users get the ability to define the "scenery" with access to a representative set of thousands of real-world highway and city maps, "environment" and "dynamic effects" |
| | **Function based Scenarios - Automatic** | By using traffic agents in the **ASM Traffic scenario**, random and function-based scenarios can be simulated. dSPACE offers a rules-based traffic-driver model with configurable driver behaviors, like slow or aggressive drivers. In addition, 3rd party traffic flow or AI-based traffic simulations, like SUMO or Vissim, can be connected. | AVxcelerate including API to automatically import scenario from real-world injestion pipeline, scenario catalogue such as SafetyPool or requirement system (CodeBeamer, …) | **Delivers customized simulation solutions** with a strong emphasis on automation. Users have access to a suite of highly automated tools meticulously designed to precisely meet their specific requirements. | Offers simulation and testing for ADAS active safety functionality. OpenSCENARIO-compatible scenario language | Library of pre-built AV and ADAS scenarios for common automated driving functions | generating log-based scenarios | Provides function-based scenario capabilities. ADAS Tutor feature suggests function-based scenario capabilities. function based sensor simulation |
| | **Scenario generation using real-world data** | The dSPACE Traffic Virtualizer tool generates logical simulation scenarios based on real world measurement data. It processes recorded object-lists, GPS/IMU-data and HD-maps and automatically generates the scenarios for simulation that can seamlessly be integrated into SIMPHERA for scenario-based test purposes.<br>dSPACE also offers to process recorded raw sensor data (Lidar point-clouds, Camera images) as a basis for scenario generation. Additionally, dSPACE offers an engineering service to create a full digital twin of the 3D environment of a scenario. | In selected ODD, extracted parameter distribution from fleet data can be utilise as input for scenario variation continous parameter sampling methods. | "AAI utilizes real-world data gathered not only from their own road tests but, more importantly, from **real-world test drives of the customer**. This data, along with their extensive library of 3D shapes, enhances the simulation experience, effectively creating a digital twin." | Generate synthetic datasets to train perception models.<br>Re-simulate the identified real-world logs to understand your AV stack's performance and determine necessary adjustments | Supports testing and validation with a focus on real-world scenarios. Digital twin | test scenario from real world data (Log-based & real world data) | Utilizes real-world data in driver monitoring systems. Simulation of complex sensor setups<br>in real-time |
| | **Artificial Trafficmodels** | ASM Traffic has a native integrated rules-based traffic driver model. In addition, 3rd party tools for random or AI-based traffic, can be connected. | Ansys can offer multi level of traffic simulation:<br>1/ trajectory based as needed for statistical testing exploration<br>2/ rules-based for endurence testing in selected road map<br>3/ AI-based for much heavier traffic condition like in Urban or complect junctions | AAI provides simulation solutions tailored to users' specific known scenario specifications. Additionally, AAI offers traffic models trained using AI for both supervised and unsupervised learning, designed to generate unknown scenarios based on SOTIF (Safety Of The Intended Functionality) principles. | edge cases that are difficult or dangerous to test in the real world | yes, based on user`s needs | included | various weather conditions, set of 3D assets and all related tools needed to set.<br>up a diverse, high-fidelity 3D environment |
| | **Support of Standards (PSV, ODR, OSI) Database for scenarios** | dSPACE tools, like ASM, supports different ASAM standards, like OpenDrive, OpenScenario, OpenSimulationInterface (OSI), XIL-API, …<br>As integration format, FMUs are supported, as well. | ASAM OpenDrive, OSI, OpenScenario XML, SOTIF, functional safety, cybersecurity (ISO 21448/ 21434) | AAI fully embraces and adheres to all ASAM standards for simulation, including OpenDRIVE and OpenSCENARIO, ensuring high compatibility, fidelity, integrability, and flexibility in simulation environments. This commitment allows customers to have the independence and freedom to compose their own solutions within the framework of these standards. | | Supports OpenDrive and OpenScenario standards. | not mentioned | OpenDrive, OpenScenario |
| | **Covered areas areas of simulation** | dSPACE Automotive Simulation Models (ASM) tool suite covers all automotive domains: vehicle dynamics (ESP, EPS, AEB, ASR), traffic (ADAS, AD), powertrain (BEVs, fuel-cell, combustion engines, hybrids), sensors (perception), cars, trucks, buses, on-road, off-road, trains, bikes, … | Ansys is the simulation leader in the industry with strong intiative in automotive trends: SdV, EV and AV. The AVxcelerate slution position for large-scale SiL / vECU testing up-to HiL /ECU with perception | AAI offers a comprehensive simulation platform that holistically covers both the left and right sides of the V-Model, ensuring robust validation and verification at every stage of the development lifecycle. AAI supports Model-in-the-Loop (MIL), Software-in-the-Loop (SIL), and Hardware-in-the-Loop (HIL) environments, enabling seamless co-simulation across various customer applications. Our platform excels in accurately modeling sensors, vehicle dynamics, and powertrains, delivering reliable and precise results that enhance development processes and optimize product performance. Through phenomenological-based testing, AAI ensures statistically valid perception error models that account for noisy inputs, delivering a high level of reliability for complex automotive systems. This approach enables AAI to simulate real-world conditions, providing a robust foundation for continuous testing and improvement across ADAS and autonomous driving systems. | | | | |
| **MAPS & OPERATIONAL DESIGN DOMAINS (ODDS)** | | | | | | | | |
| **MAPS** | **Coverage** | The scenario-management in SIMPHERA provides the basis for coverage analysis based on tags applied to the scenarios. Via scenario-based testing with different test methods (brute-force, intelligent test control, …) a broad test coverage is reached. Serves as the basis to find new unknowns (SOTIF compliant testing). | Ansys Avxcelerate offers a Scenario Manager based on ASAM openSCENARIO XML and openDRIVE. The statistical scenario variation exploration allow to vary scenario parameter, openDRIVE map description. This allow to run test coverage on the ODD and robustness analysis. | In addition to matching all of Bosch's technical capabilities, AAI provides comprehensive support for advanced simulation and modeling. AAI's platform seamlessly integrates various technical features, such as converting HERE HD maps to ODR, NDS to OpenDRIVE, and vice versa. Additionally, AAI offers a robust data pipeline that enables the generation of HD maps from raw data, allowing the creation of precise digital twins. This capability is critical for providing accurate and reliable testing environments for ADAS and autonomous driving systems. Furthermore, AAI covers both technical aspects of phenomenological-based testing and perception error modeling while also integrating sensor, vehicle dynamics, and powertrain modeling to ensure reliable performance across | Create synthetic maps and generate 3D worlds for sensor simulation | Create synthetic maps and generate 3D worlds for sensor simulation | Automated digital twin based on HD map data | Create synthetic maps and generate 3D worlds for sensor simulation |
| | **Function based ODDs** | dSPACE supports different methods to create/generate scenarios according to the customers ODD:<br>- Manual creation of scenarios in the Road- and Scenario editor to create scenarios based on expert knowledge and requirements<br>- Conversion of real-world recordings into simulation scenarios (Traffic Virtualizer)<br>- Import of scenarios from available scenario databases via OpenDRIVE/ OpenSCENARIO<br>- Integration of 3rd party models for AI-based traffic-agent simulation or abstract scenarios. | Ansys Avxcelerate offers a Design of Experiment parametric exploration that allow to openSCANERIO XML parameters, openDRIVE map description but as well any custmer specific parameter (such as function configuration, filter, ...). This allow to run function baed ODD coverage and sensitivity analysis | AAI supports function-based Operational Design Domains (ODDs) with a focus on comprehensive simulations covering object detection, lane detection, weather conditions, time of day, and more. AAI follows the ASAM OpenODD standard, ensuring compatibility and precision across various ODD scenarios. With a fully customizable simulation environment, AAI allows users to tailor simulations to specific requirements, featuring movable elements that enhance realism and practical applicability. This flexibility makes AAI an optimal solution for ADAS and autonomous driving system development, providing high-fidelity environments for rigorous testing.<br>AAI's robust capabilities include the seamless conversion of maps and the creation of digital twins using raw data to ensure detailed, real-world representations. The platform also provides support for a wide range of map formats and sensor models, offering an all-encompassing solution for ODD-related simulations across different geographic regions and road conditions. | urban, highway, customizable | urban, highway, customizable | | Offers comprehensive scenario and map generation capabilities.<br>highway, urban, country roads, and parking garages |
| | **Route based Maps** | Road data of different formats can be integrated, like OpenDrive, OpenStreetMaps (OSM), TomTom, ...<br>dSPACE has integrated solutions by 3rd party companies to integrate road models generated from HERE HD-live-maps data on demand on a "per-km"-basis. | AVxcelerate supports openDRIVE natively. In addition, the opensource map engine that is embedded (openPASS) allow to be extend to different map representation. | AAI's simulations incorporate data based on sensors mounted to the car, ensuring a realistic representation of vehicle dynamics and environmental interactions within maps and Operational Design Domains (ODDs). | | Offers comprehensive assets catalog for various scenarios. | | Integration with RoadRunner to create and import custom maps into aiSim |

