Capgemini engineering

The future of autonomous driving is almost here

Artificial intelligence dominates the second wave of game-changing advances in autonomous driving

Table of contents

Introduction

The first wave of modern advanced driver-assistance systems (ADAS) to hit the auto market two decades ago was a classic engineering systems event that integrated sensors in the vehicle to alert the driver to anomalies and, in some cases, intervene. For example, in 1999, Jaguar entered the market with its automated distance control system and a radar-based Active Cruise Control system with the Jaguar XKR.[1] In 2010, Volvo launched a pedestrian detection system that used radar and cameras to warn a driver if a pedestrian stepped in front of the car and then initiated an emergency braking procedure.[2]

However, the world has changed drastically in the last two decades. Now, ADAS and Autonomous Vehicle (AV) systems based on artificial intelligence (AI) have proliferated and data-driven engineering, test, and validation have advanced significantly. Nations worldwide are regulating safety-critical AV systems. International organizations such as UNECE, SAE International, and ISO, as well as regional organizations such as TÜV and Euro NCAP in Europe, NHTSA in the US, and CATARC in China, have established roadmaps and rigorous safety standards for autonomous driving functions, such as forward collision prevention, back-up and parking, lane assist, maintaining a safe distance, and automatic emergency brake systems. Norms and standards around ISO 26262 and SOTIF have been established within the automotive industry. All these innovations aim to improve safety and reliability.

As the technology evolves, complexity increases, especially for SAE Level 3, which has limited AV features, and Levels 4 and 5, which have complete autonomy.[3] To get there, automakers are adding more networked sensors into vehicles, such as cameras, LiDAR, and radar. They are fusing the perception results, which require sophisticated digital communications and adds complexity.

Automakers have introduced AV domain controllers, consolidating the processing, thus implementing a centralized, AI-based autonomous driving system. This advancement makes it more challenging to prove and document the decision-making process in terms of predictability, rationality, and completeness of AI systems that make decisions on behalf of the driver.

This leads to the biggest challenge automakers face: the traditional engineering of sensors and software is already enormously complex, but now so is the management of the massive amounts of data required to validate AI-based systems. Next-generation autonomous vehicle platforms can easily generate up to 200 terabytes of data a day. In a week, they can generate a petabyte of data. The amount of data needed for SAE Level 3 autonomy can easily be 200 to 300 petabytes. That is five to seven times more than the estimated size of the Google Maps database, which is estimated to run at approximately 43 petabytes for the whole globe.[4]

A large number of test scenarios and over 100 million kilometers of test drives are required to validate AV functions safely. This requires a massive amount of driving, testing, validation, and a well-thought-out end-to-end process incorporating virtual simulation, data mining, and AI.

Today, testing is done on the road, at the test bench, and in the data center. Often the validation ecosystem consists of code review, unit and component testing, Model-in-the-Loop (MiL), Software-in-the-Loop (SiL), Hardware-in-the-Loop (HiL), Vehicle-in-the-Loop (ViL) or more generally X-in-the-Loop (XiL) – which requires consistent traceability. To ensure flexibility, scalability, and cost-efficiency, a hybrid (multi-)cloud infrastructure and smooth data orchestration are critical success factors.

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1. "Adaptive cruise control," Wikipedia, https://en.wikipedia.org/wiki/Adaptive_cruise_control
2. Steinken, Melissa "Timeline: Milestones in ADAS Before 2010," Jan. 27, 2020, Adapt https://www.adaptautomotive.com/articles/51-timeline-milestones-in-adas-before-2010
3. Webpage, "SAE International Releases Updated Visual Chart for Its "Levels of Driving Automation" Standard for Self-Driving Vehicles Dec. 11, 2018, SAE International https://www.sae.org/news/press-room/2018/12/sae-international-releases-updated-visual-chart-for-its-%E2%80%9Clevels-of-driving-automation%E2%80%9D-standard-for-self-driving-vehicles
4. Mesarina, Malena "How much storage space do you need for Google maps?" Dec. 18, 2016, Stellar Peers, Medium https://medium.com/stellarpeers/how-much-storage-space-do-you-need-for-google-maps-24e83a0d5436

Throughout the overall engineering process, various players and stakeholders tend to use competing methodologies such as V-cycle, Waterfall or Agile development, speak heterogeneous languages, and use diverse metrics. Automotive research & development (R&D) engineers think in terms of system-engineering levels and functional requirements. IT engineers solve problems iteratively, often with more data, greater bandwidth, and enhanced computational power such as more CPUs, RAM, or GPUs.

As the development and validation stages are interconnected, multidisciplinary R&D and IT DevOps teams need to develop a common language and involve a new class of highly skilled staff who can safely operate in both domains to bridge the gap.

With more and more artificial intelligence and machine learning systems entering the market, especially in the field of autonomous vehicles, it becomes even more difficult to prove that these systems are predictable, dependable, rational, and correct. This calls for a more data-driven AV verification and validation process.