| | | TOOL PROVIDER (TRADITIONAL) | | TOOL PROVIDER (NEWCOMER) | | | | |
|---|---|---|---|---|---|---|---|---|
| | *FULL NAME* | **DSPACE** | **ANSYS** | **AUTOMOTIVE ARTIFICAL INTELLIGENCE** | **APPLIED INTUITION** | **COGNATA** | **MORAI** | **AIMOTIVE** |
| | *COMMENTS* | BASED ON INTERVIEW | BASED ON INTERVIEW | BASED ON INTERVIEW | | | | SOLD TO STELLANTIS |
| | **Automation** | The ModelDesk road editor provides a API for automation. This enables the users to generate road in a fully automated way. | AVxcelerate product is provided with REST API that allow to import scenario, map and 3D world from scripting. Automation is as weel supported for the creation of 3D environments for high quality physics-based sensor simulation | With a strong emphasis on maps and Operational Design Domains (ODDs), AAI provides solutions that enable high automation (with automatic correction and conversion to ODR and NDS), facilitating advanced simulation capabilities for complex environments. | Run automated tests at scale during development and validation | they provide automation | they provide automation | they provide automation |
| | **Maps for parking simulation** | dSPACE can provide example maps for parking use-cases, including sidewalks, detailed lane and line information, parking slots etc.. All parts are modeled in detail for accurate simulation of the relevant sensor signals (e.g. ultra sonic sensor). | AVxcelerate supports openDRIVE natively for road description but as well any 3D geometry format can be imported to buid the 3D represetnation of the world including parking spaces | AAI provides comprehensive coverage for all types of parking use case maps, supporting both popular and corner cases in a wide range of environments. AAI's maps are designed to facilitate testing and validation for various parking scenarios, including parallel parking, perpendicular parking, angle parking, and automated valet parking. Additionally, AAI addresses complex and corner cases, such as tight urban parking spaces, multi-story parking garages, dynamic parking situations (e.g., vehicles or pedestrians entering or exiting nearby spaces), and adverse weather conditions affecting visibility and maneuverability.<br>AAI's parking maps integrate seamlessly with the broader simulation environment, allowing for detailed testing of parking assistance systems and autonomous parking features. With the ability to simulate diverse real-world and synthetic parking environments, AAI ensures that parking-related functions can be tested and validated under any scenario, improving reliability and performance in actual deployments. | not mentioned, but most prob provided | not mentioned, but most prob provided | not mentioned | Offers an Automated Parking Assist System, indicating some level of map automation. |
| | **NDS Support** | The NDS consortium provides an ODR-exporter based on NDS map data. dSPACE has assured the compatibility of the ODR-files generated from NDS data within its toolchain. | AVxcelerate supports openDRIVE natively. But the opensource map engine that is embedded (openPASS) allow to be extend to different map representation such as NDS | AAI is a leading provider of map conversion solutions, offering an NDS to OpenDRIVE converter and vice versa, enabling seamless integration between these two widely used formats. AAI is also a proud supplier for the NDS consortium, demonstrating its commitment to supporting industry standards and providing high-quality map data for ADAS and autonomous driving applications. This capability ensures that AAI's toolchain can adapt to various geographic and functional requirements, offering flexibility for developers and engineers working with both NDS and OpenDRIVE formats.<br>By offering these conversion tools, AAI enables customers to leverage existing NDS maps while also ensuring compatibility with the OpenDRIVE ecosystem, making the platform an essential tool for creating and managing detailed map data across diverse projects and regions. | | | not mentioned but most likely provided by real world data | |
| **INFRASTRUCTURE** | | | | | | | | |
| **CLOUD** | **Cloud Native Services** | SIMPHERA is developed in a cloud agnostic way. This enables dSPACE to deploy SIMPHERA in every public available cloud environment. dSPACE is partnering with Microsoft (Azure) and AWS to make sure, that the solution works seamlessly in these environments- | Ansys offers cloud-native services via the Ansys Cloud platform, but also works with customer's clusters and deployments on AWS or Azure | AAI provides a cloud-native, multi-tenant platform that supports Microsoft Azure, AWS, and Google Cloud, offering unmatched flexibility and scalability for simulation and testing environments. Built on a microservices-based architecture, AAI's platform is designed for scaling simulations, executing aggregated analytics, and delivering high performance and efficiency.<br>Additionally, AAI provides intuitive tools and wrappers for viewing scenarios, maps, and test suites, ensuring a seamless and user-friendly experience. This flexibility allows users to harness the full potential of cloud infrastructure, enabling faster development cycles and efficient resource management for ADAS and autonomous driving system validation. | cloud-based tools | cloud-based simulation | cloud-based sim | cloud-native user interface |
| **LAB** | **On Premises** | SIMPHERA can also be deployed locally or in a hybrid manner to allow for a sophisticated cost management for the end customer, like using local GPU clusters rather than cost-intensive cloud ones.<br>In addition, dSPACE provides a large bunch of local desktop tools, like for creating roads and traffic scenarios. | AVxcelerate can deploy on on-prem customer cluster | AAI offers a hybrid approach to simulation and testing, supporting both on-premises and cloud-based solutions for maximum flexibility and efficiency. The AAI platform is designed to utilize multiple GPUs for handling sensor data on-premises, optimizing resource usage and ensuring high-performance execution. This allows for faster processing of complex scenarios and sensor data analysis, while the overall orchestration, scenario storage, evaluation, and aggregation can be managed seamlessly in the cloud.<br>AAI's hybrid architecture ensures smooth integration of testing and simulation processes, making it adaptable to various environments and operational requirements. By maximizing the use of current hardware resources, AAI delivers exceptional performance in both local and cloud-driven simulations, offering unparalleled flexibility for ADAS and autonomous driving system development. | | Provides a range of tools for simulation and testing. | simulation engine | Provides a range of tools for simulation and testing. |
| **TOOLS** | **Editing, Data, Visualization etc** | dSPACE offers a broad tool suite for editing (ModelDesk: road, scenario, vehicle parameter), data managmenet and analysis (IVS, SIMPHERA), visualization (AURELION: 3D, ControlDesk: data), automation, … | Ansys offers a broad tool suite to do Safety Analysis (Medini), Safety Management (DSM), Scenario Management (AVxcelerate Scenario Manager), Scenario exploration (AVxcelerate Explore), Exploration Analysis (AVxcelerate Analysis), sensor creation (Speos, Lumerical, Zmax, AVxcelerat Sensor Lab), sensor Simulation (AVxceletrate Sensors) | AAI offers a versatile toolbox for scenario preparation within maps and Operational Design Domains (ODDs). This toolbox includes features for editing maps, static scenes, and trajectories. Additionally, users can take advantage of Foxglove- and Tableau-based visualization and analysis capabilities. AAI also provides the flexibility for users to customize observers using Python, giving them greater control and familiarity with the tools for visualization and analysis.. | Simian, Spectral, Orbis, Logstream, carsim, trucksim, bikesim, suspensionsim, strada, Meridian, synthetic datasets, Basis, Applied test suites | | offer simulation and generating scenarios | AInotate, AIfab, AIsim, SDK, Scenario API |
| **LOCAL** | **Local usage on dev. machine + debugging (breakpoints, stepping through code and plots)** | SIMPHERA allows the integration into existing developer IDEs, like Visual Studio. Thus, debugging with breakpoints, data analysis etc. is directly possible. | Yes, e.g AVxcelerate Simulation Framework integrate in developer IDE such as VSCode allow to debugge feature behaviour during scenario execution | AAI supports comprehensive simulation execution locally against systems under test (SuT), providing full integration with debugging tools when needed. This enables users to attach a debugger and step through scenarios to gain detailed insights into system behavior. Additionally, AAI allows evaluations to be conducted locally against previous test results, providing valuable comparative analysis and helping develop precise evaluation criteria.<br>AAI's flexible infrastructure supports thorough testing and refinement processes, enhancing the overall development workflow. This level of integration ensures that users can continuously improve their systems by iterating on both local and cloud-based simulations, promoting faster development cycles for ADAS and autonomous driving functionalities. | debugging tools | | | |

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| **X IN THE LOOP** | | | | | | | | |
| **SIL** | **Software in the loop** | dSPACE fully supports the SIL use case and has accordingly carried out many customer projects and has products in its portfolio that facilitates this use case. Accordingly, dSPACE provides a toolchain for creating and integrating V-ECUs, but also to integrate more or less any 3rd party V-ECUs. This is made possible by the wide range of integration options and co-simulation possibilities. In addition to V-ECU generation or the integration of 3rd party artifacts (such as simulators, models or V-ECUs), dSPACE also provides a complete tool chain for rest bus simulation. The product portfolio for SIL includes open models for vehicle dynamics and powertrain with corresponding pre-parameterized examples as well as sensor models (i.e. radar, lidar, camera, USS) for the various use cases from raw data input to object lists with connection to various SuTs (ROS nodes, RTMaps, Windows/Linux PC, etc.). In addition to orchestration and automation, the SIL solution also includes various open and standardized interfaces for optimal integration into corresponding processes. The dSPACE SIL solution is designed to serve multi-domains in addition to the ADAS/AD use case and is to be understood as an integration platform to meet the SDV (Software Defined Vehicle) use case. | included | AAI not only surpasses industry benchmarks with its Simulation-in-Loop (SiL) solutions, but it also firmly believes in and supports standards as the foundation for driving innovation. AAI offers unparalleled flexibility with its combination of simulation engines, sensor models, vehicle dynamics models, and virtual Electronic Control Units (vECUs). By adhering to and exceeding ISO 26262 standards, AAI ensures both reliability and innovation across its V&V strategy, making it a key player in advancing automotive technology.<br>AAI's SiL platform accommodates a wide variety of vECU types and supports advanced simulation configurations that go beyond industry norms. Through innovative methods and rigorous quantitative comparisons, AAI ensures its simulations deliver credible, real-world results. Furthermore, AAI's SiL framework integrates seamlessly with Hardware-in-the-Loop (HiL) testing, enabling comprehensive, efficient, and standardized validation processes.<br>AAI's deep commitment to innovation through standards makes it a leader in the field, offering more advanced solutions than many competitors, including Bosch, while continuously pushing the boundaries of what is possible in SiL and HiL simulations. | included | included | included | included |
| **MIL** | **Module / Model in the Loop** | In addition to SIL, MIL is also fully supported, e.g. via the open Simulink Models of ASM. Example Soft-Controller for plug-and-play closed-loop use-cases are part of these models, as well. | included | AAI offers robust support for software component-based simulations in a closed-loop environment, ensuring precise and efficient testing and validation. This allows for the thorough refinement of individual software modules within the context of the complete system simulation. AAI's solution enables all software components to be | included | included | Not specified. | included |
| **HIL** | **Hardware in the loop** | In the HIL area, dSPACE supports almost all domains and provides not only the hardware and simulation models but also the interfaces for maximum efficiency in processes at OEMs and suppliers, as has been proven in countless customer projects over the past decades. Similar to the SIL or MIL context, there are many integration and coupling options for connecting third-party models or simulation and test artifacts. The necessary models for automotive applications are also provided in the HIL use case (see SIL). All dSPACE models can be used in both HIL and SIL contexts. The models are designed to be used for XIL purposes, of course. dSPACE provides an XIL-integrated tool chain by supporting the common and necessary standards. In particular, dSPACE provides an almost complete tool chain for automotive buses and can therefore support all communication matrices. Furthermore, with dSPACE it is possible to perform almost all types of SUT integration: From OTA RADAR or camera to raw data injection to HMI, 5G, LTE and V2X communication. It should also be noted here that the expertise is not limited to ADAS/AD, but that cross-domain testing is also practiced. | included | While AAI does not provide Hardware-in-the-Loop (HiL) directly today, our platform is fully capable of connecting with any existing HiL systems to support broader integration needs. However, AAI emphasizes the power of Simulation-in-the-Loop (SiL) as a more effective solution for identifying complex software issues early in the development process. We believe that SiL is better suited for uncovering intricate software challenges at the earliest possible stage, enabling faster troubleshooting and optimization of ADAS and autonomous driving systems.<br>AAI's SiL environment is designed for reusability, scalability, maintainability, and availability, ensuring robust and efficient testing solutions. By focusing on SiL for software validation, AAI provides an agile and cost-effective approach, allowing teams to solve complex problems well before the hardware is introduced. | included | included | Not specified. | included |
| **VIL** | **Vehicle in the Loop** | dSPACE supports VIL in a wide variety of ways. On the test bench, for the use in end-of-line (EOL) use cases or in PTI applications, and on the proving ground, so that any critical situations can be carried out safely on the proving ground. Various driving functions could be verified and validated by the dSPACE solutions. In addition to VIL, the dSPACE portfolio also supports DIL use cases. For EOL and PTI, dSPACE naturally focuses not only on simulation but also on the OTA option, whereby the interface to the sensor influences the model and the simulation significantly. | out of the scope | AAI leverages its deep expertise in ADAS and automated driving systems to provide high-quality simulations and component models.<br>AAI's commitment to supporting industry standards allows its maps, scenarios, and simulations to be seamlessly integrated into other platforms, ensuring flexibility and interoperability. AAI adheres to rigorous credibility processes aligned with regulatory requirements such as NCAP and UNECE, ensuring compliance and reliability across all validation scenarios.<br>In addition, AAI's simulation environment is adaptable for Vehicle-in-the-Loop (ViL) testing and can integrate with other platforms to inject objects and simulate critical, real-world ADAS performance in dangerous scenarios. This ensures comprehensive and accurate testing for any system under development. | included | driver in the loop | included | |
| **ENVIRONMENT** | | | | | | | | |
| **OS** | **Linux / Windows** | dSPACE is supporting both Win and Linux for different use-cases: Preparation parts, like road creation and scenario defintion are part of ModelDesk (Win tool), whereas the exeuction/simulation of ASM on VEOS (SIL use-case) can be either on Win or on Linux. Docker technology is supported as well. The Cloud-native SIMPHERA framework is OS independent, as accessed throug a browser. | Mostly Linux Ubuntu 20.04/22.04. High Fidelidy sensor simulation runs as well on Windows 11 | AAI offers comprehensive support for both Linux and Windows environments, catering to a wide range of users and deployment needs. AAI's platform supports cloud and cluster deployment through containerization technologies like Docker, providing seamless scalability and flexibility. For Windows users, AAI provides native builds and virtualization options such as WSL, ensuring smooth integration across various operating environments.<br>In addition, AAI's toolchain is designed to support System Under Test (SUT) environments based on platforms like QNX, Android, and others, making it adaptable to diverse system architectures and requirements. This flexibility ensures that AAI can meet the needs of different projects and technical ecosystems, whether in development or testing phases. | | Linux | | MS-Windowws, Linux Ubuntu |
| **OPEN INTERFACES** | **Tool-external APIs** | All dSPACE tools offer comprehensive APIs, like COM API, REST-API, XIL-API, … | Open architecture with documented public C++ / REST APIs. https://developer.ansys.com/docs/avxcelerate | AAI's tools implement industry-standard interfaces, such as FMI, ASAM standards, and OpenSCENARIO, depending on the use case. This approach ensures reusability across a wide range of use cases and projects while enabling seamless interoperability with both in-house and third-party tools. By adhering to these industry standards, AAI ensures its maps, scenarios, and simulations are fully compatible with other platforms, providing flexibility and efficiency in the development and testing of ADAS and autonomous driving systems. | | | | |
| | **Modularity of the toolchain** | dSPACE provides both turn-key solutions for all automotive use-cases and domains, as well as open modules to integrate 3rd party components from partners or customer. | high modularity regarding sensors | In the context of environment and a highly modular toolchain, AAI provides a toolchain that is not only highly modular and configurable but also offers exceptional flexibility in programming languages, enabling users to tailor their simulations precisely to their needs. | | | | |
| **SENSOR MODEL** | **Provide configurable sensor models** | The physics-based sensor simulation tool AURELION provides ready to use sensor models of automotive industry relevant sensors (huge partner eco-system). Additional sensor models can be configured in the tooling based on the datasheet of a sensor. | Sensor model can be configured based on specsheet up-to the definiition of e.g QE for camera, Antena Beam pattern for radar... | AAI provides flexible and configurable sensor models across multiple levels, including statistical, physical, and phenomenological models. These sensor models, created from real data, are designed to meet a wide range of simulation and testing needs. AAI's expertise in working with sensor technologies like cameras and LiDAR ensures that the simulations are as accurate and reliable as possible, supporting object detection, hazards, lane detection, and traffic sign recognition. | yes | yes | yes | yes |