While AV system and function development pose challenges, we want to address the most critical issues of current and next-generation SAE-L3+ autonomous vehicle verification and validation (V&V). This article proposes five areas of focus specifically for the V&V field that should be addressed by automakers who want to move ahead of the competition in the emerging autonomous vehicle market:

1. The dimensions of an integrated verification and validation ecosystem
2. The impact of artificial intelligence and building the digital twin to earn approval for AVs
3. The role of digitalization and software in the development of autonomous vehicles and their validation
4. The most promising emerging trends in V&V methodologies
5. Critical factors for autonomous vehicle development and its test and validation to ensure AVs become a reality

The dimensions of an integrated verification and validation ecosystem

There are four important aspects for managing an integrated V&V ecosystem: strategy, legal, organization, and technology

The strategic aspects

Recent studies report that:

- The demand for vehicles will shift drastically between 2020 and 2030. Today, global automotive manufacturer market capitalization is about $1 trillion. It is projected to increase to $1.9 trillion by 2025 and then fall to $1.4 trillion by 2030, a 35% decline in just five years. Over the same period, the autonomous mobility-as-a-service market capitalization is projected to grow from $109 billion today to $9 trillion by 2030.[5] We expect to see a shift in vehicle sales, as entry-level cars will be pushed into the mobility-as-a-service model, while luxury cars would probably still be sold on an individual basis.

- Autonomous ride-hailing is projected to reduce the cost of mobility to one-tenth the average cost of a taxi today, spurring widespread adoption. Autonomous ride-hailing platforms will generate more than $1 trillion in profits per year by 2030.[5] In addition, automakers and fleet owners could enjoy profits of $250 billion and $70 billion, respectively.[6]

- The Asia-Pacific luxury car market was $231.8 billion in 2019 and is likely to maintain a dominant position through 2030. China has the highest growth potential in the region.[7] China, South Korea, and Japan will develop vehicle and road-safety regulations for the deployment of ADAS.

In anticipation of these changes, many countries and regions are already preparing for this paradigm shift. The European Union (EU) has extended the scope of mandating ADAS systems such as automatic emergency braking (AEB) and lane departure warning (LDW) systems as well as pre-collision systems (PCS).

In North America, increasing government initiatives for mandating driver assistance systems are expected to accelerate market growth. Higher adoption of these systems in small cars is anticipated to boost market demand further.

Historically one can differentiate three facets of mobility and their relevant characteristics:

- Paradigm: Individual (cars) versus shared (bus, train, etc.) versus on-demand (taxi, rideshare) mobility
- Business model: Buy versus rent versus pay-per-use
- Way of driving: Human-controlled versus automated

We have seen a mix in both the paradigm and business model dimensions in the past two decades. However, with recent technological advances, a multitude of new business and service models are emerging. We will probably see a transition from individual/human-controlled mobility to individual/automated, shared/automated and on-demand/automated mobility in the coming years.

Imagine a smart city with shared electric, trusted pay-per-use autonomous mobility services accessible to many people. Automakers must decide today if they want to be part of this potentially huge market.

One challenge they face is dealing with market variances, such as how road traffic differs from region to region. Comparing city traffic in Shanghai, China to Mumbai, India to Los Angeles, USA, it's clear the conditions are quite different. Even with the United Nations Conventions on Road Traffic in Geneva in September 1949, and Vienna in November 1968, that established standards, there remain considerable differences in coping with market variances from a functional perspective in many regions.

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5. ARK Investment Management LLC https://ark-invest.com/articles/analyst-research/autonomous-taxi-market-value/
6. "Big Ideas 2021," Jan. 26, 2021 ARK Investment Management LLC https://ark-invest.com/big-ideas-2021/
7. "Transportation and Logistics, Luxury Car Market," Dec. 2020, Fortune Business Insights https://www.fortunebusinessinsights.com/luxury-car-market-104453

Automakers have to decide how they will address the following challenges:

1. **Markets and sales targets**
   Which markets are relevant, and what is the correct weight of each market?

2. **Regulatory requirements**
   Which regulations do automakers have to comply with in each region?

3. **AV functions and portfolio**
   Which functions are under development and shall be validated (respecting country-specific behavior and lane markings, road signs, obstacles, animals, etc.)? Is it possible to form equivalent country clusters to ease the validation process?

4. **Safety**
   Are there safety-critical impacts and implications?

5. **Test strategy**
   How to mitigate potential risk by ensuring good test coverage and test depth for all relevant markets and regions?

6. **Test methodology**
   How to mix open-loop (e.g., physical scenarios) with closed-loop (e.g., virtual scenarios) and, most importantly, how to prove the simulation is correct and sufficient for homologation?

7. **Test design and specification**
   What are the right test cases and test scenarios, and how to define and gather the respective test data?

8. **Test data**
   What amount of data is required for the development (i.e., training) of AI systems, and test and validation (e.g., net km, net miles, net hours, net scenarios, net data volume, etc.)? How to organize the data lake to find specific scenarios in the data pool easily?