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| | **Type of Sensors (Rada, Lidar, Camera,..)** | dSPACE AURELION provides physics-based sensors for Camera, Radar, Lidar and Ultrasonic Sensor. There is pixel-accurate GT data available, with classification, instance-ID, bounding boxes, semantic segmentation, ... Additionally, ASM supports the calculation of OSI::GT and phenomenolgical sensors for Bounding Boxes, Nearest Point, Radar, Ultrasonic, Lane Sensor, Traffic Sign, ...<br>Further sensor models, like for GPS or V2X use-cases are also available. All needed restbus sensor data (yaw-rate, wheel-speeds, steering angle, ...) is available, too, to satisfy full ECU networks. | ideal sensor in OSI (OSMP) standards plus hi-fidelity sensors: camera, radar, Lidar, thermal camera | AAI offers a wide range of sensor models, from physically-based to ideal, tailored for various systems under test (SUT). Our solutions encompass radar, camera, and ultrasonic modalities, with interfaces that handle raw data, processed data, and object data. AAI's sensor models are foundational for delivering robust and comprehensive solutions for advanced driver assistance systems (ADAS) and autonomous driving technologies.<br>AAI adheres to industry standards, ensuring consistency and reliability in testing, verification, and validation processes. Our commitment to ISO standards ensures that our sensor models meet the highest levels of accuracy and performance, providing comprehensive support for simulation and testing across multiple sensor modalities. | sensors, LiDar, weather variation, cameras | highly developed cameras and radars | LiDar,Cameras,IMU,GPS | Built-in sensor library includes physics-based sensor models of camera, LiDAR, radar, ultrasonic, GPS, and IMU |
| | **Connection of sensor to the device under test (HIL and SIL)** | For SIL Use-Cases dSPACE provides an all-in-one Solution to retrieve synchronized restbus and sensor data via the same ethernet based interface, called V-ESI. It uses an easy to use C++ interface to retrieve the data synchronously. It can also be used to close the loop by sending control signals back to the vehicle dynamics model.<br><br>For HIL Use-Cases we output binary sensor data via Display Port into a FPGA based device called the ESI Unit. The ESI Unit is connected to the the Device-Under-Test via physical interfaces like LVDS, CSI2, GSML, ... Restbus data can be transferred directly via the Scalexio system on the needed automotive bus. | Connection can be done either locally via: SharedMemory, RDMA or HDMI or remotely via grpc services. | AAI supports the integration of sensor models across multiple contexts, including Hardware-in-the-Loop (HiL), Software-in-the-Loop (SiL), and Software-on-the-Loop (SoL), within its flexible and modular simulation framework. While AAI focuses on SiL for identifying complex software issues in the early phases, the platform is fully capable of connecting with any HiL system, providing a comprehensive and adaptable environment for ADAS and autonomous driving development.<br>AAI also supports Hardware-on-the-Loop (HoL) setups, ensuring seamless testing and validation across all stages of development. By allowing flexible combinations of sensor models and system configurations, AAI's platform enables accurate and efficient testing tailored to specific project requirements. | | | | |
| | **Possibility to integrate 3rd party sensor models e.g. by suppliers** | The physics-based sensor simulation tool AURELION provides a HIL & SIL compatible interface to integrate third party sensor models. The data is calculated on the GPU and is made available via a Pointer to the memory on the GPU. This reduces latency since no additional memcopy operations are neccessary.<br>Additionally, AURELION provides multiple ready to use sensor models of their sensor supplier partners. | Customers connects his own SuT, which includes its own sensor models. The sensor models can either be created directly with the UI, alternatively the sensor supplier can provide an encrypted version of the sensor to be simulated. | AAI supports the integration of third-party sensor models, including those provided by suppliers, ensuring flexibility and adaptability in various simulation and testing environments. This capability allows users to incorporate external sensor models into AAI's platform for a comprehensive and customizable testing solution. | yes | yes | Customizable sensors | yes |
| | **Provide configurable vehicle model** | dSPACE provides fully parameterizable und customizable vehicle models, for cars, truck, buses, ...<br>In addition, different pre-configured vehicle types are available, like SUV, VAN, MidSizeCar, SmallCar, Truck-Trailer combinations, ...<br>As of the fully open model structure of ASM under Simulink, customized model adaptations can be done, too. | The AVxcelerate Scenario-based execusion simulation a simple "bycycle-type" vehicle dynamic.The simulation framework allow to connect to a 3rd party vehicle dynamic that replace the defaut behaviour | AAI provides configurable vehicle models, allowing users to tailor simulations to specific project requirements and vehicle configurations. This flexibility ensures accurate and relevant testing across a wide range of use cases. | very wide range | yes | yes | yes |
| | **Possibility to integrate 3rd party vehicle model** | As of the modularity of ASM and AURELION, 3rd party vehicle models can be integrated or only parts of the vehicle, like customer suspension types. | The simulation framework allow to connect to a 3rd party vehicle dynamic that replace the defaut behaviour | AAI supports the integration of third-party vehicle models, providing flexibility for users to incorporate external models into their simulations for enhanced testing and development. | yes | yes | not mentioned | yes |
| **BUS SIMULATION** | **Types of automotive busses (Ethernet, CAN, Flexray,..)** | dSPACE supports CAN, LIN, Flexray, CAN-FD and Ethernet (SOME/IP) across XIL. We make all necessary functions directly and easily accessible to the customer (e.g. end-to-end protection). Furthermore, dSPACE provides comprehensive support for AUTOSAR communication matrices and offers a complete tool chain for the communication matrices. Especially for Ethernet SOME/IP, the dSPACE solution has been used productively by OEMs from the very beginning - for over 12 years. | The simulation framework allow to connectcas much SuTs as needed. The communication bus is based on RTI DDS and can emulate commuincation between SuT. Additionnaly, customer can connect the simulaiton framework with 3rd party component such as vehicle bus communication emulator. | AAI brings extensive experience in supporting automotive bus systems and restbus development, covering a wide range of bus types, including CAN, CAN FD, CAN TP, LIN, FlexRay, Ethernet I²C (Inter-Integrated Circuit), and Ethernet (SOME/IP). AAI's solutions enable seamless integration of these bus systems with both real and virtual ECUs, offering flexibility across various testing environments. By utilizing both physical hardware and simulated solutions, AAI ensures a smooth user experience and enhanced usability throughout the development and testing processes. | | | | |
| **SYSTEM REQUIREMENTS** | **Special Datacenter components needed, e.g. MapR, openShift** | Main requirements of the cloud-based V&V solution SIMPHERA are an existing Kubertes Cluster and an attached PostGresQL Database. | AVxcelerate cloud based deployement requires Kubernetees. | AAI's Simulation-in-the-Loop (SiL) solutions are built on container technology for seamless scalability. While AAI does not operate its own dedicated data centers, we work closely with customers, leveraging their data centers or cloud providers such as AWS, Azure, and Google Cloud for scalability and flexibility. For local deployments, AAI utilizes Docker as its standard container platform, ensuring compatibility and ease of use across various environments.<br>Additionally, AAI has its own test place infrastructures to support development and validation processes, providing a robust environment for testing containerized applications in collaboration with customer infrastructure. | | | | |
| **AUTOMATION** | **To which extent is the system automated and scalable?** | All dSPACE tools provide extensive automation options, like COM-API or REST-API. Thus, all manual tasks, like creating roads and scenarios, can also be fully automated.Automated runs in a scalable manner are possible, as well (see next item). | The Ansys AVxcelerate hyper-scaler has been tested up-to 1000 parallele simulation and up-to 1M execution in a job. | AAI offers a cloud-native platform designed for multi-tenancy across leading cloud services such as Microsoft Azure, AWS, and Google Cloud. Built on a microservices-based architecture, AAI's platform is highly scalable, enabling efficient handling of simulation and aggregated analytics. With features like automatic queuing and retry mechanisms, AAI ensures smooth execution and management of large-scale simulation runs, providing reliability and performance even in complex scenarios.<br>Additionally, AAI's system is designed to leverage the full potential of available resources, including the use of multiple GPUs for sensor data processing on-premises, ensuring optimal performance and resource utilization. | | | | |
| **PARAMETER VARIATION** | | | | | | | | |
| **COMPUTE** | **Parallel computing & orchestration** | The cloud-native V&V solution SIMPHERA allows an easy scalable execution of tests, i.e. parallel simulation with variations of scenario parameter (scenario-based testing), or data replay tests for perception validation. SIMPHERA includes a full orchestration of various execution agents. | The Ansys AVxcelerate integrate an hyper-scaler using Kubernetees that spawns, monitor, execute and collect results running simulation docker. The hyper-scaler has been tested up-to 1000 parallele simulation and up-to 1M execution in a job. | AAI's cloud-based execution environment supports highly parallelized computation by running individual simulations in separate containerized environments. Our orchestration tools efficiently manage queuing, automatic retries, and the scaling of test workers to optimize both cost and throughput. AAI leverages cloud services such as Microsoft Azure, AWS, and Google Cloud to ensure scalability and flexibility.<br>Additionally, to further enhance cost-efficiency, AAI utilizes spot instances, allowing us to offer a low cost per simulation while maintaining high performance and scalability for large-scale testing and validation processes. | | | Offers advanced simulation capabilities with various computing options. | Offers advanced simulation capabilities with various computing options allowing unlimited permutation |
| **ALGORITHM** | **Sampling algorithms** | SIMPHERA includes ifferent variation methods, like brute-force parameter variation, ITC (intelligent test control with randomized, stochastic evolutionary algorithms or surrogate models), fixed parameter variation, ... Dedicated interfaces are available for integration of customer variations, too | The user benefits from differents sampling algorithms depending on his needs for safety validation. Examples are full factorial combination of parameters, latin hypercube sampling (more efficient than full factorial), monte-carlo for random concrete scenario generation, and adaptive sampling for quicker convergence towards edge case scenarios. | Morphosenthis and wide range of Algorithms | | more than 1,000 unique parameters for vehicle model adjustments. | | |

| | | TOOL PROVIDER (TRADITIONAL) | | TOOL PROVIDER (NEWCOMER) | | | | |
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| | *COMMENTS* | BASED ON INTERVIEW | BASED ON INTERVIEW | BASED ON INTERVIEW | | | | SOLD TO STELLANTIS |
| **PERFORMANCE** | | | | | | | | |
| **RUNTIME** | **Realtime factor** | ASM (vehicle + traffic) and AURELION (physics-based sensors) run in real-time for Hardware-in-the-Loop (HIL) use-cases. For SIL and cloud use-cases, also faster, but still synchronized, execution is possible. | The AVxcelerate Simulation loop allow to running faster, lower or in realtime. The realtime execution factor depends on models (eg. sensor) complexity, SuTs complexity or allocated hardware | The real-time factor in AAI simulations depends on the executed simulation engine, models, and virtual Electronic Control Units (vECUs). AAI's lightweight middleware enables simulations to run multiple times faster than real-time, optimizing performance across various configurations. AAI also supports both synchronous and asynchronous modes, as well as real-time and accelerated modes, allowing customers to tailor the simulation to their specific use case.<br>Whether working with object list-level data or raw sensor data, AAI can adjust the timing factor to match customer requirements, offering flexibility in how simulations are executed and analyzed. | Leverage sensor simulation to iterate rapidly | real-time simulation | | |
| **VISUALIZATION** | **Vizualization provided by tool** | For local (desktop) purposes, there are different visualization tools available, like AURELION for 3D visualization or ControlDesk for interactive analysis of model and controller parameters.<br>For the visual analysis of data in the cloud, SIMPHERA provides built-in visualization capabilities like 3D renderings, camera views, overlays like pointsclouds or bounding boxes, signal plotting, timeline visualizations. | AVxcelerate provide UI to visualize results of massive simulation execution | AAI provides a wide range of visualization methods tailored to different use cases, from fast and efficient web-based UIs with simple 3D visualizations to high-definition video rendering for more detailed analysis. In addition, AAI's flexible platform allows for the integration of commercial visualization tools when required, providing seamless adaptability based on customer needs.<br>AAI's approach to virtualization ensures that simulations can be viewed and analyzed in the most appropriate format for each project, enhancing usability and insight across ADAS and autonomous driving simulations. | | | | |
| | **Integration of 3rd party visualization e.g. Foxglove** | It is possible to connect 3rd party visualization tools like e.g. foxglove or business intelligence dashboards like e.g. Superset. | AVxcelerate generate output that can be visualize off-line on a desktop version FoxGlove or on an inline instance of Foxglove | In addition to AAI's highly capable in-house visualization solutions, our simulation environments offer standardized interfaces that enable seamless integration of third-party visualization tools. AAI supports integrations with tools such as Foxglove, Tableau, Flexmonster, and others, ensuring that customer-specific requirements are met with flexibility and efficiency.<br>This adaptability allows AAI to provide a tailored visualization experience within the test environment, ensuring the most suitable tools are used to meet the unique needs of each project. | | | | |
| **GPU** | **Usage/Need of GPUs** | dSPACE provides simulation solutions with CPU-only (ASM with OSI::GT sensor data) or together with GPUs (AURELION with physics-based sensor models)<br>The physics-based sensor models are accelerated through GPU usage. The demanding calculations can be distributed across multiple GPUs on one machine but through an advanced architecture it is possible to distribute the load also between multiple machines.<br>SIMPHERA itself only needs GPUs if AURELION is used for sensor data generation. It is possible to use GPUs for SUTs, e.g. for AI-based functions. | As part of the AVxcelerate deployment on cloud, we recomand allocating thru Kubernetee 1 core to execute the scenario and the simulation loop. The amont of GPU/CPU required by SuT adds on top. Only Ansys Physics-based sensors need GPUs, and Ansys supports mutli-GPUs or multi-node configurations for setups with a large number of sensors. | AAI's platform is highly flexible when it comes to GPU usage. For sensor data processing and specific use cases that benefit from GPU acceleration, AAI can leverage multiple GPUs to ensure optimal performance. However, for headless use cases without rendering, there is no strict dependency on GPUs, allowing for efficient resource usage based on the needs of the project.<br>This flexibility ensures that AAI maximizes performance while minimizing unnecessary resource consumption, providing a scalable solution for various simulation environments. | | | | Nivida, AMT, Intel |
| **CPU/RAM** | **CPU/RAM ressources for a simulation of 30s realtime** | A single headless simulation just needs 1-digit CPU power and 2-3-digits MB of RAM. But the overall system requirements highly depend on the number of parallel executions (local or in the cloud), with/without GPU, complexitiy of traffic scenario, … | As part of the AVxcelerate deployment on cloud, we recomand allocating thru Kubernetee 1 core and 1GB of RAM to execute the 30s scenario 2x faster thant realtime. A high range CPU with 64 GB of RAM is recommended while running high fidelity sensor GPU-based simulation | AAI places a high focus on efficient C++ computation to achieve competitive real-time performance. The solution is optimized for both CPU and GPU usage, with specific improvements depending on the applied models, use case, and the system under test (SUT). AAI's local GPU usage is architected to maximize performance in simulations and real-time applications, ensuring that resources are utilized effectively to meet demanding computation needs.<br>This approach allows AAI to deliver flexible, high-performance solutions tailored to the requirements of each project, whether it involves rendering or headless use cases. | | | | Intel, AMD |
| **KEY FEATURES** | **Data Replay and Data-Driven Development** | dSPACE provides sophisticated solutions for full DDD (data-driven development) pipeline: from data recording, data ingestion, data enrichment, data management, data-replay testing, automated generation of logical scenarios out of that data, scenario-based testing, ... | The Ansys Simulation loop can injest ASAM OSI Stream and stimulate SuTs and KPIs so that replay can be achieved. This allow as well for sensor model error injection. | AAI's simulation environments are designed to support end-to-end data-driven development, offering a robust platform for testing and validating models and systems under various conditions. AAI supports the integration of real-world data and enables data replay, allowing developers to recreate and analyze specific scenarios to ensure accurate simulations that reflect real-world operating conditions.<br>AAI's platform can operate in both deterministic and non-deterministic modes, providing flexibility depending on the use case. This continuous loop of data collection, simulation, data replay, and analysis accelerates model refinement and optimization, ensuring reliable real-world performance. By leveraging AAI's advanced simulation environments, developers can make informed, data-driven decisions throughout the entire development lifecycle, from design to deployment. | | | | |