9. **V&V ecosystem and test benches**
   What is the correct mix within the testing ecosystem, such as unit testing, HiL, SiL, virtual validation, etc.?

10. **Reporting measures and key performance indicators (KPIs)**
    Which reporting methodology and KPIs are the proper ones to monitor an AV-validation project and measure test results and final software quality?

11. **Tailor for reuse and delta testing**
    Which scenarios can be reused during development or validation implementing delta-testing concepts, always ensuring disjunct training and validation data sets.

These questions may appear straightforward yet are anything but easy to answer. It is essential to determine the right strategy for creating the data pool, how to fill it up with the right scenarios, and develop the optimal testing ecosystem in line with this strategy.

The proper mix between deterministic and statistical physical and virtual scenarios covering regular driving scenes and corner cases is crucially important to prove the system is deterministic and statistically correct down to the homologation.

Change is the only constant in AV systems engineering, verification and validation.

Knowing that change is a constant within an ongoing development and validation project, automakers must be ready to engage with partners capable of managing agility and coping with rapidly changing requirements.

This has a significant impact on ways of collaboration and the commercial models within the service industry.

The legal aspects

Set forth by the UN's Conventions on Road Traffic in 1949 and 1968, generally accepted standards of road traffic safety have been put in place. With the introduction of autonomous driving, UNECE has paved the way for automated vehicles with amendments to the Convention on Road Traffic entered into force on March 23, 2016.

As of that date, automated driving technologies transferring driving tasks to the vehicle will be explicitly allowed in traffic, provided that these technologies are in conformity with the UN's vehicle regulations or can be overridden or switched off by the driver.

The regulatory framework for safe and reliable autonomous driving is being created with norms and standards, such as ISO 26262, SOTIF, ASPICE, ASIL, and proposed legal frameworks currently being worked on internationally by SAE, TÜV, EuroNCAP, NHTSA, CATARC, and others. Still, the way to trusted and safe SAE-L3+ autonomous mobility and the final homologation is challenging.

It is crucial for automakers to be able to prove full traceability of requirements with test cases and the respective scenarios down to each relevant test result for each hardware or software release. They need to illustrate a proper test-depth and test coverage, transforming the classical rigid system-engineering-based development process into a more agile – but never the less trusted – data-driven development and validation process.

Apart from the systems and functions themselves, it is also crucially important to respect regional and national applicable data privacy and security regulations in each country, especially when it comes to gathering actual data from public roads in large-scale global campaigns.

Besides safety-related norms and standards such as ISO 26262, SOTIF, ASPICE, and ASIL, automakers should also consider the growing importance of the legal implications of data privacy policies, cybersecurity, and national security.

Data privacy and security may pose critical legal issues that differ from country to country and are continually evolving. For example, the EU General Data Protection Regulation (EU GDPR) is very strict on the use of personal information such as images of faces of pedestrians, license plates, and the precise GPS position of individuals. EU GDPR defines clear measures to be implemented in regards to lawful basis and transparency with respect to gathered data, data security and defined accountability and governance to safeguard the privacy rights of individuals.

In Russia, it is illegal – in fact, it is categorized as espionage – to capture images and data of critical infrastructure such as bridges, power plants, subway stations or any other relevant infrastructure.

On January 6, 2020, the U.S. government amended its dual-use export controls to cover specific software used in AI and ML applications, such as deep neural networks using either camera or LiDAR point clouds as training data. Hence, the US Bureau of Industry and Security (BIS) amended the Export Administration Regulations (EAR) to impose license requirements on the export and reexport of software specially designed to automate the analysis of geospatial imagery – and consequentially any such training or validation data – to all destinations except Canada.

Chinese laws and regulations on national security and cybersecurity also prohibit the gathering of geospatial information – which can be generated from cameras, LiDAR, and GPS sensors – without a proper license.

Before exporting data from any country, automakers must ensure they are not going to breach any data export control regulations.

Given the restrictions on data storage and processing locations, engineering companies, infrastructure providers, and automakers must implement regional or local project sites to deliver their services according to regional and country regulations. They are strongly advised to seek local legal counsel before planning or implementing any testing campaigns on public roads and align with relevant authorities before initiating any campaigns as the consequences of non-compliance could be severe. When planning to share data across the globe using hybrid (private) cloud infrastructure, all parties must implement proper data security measures. It is highly recommended to anonymize data before sharing it with other entities or project partners in different countries or to give them remote access to sensitive information. Robust data security and restrictive data governance are crucial.

Ideally, autonomous vehicle testing and validation infrastructure and the data itself should always reside in each respective country or region, especially for China, Europe, and the US.

The organizational aspects

Modern globalized AV development and validation organizations are transnational and multidisciplinary. They are flexible, nimble, and have a bias for action. They can react quickly to new situations and cope with changes throughout the product development life cycle. These development and validation organizations are free of toxic competition and politics and trimmed to find solutions to problems fast. They value cultural differences and diversity while following common core values. By leveraging remote, onsite, offsite, near-shore and offshore capabilities, these organizations establish favorable conditions for recruiting a highly skilled global talent pool.