| | | TOOL PROVIDER (TRADITIONAL) | | TOOL PROVIDER (NEWCOMER) | | | | |
|---|---|---|---|---|---|---|---|---|
| | *FULL NAME* | DSPACE | ANSYS | AUTOMOTIVE ARTIFICAL INTELLIGENCE | APPLIED INTUITION | COGNATA | MORAI | AIMOTIVE |
| | *COMMENTS* | BASED ON INTERVIEW | BASED ON INTERVIEW | BASED ON INTERVIEW | | | | SOLD TO STELLANTIS |
| **INTEGRATION** | | | | | | | | |
| **SUT / VUT / EGO** | **Homologation/ Freigabe-Prozess** | dSPACE provides an ISO 26262 certified tool chain. This means from code generation to simulation and test automation and that the dSPACE Solution can be used in the context of ASIL-D projects and an in-depth assessment of the tool chain is not necessary, so it save time on the OEM side. dSPACE also provides a calibration service for the calibration of HIL systems in order to comply with ISO 26262. Furthermore, dSPACE provides appropriate content to give a quick start to various standards (UN R157, EURO NCAP, etc.) that an OEM must comply with. When it comes to model validation, dSPACE also provides homologation-relevant content as well as corresponding tools in the context of data reprocessing in order to take into account the framework conditions of ISO 26262, EU Regulation 2022/1426 or ISO 34502 or ISO 22140, for example. dSPACE also has a consulting service to provide holistic advice from item definition to homologation, from processes, standards, regulations to V&V strategy. Furthermore, dSPACE is part of a consortium of various partners (Kontrol, TÜV Süd, Microsoft and FEV.io) that have set themselves the goal to push on virtual homologation. The aim here is to provide the associated digital test report from the regulation, the legal text or the corresponding ISO standard. This then affects the requirement definition, implementation and testing and also takes into account the corresponding infrastructural aspects. | Ansys AVxcelerate is ISO 26262 certified and such can be utilize as a trustable validation tool for safety crtitical application and sign-off process. AVxcelerate allow to connect to homologuation checker software (such as Kontol) so that regulatroy homologation can be assest during the V&V process. | AAI's Simulation-in-the-Loop (SiL) and Hardware-in-the-Loop (HiL) environments adhere to ISO 26262 standards and are developed with rigorous quality measures in the toolchain's development process. The qualification involves strict quality controls and a defined integration process tailored to specific projects, ensuring that all simulation platforms meet the highest industry standards.<br>Developed by simulation experts with extensive experience, AAI's toolchain is optimized for integration into customer projects, offering reliable and compliant solutions for safety-critical systems in ADAS and autonomous driving technologies. | V&V of ADAS included (BASIS) | V&V | | world's first ISO 26262 certified automotive simulator for verification and validation |
| | **Methods / interfaces for System-under-Test integration** | dSPACE provides corresponding integration options for every use case in the XIL context:<br>- In the MIL and SIL context, different interfaces are available depending on the use case, starting with the CoSim API, for example to couple instruction set simulators. The integration of FMUs is also a common approach and is supported accordingly. Focusing on the ADAS/AD domain, ROS nodes, RTMaps or other development environments can also be connected using the V-ESI in order to verify and validate perception or other components of the AV stack. A complete SUT integration usually also includes a bus connection (see dSPACE Bus Support).<br>- With HIL, DIL and also VIL, a wide variety of SUTs must be coupled. This includes sensors such as radar, lidar, camera and USS. However, a distinction must be made here as to whether raw data, target lists, object lists or whether the sensor is stimulated over-the-air. dSPACE provides a solution for all use cases (restriction: a lidar OTA solution is currently being developed). However, other interfaces are also required, such as LTE, 5G, V2X or GNSS. These have also already been used in various customer projects or implemented on a customer-specific basis. | SuTs ca be integrate in the simulatoin loop via open APIs based on ASAM OSI or RTI DDS and a simulation framework. | AAI's simulation platform offers a well-defined Standard API for all data structures within the data model. The integration of the system under test (SUT) is facilitated by an efficient semi-automated workflow, including code generation and additional implementation to connect data structures received via the standard API to the SUT-specific interfaces. This integration process follows the tool qualification guidelines in accordance with ISO 26262 standards.<br>AAI supports various types of sensor interfaces, including:<br>**Direct raw sensor data injection** (e.g., ultrasonic echoes, camera images) via specialized hardware adapters.<br>**Over-the-air solutions** for video using real sensor heads (e.g., camera) by filming a monitor.<br>**Injection of pre-processed data** (e.g., radar locations) via bus interfaces such as CAN-FD and Ethernet.<br>**Object lists** transferred via bus interfaces or proprietary interfaces, with (de)serialization tools available for data conversion between simulation (x86) and target architecture (e.g., ARM).<br>For bus interfaces, AAI supports hardware I/O interfaces and protocols such as CAN, CAN-FD, FlexRay, and Ethernet (SOME/IP). The platform also supports multi-ECU systems, providing flexibility with virtual ECUs integrated via FMI/FMU alongside real ECUs. | | Supports model interfaces like Simulink and ROS. | | Provides interfaces for comprehensive system integration. |
| | **Integration of Instruction Set simulation and processors** | dSPACE provides the CoSim API which has already been used to connect a wide variety of instruction set simulators such as Synopsys Virtualizer, ASTC VLAB or QEMU in various projects. | Ansys supports industry standards including ASAM OpenDrive, OpenScenario XML, Open Simulation Interface (OSI), and Functional Mock-up interface (FMU). | AAI's modular simulation framework supports the integration of Instruction Set simulations and processors, enabling precise and efficient validation of system components. This capability allows AAI to simulate complex virtual Electronic Control Units (vECUs) and processors, ensuring that the system under test is fully representative of real-world conditions.<br>With AAI's support for Instruction Set simulation, developers can gain deeper insights into how software interacts with hardware at a low level, making it an essential tool for optimizing ADAS and autonomous driving systems. | | Supported industry standards include OpenDRIVE, OpenSCENARIO, Open Simulation Interface (OSI), Robot Operating System (ROS) 2.0, Functional Mock-up Interface (FMU) | | Supported industry standards include OpenDRIVE, OpenSCENARIO, Open Simulation Interface (OSI), Robot Operating System (ROS) 2.0, Functional Mock-up Interface (FMU) |
| | **Supported levels of V-ECUs** | The dSPACE solution can generate corresponding V-ECUs of level 1, 2 and 3, which can then of course be integrated into the simulation. Models of V-ECUs (L0) can be easily integrated via Simulink or FMU. The integration of L1 to L3 can then also be carried out via FMUs. Level 4 V-ECUs (including its simulators) can also be integrated by using CoSim API. | The simulation framework allow to connect with 3rd party component such as model, rehosted software, dockerize software or v-ECU simulation platform | AAI's platform supports flexible combinations of simulation engines, sensor models, vehicle dynamics models, and virtual Electronic Control Units (vECUs). AAI offers support for various levels of vECUs, going beyond standard offerings, and enabling customers to simulate and validate both base and complete software stacks. With the ability to integrate across multiple vECU types, AAI provides a robust environment for testing and optimizing ADAS and autonomous driving | | | | supports ECU |
| | **Integration of several SuTs and their communication** | In many projects, whether in HIL or SIL, VIL or DIL, dSPACE has set up component, domain simulations up to virtual vehicles. In SIL applications, high double-digit artifacts such as FMUs, V-ECUs or bus containers are integrated and simulated. Especially in the HIL context and sensor simulation, dSPACE has been able to set up several HIL test systems in recent years, which calculate the corresponding raw data in real time for more than 20 sensors such as radar, lidar and camera based on the AURELION high-fidelity sensor simulation and then feed it into the corresponding interface and SUT. In most projects, bus support plays a decisive role and is part of such validation systems, as interface and performance tests are usually carried out in addition to safety and security tests. Cybersecurity tests in particular are increasingly being validated with dSPACE HIL technology. | The simulation framework allow to connectas much SuTs as needed. The communication bus is based on RTI DDS and can emulate commuincation between SuT. Additionnaly, customer can connect the simulaiton framework with 3rd party component such as vehicle bus communication emulator. | Co-simulation is a core capability within AAI's toolchain, enabling seamless integration of a wide array of simulation components. AAI allows for the flexible combination of multiple models, virtual ECUs, and physical ECUs, depending on whether the system is operating in a Simulation-in-the-Loop (SiL) or Hardware-in-the-Loop (HiL) environment. This co-simulation capability provides a robust foundation for complex simulations and allows users to refine individual components while maintaining system-level integrity. | | | | |
| **MATURITY AND AVAILABILITY** | | | | | | | | |
| **ENDURANCE TESTS AND CURRENT INTEGRATION** | | 35+ years of experience: thousands of industry-proven successful and worldwide projects.<br>dSPACE is certified according to ISO 9001.<br>dSPACE simulation environment is certified according to ISO 262626.<br>dSPACE tools, simuatlions, systems are designed for 24/7 tests, incl. long endurance runs. | The software is ISO 26262 certified and thoroughly tested by the Ansys Quality Assurance team and by its team of engineers. The software is deployed in production at BMW https://www.ansys.com/news-center/press-releases/5-3-22-the-bmw-group-and-ansys-co-developing-simulation-software-for-automated-and-autonomous-driving<br>The Ansys tool was used by BMW for Personal Pilot level 3 homologation. Ansys is proven for validating high level of autonomy feature. | customer ready | | | | aiSim 4 is designed for high-mileage tests, indicating robust endurance testing capabilities enabling exploratory testing and metrics driven testing |

| | | TIER1 SUPPLIER | CHIPMANUFACTURER | | HYPERSCALER | |
|---|---|---|---|---|---|---|
| | *FULL NAME* | BOSCH | NVIDIA | QUALCOMM | AWS | MICROSOFT AZURE |
| | *COMMENTS* | BASED ON INTERVIEW, INCLUDES ETAS & FIVEAI | | | BASED ON INTERVIEW | |
| **PLATFORM** | | | | | | |
| **WORKFLOW MANAGEMENT** | **Test Management - ISO 34502** | Bosch ADAS development includes cutting-edge test management process and capabilities, meticulously designed to align with ISO 26262 standards and seamlessly integrated within our comprehensive Process Library. Application of state of the art test management tools ensures traceability from requirements to test reports resulting in colloborative development and compliance in test management endeavors. The tool offers various use cases, including BSW, CSW/ASW, system integration, and validation support. BOSCH offers TraiNCAP, a tool that validates evolving scenarios by "training" on various situations and using sensor data to create a digital twin. | Nvidia Website and blog does not provide information. Only very little information on NVIDIA DRIVE Sim available. Access to the SIM is only available to existing NVIDIA partners and currently no new partners are accepted (Status October 2024). | Qualcomm's Snapdragon Ride™ Platforms are designed for rapid creation of safe, scalable, and updateable ADAS solutions, although specific ISO 34502 compliance details are not explicitly mentioned. | AWS is not offering a managed service for ADAS/AV test management specifically but provides access to various partner test mangement tools, such as dSPACE, Siemens, Tracetronic, IPG Automotive, Synopsis, Panasonic, b-plus, NetApp, IAV hosted on AWS infrastructure. These solutions are available as SaaS offerings and deeply integrated with the AWS infrastructure. Some of our customers decide to build their own platforms and joint teams of the customer, AWS Professional Services and partners build these platforms e.g. the Orion Platform of BMW, the CAEdge solution of Continental or the Virtual Engineering Workbench (VEW) for Stellantis. | |
| | **Scenario Management - ISO 34502** | Bosch Simulation tools include wide range of Scenario Generation capabilites ensuring a fully flexible, modular and efficient simulation approach tailored for all use cases, including Verification and Validation (V&V).<br>Strong emphasis on reuse of scenarios across various test environments, as well as across various customer projects, maximizes efficiency and consistency of our testing practices. Users begin by selecting maps and configuring parameters, with the option to use test scenarios created by others or create their own. The parameterization process is sophisticated, using Open-Scenario for management, with the initial test setup conducted manually but completed by the API. | Nvidia Website and blog does not provide information. Only very little information on NVIDIA DRIVE Sim available. Access to the SIM is only available to existing NVIDIA partners and currently no new partners are accepted (Status October 2024). | Qualcomm's solutions support efficient scenario management for autonomous vehicles. | available via partners | |
| | **Data Management - ISO 34502** | Assuming the questions refers to kpi result storage and visualization of simulation jobs:<br>Bosch provides integrated, cloud-native Data Management platform for comprehensive KPI result storage and visualization of simulation jobs. The flexible tool architecture also supports rapid data model changes and baselining, adapting seamlessly to evolving project needs.<br>Equipped with local development environment and cutting-edge continuous deployment and continuous release automation, our solution guarantees efficient operations. The solution provides exceptional insights and performance tracking with built-in support for aggregation and comparison of results | Nvidia Website and blog does not provide information. Only very little information on NVIDIA DRIVE Sim available. Access to the SIM is only available to existing NVIDIA partners and currently no new partners are accepted (Status October 2024). | Robust data management capabilities are expected, essential for handling large datasets in ADAS/AD development. | available via partners | Azure Data Factory is a data integration service that allows creation of data-driven workflows in the cloud for orchestrating and automating data movement and data transformation. |
| | **Analytics - Safety Arguments** | The simulation environments at Bosch supports a wide range of critical use cases. It supports closed-loop software requirement verification tests (up to SIL/HIL ASIL B) through continuous testing, ensuring robust and reliable performance of the function. Data driven models bound to the platform allow for quantitative simulations for virtual NCAP testing and sensor model development.<br><br>It enhances development by enabling debugging of ADAS software during closed-loop simulations, predicting outcomes of original EURO NCAP car-based tests during development, and providing the new 2026 virtual robustness NCAP tests. Bosch's solution spearheads support for all quantitative SIL activities, ensuring comprehensive coverage and precision.<br><br>The platform features automated testing, advanced KPI analysis, and distributed simulation capabilities that seamlessly integrate across cloud, on-premise, and local environments. | Nvidia Drive support active Safety applications like automatic emergency breaking, lane departure warning, and more.<br>No clear information on Nvidia Sim was available. | Qualcomm's platforms likely include analytics features for safety arguments and KPI calculation and evaluation. | available via partners | Azure Data Lake is a scalable data storage and analytic service for big data analytics workloads that require developers to run massively parallel queries. |
| | **Safety - ISO26262 compliant** | Bosch XiL Simulation Framework stands out as a certified solution according to ISO 26262, ensuring safety and reliability for System Under Test (SuT) testing up to ASIL B for both Software-in-the-Loop (SIL) and Hardware-in-the-Loop (HIL) environments.<br><br>The framework guarantees the highest standards for software verification tests, delivering exceptional confidence and compliance in testing processes. | The Nvidia DRIVE Hyperion compute architecture is based on the DRIVE Orin system-on-a-chip (SoC). NVIDIA DRIVE core development processes are certified as ISO 26262 compliant by TÜV Süd.<br>Also Adheres to Global NCAP | Qualcomm's products are designed to meet high levels of automotive safety, which may imply ISO26262 compliance. | AWS follows a shared responsibility model: AWS supports 143 security standards and compliance certifications as described on the AWS Compliance Programs page, including PCI-DSS, HIPAA/HITECH, FedRAMP, GDPR, FIPS 140-2, ISO/IEC 27001:2022, 27017:2015, 27018:2019, 27701:2019, 22301:2019, 20000-1:2018, 9001:2015, and CSA STAR CCM v4.0 and NIST 800-171 | |
| | KPI CALULATION AND EVALUATION | Bosch simulation toolchain excels in KPI calculation and evaluation at multiple levels (system and sub-system). Whether performed online or offline (in-situ or post-processing), our toolchain ensures accurate and efficient analysis. For offline evaluations, it collects and analyzes ASAM-compliant .mf4 data from the controller under test alongside a ground truth file, delivering precise insights. Additionally, our solution is highly adaptable, capable of fulfilling specific customer requests within their unique contexts. Users can also integrate commercial alternatives | | The Snapdragon Ride Platform likely supports KPI calculation and evaluation, but specific details are not provided. | available via partners | available via partners |