Companies must find a good balance between corporate processes – especially relevant for developing safety-critical systems – and an agile and flexible entrepreneurial mindset embedded in the corporate culture. Speed, agility, and quick decision-making are as important as the cultural integration of geographically interconnected delivery units. Service providers must be able to deliver locally in all regions: APAC, EMEA, and the Americas.

Digitalization and working remotely are part of today's daily business life and align well with these interconnected, centralized, but physically distributed organizations. Volkswagen CARIAD is a good example of a strong, fast-paced centralized unit within the corporate ecosystem.[8]

8. "Markus Duesmann takes charge of Car.Software organization at the Volkswagen Group," Jul. 15, 2020, Vollkswagen, https://www.volkswagenag.com/en/news/2020/07/Car_Software_organization.html

Automakers are implementing almost the same AV V&V ecosystem on their way to homologation:

- **V&V ecosystem**
  Critical evaluation of core and context activities for ADAS V&V

- **Test strategy and orchestration**
  Define a clear test strategy and automated test orchestration from process design to test execution and reporting, efficiently integrating and managing changes along the development process leveraging AI

- **Data production**
  Conduct actual road-vehicle data collection campaigns and produce virtual data for test scenarios that adhere to global and regional regulations

- **Data management and AI**
  Cover the entire augmented data process from ingestion, post-treatment, data labeling, and enrichment, leveraging AI to ensure the quality, privacy, and security of the data

- **Tool integration and digital continuity**
  Ensure digital continuity by seamlessly connecting all software tools into a coherent toolchain and extending integration to other partners and data sources

- **Hybrid cloud infrastructure**
  Define your infrastructure strategy, design its architecture, and provide a scalable hybrid cloud solution to support ADAS development

While some of these building blocks should be implemented onsite or per region, others may be centralized for the entire organization. Engineers often ask themselves whether they have access to all necessary critical information about the test process. This is where analytics and AI come in handy.

Automakers must bridge the gap between classical system's engineering, Agile, SCRUM-based approaches, DevOps, LeSS, continuous integration (CI), and continuous delivery (CD).

Automakers should aim to assemble the best people with the right expertise, mindset, and background at every stage in the process. Qualified engineers require about eight years of experience, auto industry know-how, and a proven ability to manage large-scale campaigns. Of growing importance, team members should have a collaborative and flexible mindset, which will significantly impact the success of ambitious AV projects.

OEMs and Tier-1 suppliers need to install a joint, cross-functional management and architecture team as early as possible within their development process. This team would model the complete end-to-end data flow across the value chain and address dependencies between the vehicle, measurement system, re-simulation of HiL/SiL, and data management infrastructure to ensure neat and smooth operations.

Those who can build cross-country, culturally integrated, flexible, agile, and multidisciplinary teams – tasked with mastering the automotive R&D domain, including cloud and IT – will move ahead of the competition.

The technological aspects

The development of AV systems, sensors, and functions is technologically very complex. When it comes to the validation of these systems, the complexity of the validation toolchain should not be underestimated. The major technological building blocks of the validation ecosystem include:

- **The vehicle and network**
  Usually, a current series production vehicle serves as the carrier platform for next-generation systems and technology. Regularly, existing networks and signals have to be translated into next-generation protocols. 5G will be a significant driver for shared and smart mobility.

- **(Pre-) series development sensors and electronic control units**
  Under test, the units comprise the next-generation systems under development, such as the camera, radar, LiDAR, far-infrared (FIR), or similar sensor technology.

- **Secondary sensors**
  These sensors, including high-quality LiDAR, high-quality cameras, differential GPS or similar, are regularly used to create validated ground truth automatically.

- **AV functions and HD maps**
  The autonomous driving functions are developed and under validation in either active or deactivated (passive/shadow) mode, and dynamic HD maps are created and constantly updated.

- **Measurement systems and technology**
  In data collection campaigns, it is important to ensure the (ideally encrypted) recording and visualization system. The system must be able to cope with the required data rates and provide necessary logging channels and watchdogs to monitor the overall system status to detect issues early.

- **Test ecosystem and test benches**
  The lab environment for test and validation must include MiL, ViL, HiL, SiL, virtualization, etc.

- **Validation toolchain, analytics, and AI platform**
  The software toolchain for PLM requirements includes a test management suite, a data management suite, orchestration, issue management, simulation tools, DevOps, and CI/CD integration.

- **Microservices platform**
  This platform provides an abstract framework to integrate various microservices on top of the underlying IT infrastructure. It leverages virtualization and "Dockerization," security and governance and provides required orchestrators, logging mechanisms, and more generalized interfaces for the overall service ecosystem.

- **IT infrastructure, hybrid cloud, and connectivity**
  The infrastructure includes geo-distributed, virtualized and secure hybrid on/off-premises scale-out cloud and IT infrastructure with hot, warm, cold archive storage, compute, networking, and connectivity. Frequently traceable data logistics, ingest, and data quality are important but often underestimated areas.

During pre-development, it is essential to figure out the suitable sensor set. Also, it is necessary to ensure the digital continuity of existing and new tools. Carmakers and Tier-1 suppliers bring the historical tools that they have invested in developing for years. It makes no sense to abandon them. Instead, they need to be integrated and interfaced to build a coherent system architecture and tooling ecosystem. To achieve accuracy in virtual testing, it is essential to understand and clearly define the areas requiring investment.

Interestingly, collaborations are developing between fleet owners and car-sharing and Mobility-as-a-Service (MaaS) providers that operate large fleets. Examples of typical systems engineering tools include IBM Rational DOORS and Rhapsody, Intland codebeamer, Sparx Systems Enterprise Architect, and also MATLAB Simulink/TargetLink, AUTOSAR related toolsets, Vector CANape or CANoe, Elektrobit EB tresos, Continental MTS, simulation environments such as IPG Automotive CarMaker or VIRES Virtual Test Drive, dSPACE vEOS or ControlDesk, and many others. All these tools come within the best-case standardized or, in the worst case, proprietary file formats.

On top of the classical toolset, it is important to have the right data management tools for data ingest, data decoding, data quality, orchestration, and reporting in place throughout the process. On the platform and framework side, lightweight virtualization with Docker, Kubernetes, or similar platforms is important, as is the integration with AI frameworks such as Caffe and TensorFlow.

Additionally, DevOps and CI/CD tools such as Atlassian, Jira and Confluence, Git version management and many others may be integrated into a consistent ecosystem. Many additional tools already exist, including data ingest and quality assurance or data exchange tools with partners and suppliers. And many tools with evolving requirements coexist and need to be integrated into historic toolsets for software or hardware loop, virtual simulation orchestration, KPI generation dashboard analytics, AI, and scenario detection and classification.

Automakers and suppliers must consider that the vehicles, sensors and systems used for AV training and validation data production are regularly in the early pre-development stages of the final product and prone to failure. The overall stability and accuracy might be worse than expected, so continuous quality assurance and issue management processes must be implemented to manage the system availability properly and cope with unexpected issues.

Missing signals and parameters nobody thought of to collect when entering the validation phase or sensor calibration issues might lead to severe problems during re-simulation. Not synchronizing data channels properly with each other or not being able to deterministically re-simulate system and function behavior once created in the lab or at a test bench afterward may lead to, at best, severe project delays. Entering a global data collection campaign with an insufficiently validated sensor set that potentially creates useless data will either have to be fixed afterward with enormous effort or, in the worst case, re-created.

Today's AV test vehicles easily produce 64-plus TB of data each day. Regular test campaigns involve over one million test kilometers, which is effectively a fleet size of eight to twelve vehicles operated for a whole year. Consequently, automakers produce an enormous data volume of 150-plus petabytes per series development project that has to be managed, organized, stored, and processed to derive valuable knowledge from it relying on transparent reporting and analytics.

Capgemini Engineering, along with infrastructure providers, such as AWS, Microsoft, and Google, and technology providers, such as NVIDIA, Intel, and Dell Technologies, are teaming up to create an integrated, end-to-end AV verification and validation ecosystem. The team is tackling the complex testing challenges and addressing five questions about the potential viability of SAE Level 3+ for partly and fully autonomous driving with the driver engaged. Above all, it is crucially important to be able to manage change throughout ambitious AV projects. Engineers must be able to estimate the impact of a change throughout the whole product development lifecycle – from the early design stages to the final homologation.

For instance, when a change is made in a sensor's positioning in the car, it may impact the sensor's calibration and how it perceives the world. Another good example may be a change to the windshield angle, which most likely affects the front camera's optical path and its perception of reality. Similarly, a change to a vehicle's bumpers design may impact short-range corner radar sensors mounted behind them. It also raises questions. For instance, is the data reusable that was gathered before the sensor was repositioned? This is one of the most challenging problems the auto industry is working on.

The many variables in sensor positioning and the necessity of having 50-plus test vehicles operational at any given time require absolutely accurate precision throughout the whole process to ensure the highest possible quality of test results.

To ensure the highest quality test results and the reuse of the data, carmakers must answer three fundamental questions:

- How can the test process be optimized?
- How can the data be collected in a smarter way? Specifically, is there a way to improve the data's value by creating more information from less data?
- How can the test budget be optimized when it is very difficult to plan and foresee in the next few months?

The impact of artificial intelligence and building the digital twin to earn approval for autonomous vehicles

With the rise of AI, it gets more challenging to prove that statistical learning-based AI algorithms are operating as intended. Increasingly strict regulations, the need for massive volumes of data, time-to-market pressures, and growing complexity in the process are driving automotive V&V services. New technologies such as virtualization and simulation create significant changes in the way automakers design, market, and maintain vehicles.

Automakers must demonstrate the safety of their V&V process to earn approval from regulators for the AV systems and functions. This means they must answer six questions about overall system safety and quality:

Correct
For example, does the highly autonomous driving function work as intended?