| | TIER1 SUPPLIER | CHIPMANUFACTURER | | HYPERSCALER | |
|---|---|---|---|---|---|
| *FULL NAME* | **BOSCH** | **NVIDIA** | **QUALCOMM** | **AWS** | **MICROSOFT AZURE** |
| *COMMENTS* | BASED ON INTERVIEW, INCLUDES ETAS & FIVEAI | | | BASED ON INTERVIEW | |
| **Integration into CI/CD/CT pipelines.** | Bosch's cutting-edge simulation solution seamlessly integrates into any CI/CD/CT pipeline of our customers, offering advanced pipeline automation and DevOps integration for fast builds, quick testing feedback, and endless scalability, thanks to its cloud-agnostic architecture. Automated tests can be scheduled to run weekly, nightly, or triggered by pull requests (PRs), acting as a crucial quality gate to ensure the highest standards. | The NVIDIA DRIVE Level 2+ solution is trained and validated on NVIDIA DRIVE Infrastructure—a true end-to-end development process based on a unified computing architecture. It starts with NVIDIA DGX™ systems, which enable streamlined, largescale DNN training and optimization. Using the power of GPUs and AI, developers can comprehensively train DNNs for autonomous vehicle perception, planning, control, and more. The NVIDIA DRIVE Constellation™ and NVIDIA DRIVE Sim™ platforms provide a virtual proving ground with a near-infinite variety of driving conditions to test and validate DNNs on the same hardware as in the vehicle. Combined with the DRIVE AV solution, DRIVE Infrastructure creates a continuous development cycle for constant improvement.<br><br>https://developer.nvidia.com/sites/default/files/akamai/drive/auto-print-drive-product-brief-final.pdf | Qualcomm's solutions are likely to be integrable into CI/CD/CT pipelines, but specific details are not provided. | For customers like Stellantis, the Virtual Engineering Workbench was built to provide pre-configured runtime environments (digital toolchains) and virtualized hardware abstraction environments. These runtime environments can be integrated into customers' existing CI/CD environments to improve consistency, code quality and reproducibility. | |
| **Integration into the development enviroment** | Bosch Simulation Tooling offers a comprehensive suite of capabilities for seamless integration into development environment that supports debugging, visualization, and analysis in local IDEs or via a web interface in the cloud, ensuring maximum flexibility and convenience. We prioritize providing the best possible developer experience for our internal function developers and testers by utilizing modern, virtualized technologies that seamlessly integrate with state-of-the-art software development processes. Our innovative debugging container delivers the entire debugging setup to a developer's machine ffering rapid test, performance, and debugging feedback | With their offered APIs, you can connect to a vast ecosystem of partners building simulation tools for vehicle dynamics and traffic. You can also bring in USD content to expand to new locales and tackle new operational design domains (ODDs). | | AWS supports several ways of integrating the OEMs or 1st Tier suppliers environment. Stellantis for instance virtualized their complete Automotive SW development and testing environment using the Virtual Engineering Workbench. Developers can select from a variety of available instance types. They have access to their data, IDEs, simulation tools on these environments. It avoid the need to copy large amounts of data to the development machines, which is vital especially in AD development. At the same time ensures development environments are replicable, no more "but it works on my machine". Additionally new developers can be onboarded in days instead of weeks. SW which is build on the virtual machines can be tested on virtual targets directly or deployed on HiL setups.<br><br>It eases also the pain of aligning a global process. | |
| **SCENARIO GENERATION** | | | | | |
| **User defined Scenarios** | Bosch's scenario capabilities empowers the developers with a graphical scenario editor featuring intuitive drag-and-drop functionality and live debugging within the editor.<br><br>The tool supports OpenSCENARIO DSL or XML exports, ensuring flexibility and compatibility with various formats. For those who require precise control, our solution also includes a text-based editor specifically designed for OpenSCENARIO DSL scenarios. | | Qualcomm provides user-defined | AWS supports Partner solutions for scenario creation, such as classic scenario editors like dSPACE ModelDesk or automation scenario extraction methods from real-world data found in tools like Siemens SimCenter Autonomy or IPG's Scenario RRR.<br><br>Currently, our partners are exploring extended methods to create scenarios by augmenting these classic approaches with generative AI. For instance, at the AWS Automotive Symposium in Munich, dSPACE showcased a "Natural Language-based Scenario Generation" demo, which leveraged Amazon Bedrock's GenAI backend for natural language processing capabilities.<br><br>Amazon Bedrock is a fully managed service that offers a choice of high-performing foundation models (FMs) from leading AI companies like AI21 Labs, Anthropic, Cohere, Meta, Mistral AI, Stability AI, and Amazon through a single API, along with a broad set of capabilities you need to build generative AI applications with security, privacy, and responsible AI. Using Amazon Bedrock, you can easily experiment with and evaluate top FMs for your use case, privately customize them with your data using techniques such as fine-tuning and Retrieval Augmented Generation (RAG), and build agents that execute tasks using your enterprise systems and data sources. Since Amazon Bedrock is serverless, you don't have to manage any infrastructure, and you can securely integrate and deploy generative AI capabilities into your applications using the AWS services you are already familiar with. | Microsoft Azure Machine Learning (Azure ML) provides tools and frameworks for developers to create their own machine learning and artificial intelligence (AI) services. Azure AI Services by Microsoft comprises prebuilt APIs, SDKs, and services developers can customize. These services encompass perceptual and cognitive intelligence features such as speech recognition, speaker recognition, neural speech synthesis, face recognition, computer vision, OCR/form understanding, natural language processing, machine translation, and business decision services. Many AI characteristics in Microsoft's products and services, namely Bing, Office, Teams, Xbox, and Windows, are driven by Azure AI Services. |
| **SCENARIOS** | | | | | |
| **Function based Scenarios - Automatic** | Function based scenarios are fully supported with varying levels of control as required. Agents can be moved along a precise set of waypoints or can be configured to follow a lane or complete an A->B style route navigating lanes and junctions as needed. Agents can be configured with automatic "behaviours" such as performing adaptive cruise control, obeying traffic lights, or giving way at junctions, to simplify scenario creation where precise control is not needed. Agents can be sychronised to reach particular points with a given speed to ensure that precise events happen as desired. Users can customize maps by drawing elements such as pedestrian paths and vehicle routes, incorporating traffic regulations, and integrating external tools like CARLA to address missing features. | Functions for creating specific scenarios exist, e.g. Accident scenario generation | The Snapdragon Ride SDK supports customizable ADAS applications, which may include function-based scenarios. | available via partners | |
| **Scenario generation using real-world data** | Real world data can be used to speed up scenario creation process by automatically extracting positions, speeds, and sizes of agents. These can be further refined through batch operations and manual editing. Modifications can be made to assess how the tool predicts real-world behavior under altered conditions, such as a van suddenly changing lanes near the test vehicle. | Real world scenarios can be reconstructed in the simlulation and servce as the foundation for variations. | Qualcomm's solutions likely support this, but specific details are not provided. | available via partners | |
| **Artificial Trafficmodels** | Bosch Traffic generation models uses unique source/ sink methods to generate traffic streams specific routes and regions around the ego thereby enhancing accuracy and applicability of simulations. In addition, the modular framework from Bosch allows to integrate any types of third party models. | Dynamic driving scenarios can be generated using self-supervised learning. Also realtistic traffic scenrios can be generated through BITS. | Specific details on support for artificial traffic models are not provided. | available via partners | |
| **Support of Standards (PSV, ODR, OSI) Database for scenarios** | Bosch relies as much as possible on ASAM standarts for interfaces, including OpenDrive and OpenScenario.(OpenSCENARIO XML and DSL are both supported.)<br>Open Simulation Interface (OSI Standard) is supported for the interface to the system under test or other internal modules, such as simulation data recording and perception error models. | | Specific details on standards support are not provided. | available via partners | |
| **Covered areas areas of simulation** | Bosch as a system supplier is highly skilled in the modeling of all aspects of the automotive chain. Simulation is targeted at phenomenological based testing with statistically valid perception error models to test how the system behaves with noisy inputs.<br>By accurately modeling sensors, vehicle dynamics, and powertrains through co-simulation with customer applications, Bosch ensures precise, reliable results that enhance your development processes and product performance. | Many different scenarios can be generated. Sensor Input can also be adjuste, allowing for synthetic data input (e.g. Camera footage) | | available via partners | |