Complete
Is the system complete in the sense that it covers all possible situations?

Rational
Do the functions make rational decisions under any given circumstances? Which in itself is already a challenging philosophical question.

Stable and robust
Given adverse conditions, would the systems and functions still operate within expected norms?

Safe
Can the systems be trusted?

Compliant
Most importantly, do the system and functions comply with applicable norms, standards, and regulations?

These questions are challenging, but they can be answered in the affirmative when leveraging not only real-world data but also virtual simulated models.

For example, validating a fully automated SAE Level 4 system would require 240-plus million kilometers of data collected on public roads leveraging a theoretical fleet size of more than 2,000 cars that would need to be operated for an entire year. A fleet of ten vehicles being operated for a year represents approximately 150 to 200 petabytes of data. The cost of scaling testing up to 2,000 vehicles is prohibitively expensive, especially when it requires IT infrastructure in the exabyte region (1 exabyte = 1,000 petabyte = 10^{18}bytes). The only option is for automakers to change the testing methodology. While real-world physical testing will continue, the focus will change gradually to include simulation. This means lower costs, which will enable automakers to scale up their test coverage more rapidly.

Capgemini Engineering delivers a robust managed service to the auto industry, with many co-development sessions and workshops with its clients. The carmaker is involved in the end-to-end decision-making process, and our engineers share our ideas, vision, and strategy as we progress down the road together.

Real-world testing as the basis for virtual simulation

In the past, test data was collected more or less simultaneously during testing. Now, with the massive volume of test data required, the methodology is changing. Test data is gathered independently from the actual test process itself and before validation and verification takes place. Today's testing ecosystems and testing tools are being used in a combination of simulation and physical testing.

It is essential for testing to include real cars, people, and roads to capture reality. However, there is a risk of not capturing the necessary volume of data to validate the process. Notably, physical tests will more frequently be used to validate not only systems and functions but also their models. In the end, it all comes down to one central and crucial question: do you have the right data pool at hand and can you manage it?

Simulation-based validation

Simulation can be a superior and less expensive solution than real-world testing as it scales more easily by adding computational power in a data center. However, it is vital to prove the simulation results are as adequately good as physical testing and lead to sufficiently identical results. A case in point is virtual obstacles, which are often derived from real-world scenarios. These can be more practical than devising real-world tests. For example, it is possible to add virtual children, pedestrians, and cyclists who make unexpected moves, like hopping in front of a moving car from behind an obstacle. These scenarios must be tested, and it is easier and safer to test them in the virtual world. To be successful, simulations and models must be trained on the right data pool.

Startup companies, such as Cognata, are leading the way in the virtual simulation market, together with other simulation companies such as VIRES and IPG Automotive, and tool providers such as dSPACE, National Instruments, and Elektrobit. With DRIVE Sim and DRIVE Constellation Vehicle, Nvidia offers a test and validation suite to virtually validate billions of miles in the data center.[9]

The roll-down to virtual homologation is a critical step. Organizations such as SAE International, TÜV, NHTSA, and CATARC are working to define the proper standards for a safe and trusted virtual homologation.

9. Autonomous Vehicle Simulation, Nvidia https://www.nvidia.com/en-us/self-driving-cars/drive-constellation/

With automatic 2D and 3D labeling, Capgemini Engineering derives entirely virtual scenarios from real-world data providing a well-defined digital twin while leveraging industry standards such as OpenDRIVE and OpenSCENARIO. Consistent environment and sensor models and an AI-based test process optimizer help cover otherwise hard to validate corner-cases.

Artificial intelligence on the rise

Another critical trend is AI-driven automation. To test whether sensors perceive an object at the right distance and point in time requires a validated ground truth to confirm the sensors correctly perceive what is actually happening. For example, can the sensors accurately validate that a pedestrian is far away from the car and moving in a specific direction? To correctly identify objects like pedestrians requires manual labeling. However, three-dimensional automatic labeling and AI-driven methods such as automated scenario extraction are most promising in synthesis, virtualization, simulation, and automation to improve the end-to-end test process.

Automatic data enrichment – such as automatic 2D and 3D labeling and meta-data tagging – requires equipping vehicles with high-quality secondary sensors such as LiDAR systems or high-resolution camera systems that are calibrated to each other and the rest of the vehicle's sensor systems.

With deep neural networks on the rise – specifically, generative model-based networks (GANs) – AI helps massively to speed up the test and validation process. Trained in the data center and brought to the edge, the decision-making process is taken right into the vehicle. Going one step further, AI methods can even be used to significantly enhance the test coverage by solving an inherent optimization problem, thus improving the overall test quality.

The role of digitalization and software in the development and validation of autonomous vehicles

Imagine smart cities with fully autonomous electric vehicles offering intelligent mobility services to their residents on a pay-per-use basis. New AV functionality is trained in the cloud using deep learning and pushed to the edge into the vehicles via over-the-air (OTA) update functionality. With this concept, innovative new business models will arise.

For private autonomous mobility, consumers may be able to freely decide which functions they want to activate when and just pay for it when it is in use. For example, suppose a car buyer is looking for a car primarily to shop and commute within an urban environment and do errands around town. In this case, they are unlikely to need the autopilot for highway driving very often. So why should they pay for it when they buy the vehicle? Instead, they could order the autopilot function for a limited time when they are going on a long trip.

Understanding how the digitalization of driving is being socialized requires rethinking the auto lifecycle model as automakers begin to offer software upgrades on a pay-per-use basis. For example, during hurricane warnings on the US Gulf Coast, Tesla installed extended battery range software OTA for Tesla owners who needed to evacuate.

The foundation of automotive development to date has been primarily hardware-based for classical automakers. Technology companies such as Tesla and Lucid follow a more software-centric approach. Many automakers are currently working on global OTA software features for systems engineering and system development processes. The trend is to install powerful but more generic control units into vehicles and periodically enhance the features' software. Even a year after the vehicle has been sold, it may not require any hardware upgrades but rather just software updates, so new, more complex software features can be installed. This model enables less costly and more efficient in-place software upgrades and more granular feature-release management.

Within a well-defined CI and CD environment, beta versions of new AV functions may be first validated in simulation and then only activated in a passive shadow mode within parts of the fleet under controlled conditions. The feature is not active, but the engineering team can gather valuable test data. Once the testing is complete and the feature is approved, it is activated OTA into the fleet. Waiting for the next vehicle model to be released to get a technology upgrade becomes a thing of the past. This opens up a new world to automakers, putting in place a software-centric Agile, DevOps, and CI/CD-driven release process that accelerates time-to-market while not sacrificing the overall product quality guaranteeing the fulfillment of strict safety standards.

Together with our partners, Capgemini Engineering is offering a blueprint reference architecture that integrates the AUTOSAR Adaptive Platform with cloud-based continuous systems engineering processes and a consistent validation ecosystem.

The most promising emerging trends in verification and validation methodologies

Intelligent Industry is emerging as a hybrid between classical R&D, cloud and IT.[10] For the development and validation of AVs, we see the following megatrends being of the utmost importance:

- **Virtual simulation and digital twins**
  Physical testing alone will still pertain but will not be sufficient by any means for complete and trusted validation of AVs. Real-world data will be used to prove the simulation right and is required to build sophisticated simulation models and a digital twin of reality.

- **Data and cloud**
  These are the basis for data-driven engineering and validation, future autonomous vehicles, and smart IoT machines in general.

- **Analytics and AI**
  Transparency throughout the whole development and V&V process is the key to a trusted and safe homologation. Leveraging machine-driven learning, AI, and deep learning will become the most critical driver to optimize and speed up the AV V&V process.

- **Collaboration and standardization**
  Governments, regulators, standardization institutions, automakers, technology companies, suppliers, and engineering and IT service providers must join forces now to create the autonomous future together.

With the rise of AI, the testing methodology becomes more data-driven while processes, methods, and tools need to be adapted rapidly. With the rise of AI and the amount of testing needed for SAE-L2-plus and above, automakers enter the realm of data-driven engineering. Previously gathered from disjunct datasets, the data is used to train, test, and validate highly autonomous driving functions that are increasingly based on machine learning. The data has to be gathered smartly and statistically well distributed. For example, it does not make a lot of sense to train an AI algorithm with data created during spring and summer and then validate it with data from fall or winter. Real-world data from public roads is also used to build a digital twin of reality and further scale up the data lake with virtual scenarios.

Autonomous driving is an outcome of Intelligent Industry powered by data. Today's complex systems engineering projects require a scalable, hybrid cloud infrastructure. It adapts much better to the individual needs at every stage of the project than a monolithic on-premises data center environment. The data's growing importance and sensitivity require strong data security and governance regarding privacy policies, cybersecurity, national security, export regulations, data review, and anonymization. The richness and quality of the data and one's ability to manage it smoothly are essential for success.

AI is at the heart of function development and significantly helps to optimize the overall V&V process. For example, virtual scenarios and behavior can be learned from data. Classifiers and data mining improve how specific scenarios may be identified much easier in the pool. And analytics provide data-driven insights to derive smart project decisions early on and throughout the entire engineering project.

Relevant for collaborative engagements, SAE International announced the formation of the IAMTS consortium, which includes TÜV, NHTSA, and CATARC, and engineering service and tool providers.[11] The main objective is to standardize the AV validation processes across geographies. For example, in the US, AV regulations can be different from state to state. California is already very active and mature compared to other states. In Europe, the objective is to create future standards. The competition is tough, and companies need to be early to the race if they expect to get the right processes, tools, and methodologies in place to be competitive in the future.