| | | TIER1 SUPPLIER | CHIPMANUFACTURER | | HYPERSCALER | |
|---|---|---|---|---|---|---|
| | *FULL NAME* | BOSCH | NVIDIA | QUALCOMM | AWS | MICROSOFT AZURE |
| | *COMMENTS* | BASED ON INTERVIEW, INCLUDES ETAS & FIVEAI | | | BASED ON INTERVIEW | |
| **MAPS & OPERATIONAL DESIGN DOMAINS (ODDS)** | | | | | | |
| **MAPS** | **Coverage** | Bosch solutions offer robust support for externally provided HD maps from sources like RoadRunner and Atlatec, ensuring seamless integration into projects.<br><br>Our advanced synthetic map creation tooling allows for export to multiple map formats, including OpenDRIVE, Lanelet2, and internal formats, providing comprehensive coverage for various operational design domains. | | Qualcomm's positioning technologies support connected navigation, which may imply comprehensive map coverage. | available via partners | |
| | **Function based ODDs** | Simulations can be run on maps which are representative of the real world, either those created through an HD mapping process, or SD maps derived from fleet data. The latter in particular provides significant coverage of the target ODD.<br>Where real-world maps are not available, synthetic maps can be created to represent the remainder of the ODD. These can be created in code, via an editor, or by defining a map variants and parameterising at scenario exploration time. | With these APIs, you can connect to a vast ecosystem of partners building simulation tools for vehicle dynamics and traffic. You can also bring in USD content to expand to new locales and tackle new operational design domains (ODDs). | Specific details on these map types are not provided. | available via partners | |
| | **Route based Maps** | Support crowd-based maps collected from fleet data.<br>On all map formats, agents can be configured to follow an A->B style route, navigating junctions as required. | | | available via partners | |
| | **Automation** | Automated creation of parameterised synthetic maps based on user defined road maps and joins.<br>Automated creation of real-world maps based on crowd-sourced fleet data. | | | available via partners | |
| | **Maps for parking simulation** | Maps for parking simulation require special features. Examples are the addition of custom markings to the map in order to cover parking slots in different countries - both alongside a street or within a bigger parking area. In addition maps for multi-level parking garages has to be covered. Bosch simulation tooling is routinely used for the development of parking features and therefore offers the capabilties to handle the above mentioned features. | | Qualcomm's solutions support these features, but specific details are not provided. | available via partners | |
| | **NDS Support** | supported | | Specific details on NDS support are not provided. | | |
| **INFRASTRUCTURE** | | | | | | |
| **CLOUD** | **Cloud Native Services** | Bosch offers a cloud-native, multi-tenant platform within Azure and other vendors, utilizing a microservices-based architecture.<br>Our platform is designed for scaling simulations and aggregated analytics, providing unmatched performance and efficiency.<br>Additionally, we provide convenient wrappers for viewing content such as scenarios, maps, and test suites, ensuring a seamless and user-friendly experience. | NVIDIA DRIVE Infrastructure encompasses data center hardware, software, and workflows—both on premises and in NVIDIA DGX Cloud & Omniverse. It includes developer-friendly APIs for physically based sensor simulation and realistic behavior to accelerate AV testing and validation at cloud scale. | | by definition | by definition |
| **LAB** | **On Premises** | Bosch supports the execution of individual scenarios on-premises, combining the best of local and cloud-based solutions. While the overall orchestration, scenario storage, evaluation, and aggregation are managed in the cloud, a configurable pool of on-premises workers can handle individual workloads and report back results. This hybrid approach ensures flexibility, efficiency, and seamless integration of testing and simulation processes. | | | AWS supports hybrid setups for combined HiL-SiL setups:<br>AWS provides a range of services and solutions that enable hybrid setups, combining on-premises infrastructure with cloud resources for HiL and SiL testing in the automotive industry.<br><br>1. AWS Outposts: AWS Outposts is a fully managed service that extends AWS infrastructure, services, and tools to on-premises or co-located data centers. This allows organizations to run HiL and SiL workloads on the same AWS services and APIs used in the cloud, while keeping sensitive data and low-latency workloads on-premises.<br>2. AWS Wavelength: AWS Wavelength enables developers to build ultra-low latency applications by deploying AWS compute and storage resources at the edge of telecommunications providers' 5G networks. This can be beneficial for real-time HiL and SiL testing scenarios that require minimal latency.<br>3. AWS Direct Connect: AWS Direct Connect provides a dedicated network connection between an organization's on-premises infrastructure and AWS, enabling secure and consistent data transfer between HiL and SiL systems and cloud resources.<br>4. AWS IoT Greengrass: AWS IoT Greengrass allows organizations to run AWS Lambda functions, machine learning models, and other services on edge devices or on-premises servers, enabling local data processing and decision-making. This can be useful for processing and analyzing sensor data from HiL setups in real-time.<br><br>Real-time and recorded data processing:<br>In combined HiL-SiL setups, both real-time and recorded data processing scenarios can be supported using AWS services.<br><br>1. Real-time processing: AWS IoT Core and AWS IoT Greengrass can be used to ingest and process real-time data streams from HiL setups, enabling immediate analysis and decision-making. AWS services like Amazon Kinesis and Amazon SageMaker can also be used for real-time data processing and model deployment.<br>2. Recorded data processing: AWS storage services like Amazon S3 and Amazon Elastic File System (EFS) can be used to store recorded data from HiL and SiL testing scenarios. This data can then be processed and analyzed using AWS analytics services like Amazon Athena, Amazon EMR, and Amazon SageMaker for model training and validation.<br><br>Caching on the edge with AWS partners:<br>AWS partners with companies like Seagate and Equinix to enable edge caching solutions for automotive use cases, including combined HiL-SiL setups.<br><br>1. Seagate: AWS and Seagate collaborate to provide edge caching solutions using Seagate's Lyve Cloud and Lyve Edge solutions. These solutions enable organizations to cache data closer to the HiL and SiL infrastructure, reducing latency and bandwidth requirements for cloud connections.<br>2. Equinix: AWS and Equinix have a strategic partnership that allows organizations to deploy AWS Direct Connect and AWS Outposts within Equinix data centers, enabling low-latency edge caching and processing for automotive workloads.<br>By leveraging edge caching solutions from partners like Seagate and Equinix, combined HiL-SiL setups can benefit from reduced bandwidth requirements for cloud connections, improved performance, and lower latency for real-time data processing and analysis. | The Microsoft Azure Service Bus allows applications running on Azure premises or off-premises devices to communicate with Azure. This helps to build scalable and reliable applications in a service-oriented architecture (SOA). Azure Stack HCI is a hyper-converged infrastructure (HCI) product that uses validated hardware to run virtualized workloads on-premises to consolidate aging infrastructure and connect to Azure for cloud services. |
| **TOOLS** | **Editing, Data, Visualization etc** | Bosch provides a versatile mix of local and cloud-based tools designed that ensures integration and interchange of tooling across various projects.<br>The infrastructure supports both individual instances—whether local or cloud-based—for scenario creation and result visualization, as well as cloud-based aggregation tools for curating and searching data and analyzing large test runs. This hybrid approach ensures that you have the flexibility and scalability to meet the unique demands of every project. | | | | Azure Web Sites allows developers to build sites using ASP.NET, PHP, Node.js, Java, or Python, which can be deployed using FTP, Git, Mercurial, Team Foundation Server, or uploaded through the user portal |

| | | TIER1 SUPPLIER | CHIPMANUFACTURER | | HYPERSCALER | |
|---|---|---|---|---|---|---|
| | *FULL NAME* | BOSCH | NVIDIA | QUALCOMM | AWS | MICROSOFT AZURE |
| | *COMMENTS* | BASED ON INTERVIEW, INCLUDES ETAS & FIVEAI | | | BASED ON INTERVIEW | |
| LOCAL | **Local usage on dev. machine + debugging (breakpoints, stepping through code and plots)** | Bosch's infrastructure allows individual simulations to be executed locally against a system under test, with the option to attach a debugger if needed. Additionally, evaluations can be run locally against previous test results, aiding in the development of precise evaluation criteria. This flexibility ensures thorough testing and refinement processes, enhancing the overall development workflow. | | | | |
| **X IN THE LOOP** | | | | | | |
| SIL | **Software in the loop** | Bosch's Simulation-in-Loop (SiL) solutions support flexible combinations of simulation engines, sensor models, vehicle dynamics models, and virtual Electronic Control Units (vECUs).<br>We accommodate multiple vECU types to meet specific project requirements, including vECU type 1 and vECU type 3.<br>With extensive experience in release tests across multiple customer projects, our qualified test environment adheres to ISO 26262 standards, forming a critical part of the V&V strategy in Bosch projects.<br><br>Innovative methods and quantitative comparisons are employed in validating SiL results with vehicle measurements ensuring credible and reliable simulations.<br><br>Our common XiL Core framework serves as the backbone, creating synergies with Hardware-in-Loop (HiL) testing for comprehensive and integrated validation processes. The XiL Cluster Simulation Loop is facilitated through applications like Sebastos Automation, NCAP Smart Scenarios, Dstats, and VisMO AI. | | | Using the Virtual Engineering Workbench, customers have access to virtual environments in different levels of abstraction from the target hardware (L1 to L4). These envrionments can be used for SiL testing or providing quick feedback to developers / testers in manual scenarios. | |
| MIL | **Module / Model in the Loop** | Bosch offers an in-house solution for enabling the capabilities of software component-based simulations in closed loop. This robust approach ensures precise and efficient testing, allowing for thorough validation and refinement of individual software modules within the complete system simulation. | | | | |
| HIL | **Hardware in the loop** | Bosch's Hardware-in-Loop (HiL) solutions leverage synergies with our Simulation-in-Loop (SiL) capabilities, utilizing the common XiL Core framework as the backbone. With extensive experience in numerous customer projects, our HiL environment is a proven choice for series releases. Our tools are qualified according to ISO 26262, ensuring the highest standards of safety and reliability.<br><br>We emphasize collaborative development, close coordination, and direct contact with developers to maintain consistency across all use cases. Strategically important non-functional requirements, such as reusability, scalability, maintainability, and availability, are prioritized to deliver robust and efficient testing solutions. | | | ECUs in the AV/ADAS domain leverage purpose-built hardware, such as Neural Processing Units (NPUs), Application-Specific Integrated Circuits (ASICs), and Image Signal Processors (ISPs). While individual functional components of the overall system can undergo separate testing, validating the full system requires a mechanism to reprocess the elements that run on specialized hardware accelerators. Specialized hardware accelerators can be emulated. However, this emulation is compute intensive and often inefficient, e.g. the emulation of an ISP can take up to 160x longer than on the actual hardware. AWS offers different approaches to help customers validate their system in an efficient way:<br><br>For customers such as Stellantis, dSPACE supported a proof-of-concept, in which HiLs in corporate data centers have been integrated with virtualized runtime environments and SiL setups.<br><br>For BMW parts of Qualcomm chips were integrated into the AWS data center and made available via EC2 instances. These so called SoftHiLs allows BMW to efficiently process data directly in the cloud without the need of downloading the data. | |
| VIL | **Vehicle in the Loop** | Bosch leverages its broad system understanding to develop high-quality component models for comprehensive vehicle simulations in the ADAS field. Our extensive expertise in vehicle measurement technology and system-level validation enables us to create premium ADAS simulations. We adhere to a rigorous credibility process in accordance with regulatory requirements such as NCAP and UNECE. Additionally, Bosch has substantial experience in Vehicle-in-Loop (ViL) testing, particularly with the targeted injection of objects to test ADAS performance in critical and dangerous scenarios. | | | | |
| **ENVIRONMENT** | | | | | | |
| OS | **Linux / Windows** | The majority of Bosch's tools are designed for Linux, catering to the extensive group of internal Linux desktop users and supporting cloud and cluster deployment through containerization (e.g., Docker). For Windows users or projects utilizing tools from the Windows ecosystem, we offer native Windows builds or virtualization solutions such as WSL, ensuring seamless integration and flexibility across different operating environments. | DriveOS is Linux based | | Amazon provides many managed compute options, and Amazon EC2 provides out-of-the box support for Windows, Linux etc | Azure provides all common used versoins of Linux, including Microsoft's own Linux-based Azure Sphere |
| OPEN | **Tool-external APIs** | Depending on the use case, our tools implement industry-standard interfaces such as FMI, ASAM standards, or OpenSCENARIO. This approach ensures reusability across various use cases and projects and enables seamless interoperability with both in-house and third-party tools. | | | | |
| | **Modularity of the toolchain** | Modularity is a fundamental principle in our tool design, driven by the need to cater to a diverse and extensive user base. To meet varied requirements and custom-tailor new simulation setups from existing solutions, our approach emphasizes a highly modular simulation toolchain.<br><br>We continuously maintain and enhance this modularity, ensuring that our tools remain adaptable and scalable to meet evolving needs. Modules are reusable, with built-in support for scenario analysis and variation | | | | |
| | **Provide configurable sensor models** | Bosch provides configurable sensor models across multiple levels including statistical, physical and phenomenological, to meet diverse simulation and testing needs. | | | | |
| | **Type of Sensors (Rada, Lidar, Camera,..)** | Bosch offers a comprehensive range of sensor models, from physically-based to ideal, tailored for systems under test. Our solutions cover Radar, Camera, and Ultrasonic modalities, with interfaces that handle raw data, processed data, and object data. We also integrate foundational models to deliver robust and comprehensive solutions for advanced driver assistance systems (ADAS) and autonomous driving technologies. Additionally, Bosch contributes to ISO 11010-2, which provides a standard framework for defining and categorizing simulation models based on various sensor modalities, ensuring consistency and reliability in testing, verification, and validation processes. | Nvidia offer support for cameras, lidar, radar, and ultrasonics sensors. | | | |