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10. "Intelligent Industry – Powered by Data," Capgemini https://www.capgemini.com/service/intelligent-industry/
11. Kucinski, William "IAMTS association will establish standardization and testing for connected vehicles," Apr. 10, 2019 SAE International https://www.sae.org/news/2019/04/wcx-2019-iamts-association-will-establish-standardization-and-testing-for-connected-vehicles

Critical factors for autonomous vehicle development, test and validation to ensure they become a reality

The most critical question consumers will be asking about autonomous vehicles is: "Can I trust them?" So how exactly do automakers create public trust in these vehicles and the underlying technologies?

Safety and Trust: OTA is a smart way to gradually improve the functionality of today's vehicles by software-defined means. But for autonomous driving, strict processes fostering safety and trust must be implemented in line with ISO 26262, ISO/DIS 21448 (SOTIF), SAE J3016 and the Self-Organizing Traffic Information System (SOTIS), a functional safety standard. Indeed, these and other standards will be crucial to the success of AVs.

Some fast-moving players and technology or mobility services companies such as Tesla, Uber, Lyft, and Waymo are making significant progress. Also, classical automakers such as Volvo, Daimler, Audi, FCA, Toyota, and many others, as well as major Tier-1 suppliers such as Bosch, Continental, Magna, and others, are stepping up to address the AV challenge.

Security and Privacy: Automakers must by any means protect people and infrastructure and guarantee the sovereignty of markets and countries in all the autonomous mobility services that will soon be operating. ISO 27001 defines data security and privacy standards and ensures that tests of massive data sets are handled correctly, encrypted, and anonymized to avoid unwarranted access. This standard is crucial for providers to earn EU GDPR approval, not only downstream with the carmakers' customers but upstream with suppliers, specifically international suppliers, where data may move between country borders.

Compliance with these standards ensures key decision-makers at every level are involved in the development process. Automakers must run test campaigns aligned with local authorities in the countries where they operate. This will ensure they avoid situations where their collected data is confiscated or destroyed, or worse, leads to diplomatic issues or even espionage charges.

Efficiency: The only chance the automotive industry has to make autonomous vehicles a reality any time soon at a significant speed and a reasonable development cost is to join forces with companies in the digital, cloud, and engineering service provider industry.

AV engineering and V&V projects rely on very complex cost mechanics that depend on economies of scale and whether costs are fixed or variable. For example, for global data collection projects, vehicle transport is a fixed cost. The time the vehicle is used in the country and the distance traveled to gather data are variable costs. For example, if a vehicle is shipped to Singapore for two days of driving, the fixed cost per day is relatively high. If it's in the country for six weeks, it is significantly lower.

Automakers must understand these mechanics and figure out the right strategy to stay within budget. Specifically, which countries do they target for testing and how much time do they need to spend there?

To address constant changes throughout AV development and V&V projects, smart commercial models must be put in place with suppliers, such as pricing catalogs and complex pay-per-use models.

The mandates of safety, security, privacy, and efficiency pertain to all dimensions of AV development, including strategy, legal, organizational, technological, and financial.

Endnote

Autonomous driving is changing the way we think about mobility; it will help make roads safer and prevent accidents and fatalities. It is both a great market to work in and, at the same time, a vast, complex, and fast-moving domain. AI systems play a pivotal role in AV development as the field evolves and algorithms learn all by themselves. But questions remain.

How is the automotive industry dealing with the pace of change? How are automakers managing the evolution of AI systems in the car?
Tesla is currently working on predictable neural networks and deterministic AI algorithms to create hybrid systems that merge classical systems engineering and AI-based systems. Other automakers are making similar advances.

It is crucial to consider unpredictability in these models and ensure companies build trust in AI with proven, rational and smart decision making. Black box solutions will not be acceptable.

How do automakers definitively demonstrate the safety of their autonomous vehicles?
On the one hand, AV testing regulations are getting more strict to ensure safety. On the other hand, the technologies are becoming more complex. The adoption of AI systems in vehicles must be a gradual, phased process involving governments, lawmakers, automakers, and intelligent industry.

For instance, in Shanghai, a testing site has been built that corresponds to a city with a population of millions. Levels 4 and 5 autonomous vehicles will be allowed, and new technology will be integrated as it is approved. Such an investment helps build trust in AD. The government can create legislation in collaboration with manufacturers as they develop the technology. This type of phased collaboration is the right way to proceed.

Today's crucial question is: How confident are we in the technologies that will drive consumer demand and acceptance of autonomous driving?

We will know the answer within a couple of years.

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About Capgemini Engineering

Capgemini Engineering combines, under one brand, a unique set of strengths from across the Capgemini Group: the world leading engineering and R&D services of Altran – acquired by Capgemini in 2020 - and Capgemini's digital manufacturing expertise. With broad industry knowledge and cutting-edge technologies in digital and software,Capgemini Engineering supports the convergence of the physical and digital worlds. It helps its clients unleash the potential of R&D, a key component of accelerating their journey towards Intelligent Industry. Capgemini Engineering has more than 52,000 engineer and scientist team members in over 30 countries across sectors including aeronautics, space and defense, automotive, railway, communications, energy, life sciences, semiconductors, software & internet and consumer products

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