| | | TIER1 SUPPLIER | CHIPMANUFACTURER | | HYPERSCALER | |
|---|---|---|---|---|---|---|
| | *FULL NAME* | **BOSCH** | **NVIDIA** | **QUALCOMM** | **AWS** | **MICROSOFT AZURE** |
| | *COMMENTS* | BASED ON INTERVIEW, INCLUDES ETAS & FIVEAI | | | BASED ON INTERVIEW | |
| | **Connection of sensor to the device under test (HIL and SIL)** | Bosch supports integration of sensor models across various context including Hardware-in-the-Loop (HiL) / Hardware-on-the-Loop (HoL) and Software-in-the-Loop (SiL) / Software-on-the-Loop (SoL) within our modular simulation framework. | | | | |
| | **Possibility to integrate 3rd party sensor models e.g. by suppliers** | **yes** | Supports Integration via other providers | | | |
| | **Provide configurable vehicle model** | **yes internal vehicle model and vehicle models from 3rd parties** | | | | |
| | **Possibility to integrate 3rd party vehicle model** | **yes** | | | | |
| **BUS SIMULATION** | **Types of automotive busses (Ethernet, CAN, Flexray,..)** | Bosch brings extensive experience in automotive bus systems and restbus development, supporting a wide range of bus types including CAN, CAN FD, CAN TP, LIN, FlexRay, Ethernet I²C (Inter-Integrated Circuit), and Ethernet (SOME/IP). Our solutions enable seamless integration of these bus systems with real or virtual ECUs, utilizing both physical hardware and simulated solutions while prioritizing user experience and usability. | | | | |
| **SYSTEM** | **Special Datacenter components needed, e.g. MapR, openShift** | Our SiL solutions are built on container technology, requiring a Container Orchestration Platform for cloud scalability. Currently, we utilize Kubernetes clusters to manage and scale our containerized applications. For local deployments on PCs, any container platform can suffice, with Docker being our standard choice. | | | | |
| | **To which extent is the system automated and scalable?** | Our system is cloud-native and designed for multi-tenancy within cloud services (e.g., Azure), utilizing a microservices-based architecture. It is highly scalable, focusing on simulation and aggregated analytics. The platform features automatic queuing and retry mechanisms to efficiently manage and execute large-scale simulation runs. | | | | |
| | | | | | | |
| **COMPUTE** | **Parallel computing & orchestration** | Our cloud-based execution environment allows for highly parallelized computation by running individual tests in separate containerized environments.<br>Orchestration tooling efficiently manages queuing, automatic retries, and scaling of test workers to optimize both cost and throughput.<br>Additionally, we utilize spot instances to achieve a low cost per simulation, further enhancing cost-efficiency. | | | AWS supports 3rd party suppliers and also In-house tooling like AWS Batch. Managed Kubernetes clusters ECS | Azure provides optimisation methods for computing, highly depending on the use case |
| **ALGORITHM** | **Sampling algorithms** | Our system supports both brute-force exploration of parameter spaces and search-based exploration, utilizing evaluation metrics to identify and focus on potential areas of interest. When incorporating real-world data, our search algorithms efficiently estimate failure probabilities, enhancing the precision and reliability of the exploration process. | | | | |
| **PERFORMANCE** | | | | | | |
| **RUNTIME** | **Realtime factor** | Realtime Factor depends highly on the executed simulation engine, models and vECU. The simulation middleware itself is very lightweight and the execution is multiple times faster than realtime. | | | AWS supports latest GPUs from Intel, Nvidia. Together with Qualcomm, AWS introduced their AI100 chips as instances in the cloud. This instances enable realtime processing by making the vehicle HW available in the cloud.<br>AI100 instances can be scaled up or down on-demand, allowing automotive companies to allocate resources as needed for their workloads, enabling efficient resource utilization and cost optimization. | Azure Stream Analytics is a Serverless scalable event-processing engine that enables users to develop and run real-time analytics on multiple streams of data from sources such as devices, sensors, websites, social media, and other applications. |
| | **Vizualization provided by tool** | Depending on the use case Bosch offers different visualization methods ranging from fast & efficient Web UIs with simple 3D visualization to high definition video rendering methods. In addition, Bosch can integrate also commercial visualization tools into its modular Simulation framework in case required & requested. | | | | |
| | **Integration of 3rd party visualization e.g. Foxglove** | Besides the very capable inhouse vizualization solutions, Bosch simulation environments have standardized interfaces that enables integration of any third party vizualization components in the test environment. | | | Foxglove on AWS is supported on e.g. Amazon EC2 or EKS and has been used by customers like BMW. | |
| **GPU** | **Usage/Need of GPUs** | Bosch solutions have the flexibility to include GPUs as required for the use case. In general for headless use cases without rendering there is no dependency on GPU. | | | | |
| **CPU/RAM** | **CPU/RAM ressources for a simulation of 30s realtime** | yes, high focus on efficient C++ computation to achieve competitive real time factors. Specific numbers depend strongly on the applied models, use case, DUT … | | | | |
| **KEY FEATURES** | **Data Replay and Data-Driven Development** | Bosch's simulation environments are integral to end-to-end data-driven development by providing a robust platform for testing and validating models and systems under a variety of conditions.<br>These environments support integration of real-world data and enable data replay, allowing developers to recreate and analyze specific scenarios ensuring highly accurate simulations that reflect actual operating conditions.<br><br>The continuous loop of data collection, simulation, data replay, and analysis facilitates rapid iteration and refinement of models, ensuring that the final product is both reliable and optimized for real-world performance. By leveraging these advanced simulation environments, developers can make data-driven decisions at every stage of the development process, from design to deployment. | | | | |

| | | TIER1 SUPPLIER | CHIPMANUFACTURER | | HYPERSCALER | |
|---|---|---|---|---|---|---|
| | *FULL NAME* | BOSCH | NVIDIA | QUALCOMM | AWS | MICROSOFT AZURE |
| | *COMMENTS* | BASED ON INTERVIEW, INCLUDES ETAS & FIVEAI | | | BASED ON INTERVIEW | |
| **INTEGRATION** | | | | | | |
| SUT / VUT / EGO | **Homologation/ Freigabe-Prozess** | SiL and HiL are qualified according to ISO 26262 and the Bosch Tool Development Process. This qualification involves rigorous quality measures in platform development and a defined Integration Process for the XiL environment in specific projects, with corresponding quality measures. The Integration Process was developed by simulation experts with extensive experience in simulation platform development and project-specific integration. | | Qualcomm solutions support homologation and various methods/interfaces for System-under-Test integration. | | |
| | **Methods / interfaces for System-under-Test integration** | The Simulation Platform offers a defined Standard API for all data structures in the data model. Core part of the System under test integration is an efficient semi-automated workflow including code generation and additional integration implementation to connect the data structures received on the standard API with the System under test specific interfaces. The integration process is defined as part of the Tool Qualification according to ISO26262. Bosch has many years of experience with this integration and a pool of corresponding experts.<br><br>- Different types of sensor interfaces possible:<br>1. direct raw sensor data injection (e.g. for ultrasonic -> echos; camera -> images) via special hardware adapters (interface boxes)<br>2. over the air solutions for video using the real sensor heads (camera), over-the-air: filming a monitor<br>3. injection of pre-processed data (e.g. radar locations) usually via Bus interfaces (CAN-FD, Ethernet)<br>4. object lists for which usually either a bus interface is used or some proprietary interface and/or protocol for which specific (de)serialization tools are available to convert data from simulation (e.g. x86) to target architecture (e.g. ARM) implementation can be customer-specific<br><br>- for Bus Interfaces:<br>-- Support of hardware I/O Interfaces and the respective protocols such as CAN, CAN-FD, Flexray, Ethernet (SOME/IP)<br>-- multi ECU systems also supported with a flexible mixture of virtual ECUs (via “restbus”, integration e.g. via FMI/FMU) and real ECUs | | | | |
| | **Integration of Instruction Set simulation and processors** | The Bosch modular Simulation Framework offers the possibility tointegrate vECU Type4 simulation solution offering the Integration of Instruction Set simulatmion and processors. | | | | |
| | **Supported levels of V-ECUs** | Bosch applies vECUs of type 1 and type 3 (Complete SW, Base SW) | | | | |
| | **Integration of several SuTs and their communication** | The Co-simulation capability is a core concept of Bosch’s XiL Core Framework enabling integration of wide array of simulation components . For example a multitude of models or also multiple virtual or physical ECUs could be combined depending on SiL or HiL environment. | | | | |
| **MATURITY AND AVAILABILITY** | | | | | | |
| ENDURANCE TESTS AND CURRENT INTEGRATION | | High experience in HiL/SiL since decades in context of simulation of ADAS systems for all system levels and use cases. Products are proven in use in multiple customer projects. Certification and qualification of the modular simulation framework are highlighted in the questions above (e.g. ISO 26262, etc. ) The tool follows a systematic process of extracting, modeling, exploring, and analyzing data, with data extraction scripted rather than AI-driven. The tool has reached a high level of maturity, being used internally at BOSCH at level 4 and by customers for several years. A collaboration with CARIAD validates its effectiveness, having been tested and employed by multiple OEMs. | Computing technology and Driving platform open for codevelopment and Nvidia is cooperating wth many partners including but not limited to Mercedes-Benz, Volvo, Hyundai, BYD. | | World wide regions with several availability zones allow relyable reprocessing at scale around the globe. Customers such as MobileEype leverage spot pricing to save up to 90%<br><br>AWS Spot Pricing, also known as Spot Instances, is a pricing model offered by AWS that allows customers to bid for and utilize unused EC2 computing capacity at significantly lower costs compared to On-Demand Instances. These are spare EC2 instances that AWS sells at discounted prices, which can be up to 90% lower than the On-Demand Instance pricing. Spot Instances are available at a discount of up to 90% off compared to On-Demand pricing. | |

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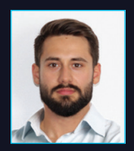

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# Get the future you want

# About Capgemini

Capgemini is a global business and technology transformation partner, helping organizations to accelerate their dual transition to a digital and sustainable world, while creating tangible impact for enterprises and society. It is a responsible and diverse group of 340,000 team members in more than 50 countries. With its strong over 55-year heritage, Capgemini is trusted by its clients to unlock the value of technology to address the entire breadth of their business needs. It delivers end-to-end services and solutions leveraging strengths from strategy and design to engineering, all fueled by its market leading capabilities in AI, cloud and data, combined with its deep industry expertise and partner ecosystem. The Group reported 2023 global revenues of €22.5 billion.

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