FROST & SULLIVAN

AUTOMATED DRIVING – CHALLENGES IN SIMULATION

MathWorks®

EXECUTIVE SUMMARY

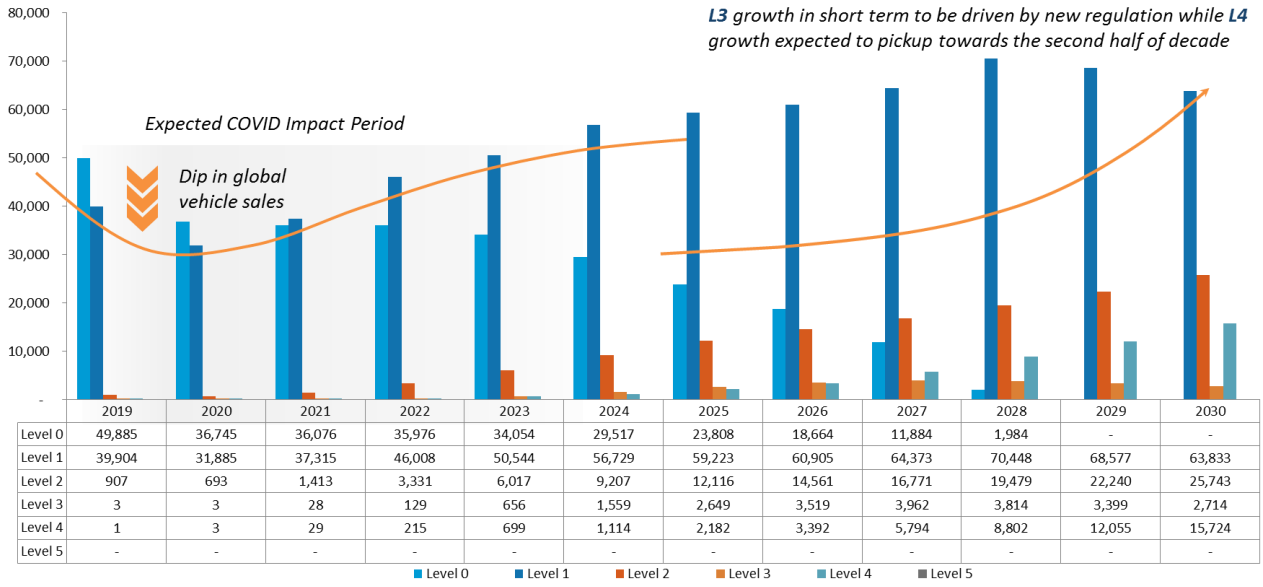
The automotive industry is transforming from being primarily hardware defined to becoming software driven. Automated driving (AD) is one of the main catalysts of this shift and is creating massive opportunities and challenges for automakers. Intensifying safety and certification requirements and spiraling complexity are highlighting the key role of simulation in AD development. This, in turn, is underlining the need for accurate and reliable simulation; for simulation tools that are able to effectively identify and collect relevant data and leverage real world driving conditions to cover, create and test a range of potential AD scenarios. Meanwhile, the breakneck speed of advances is emphasizing the need for regulatory standardization and deeper collaboration across the ecosystem between OEMs and simulation tool developers.

MATHWORKS - FROST & SULLIVAN'S EXECUTIVE ROUNDTABLE

Automated driving (AD) represents an area of tremendous growth in automotive R&D. The challenge to bring to market AD features continues to revolve around the safety of the system and software. Exhaustive testing is required to verify complex AD algorithms and physical road testing has its limitations. Simulation has emerged as a key tool that is helping developers bring AD applications in new-generation vehicles to the market.

Autonomous Vehicle Forecast – adoption of L3,L4 and L5 AD hinges on a combination of regulatory framework development and technical integration

Exhibit 1: Autonomous Vehicle Sales Units (Thousand)



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Level 0	49,885	36,745	36,076	35,976	34,054	29,517	23,808	18,664	11,884	1,984	-	-
Level 1	39,904	31,885	37,315	46,008	50,544	56,729	59,223	60,905	64,373	70,448	68,577	63,833
Level 2	907	693	1,413	3,331	6,017	9,207	12,116	14,561	16,771	19,479	22,240	25,743
Level 3	3	3	28	129	656	1,559	2,649	3,519	3,962	3,814	3,399	2,714
Level 4	1	3	29	215	699	1,114	2,182	3,392	5,794	8,802	12,055	15,724
Level 5	-	-	-	-	-	-	-	-	-	-	-	-

Notes: Impact of recent announcements of Level 3 regulations have been considered along with COVID impact
L2+ have not been considered in this forecast

Source: Frost & Sullivan, 2021

While simulation for AD offers multiple benefits, including time and cost savings, it has its own set of challenges. Some of these include the need to build realistic virtual scenarios, integrate different systems from multiple domains and ensure the reliability of environment, vehicle, and sensor models without compromising on simulation speed.

Accordingly, the theme of MathWorks 2nd Executive Roundtable held virtually earlier this year was "Automated Driving – Challenges in Simulation." It brought together stakeholders from across the ecosystem, including leading global OEMs, start-ups, tier 1s, and engineering service providers. Panelists shared insights into the importance of simulation in AD development, the major challenges in the space, and the strategic responses being adopted to overcome them.

The event was co-hosted by global growth consulting company, Frost & Sullivan, with

KAUSHIK MADHAVAN (Panel Moderator)

VP MOBILITY PRACTICE
Frost & Sullivan, South Asia & India

Among the panelists were:

SUNDARRAJAN RAMALINGAM

VICE PRESIDENT
Mercedes-Benz Research and Development India Ltd.

SHAJU S.

GENERAL MANAGER & HEAD OF AUTOMOTIVE BUSINESS UNIT
Tata Elxsi

RAJA DURGESH VIPPARTHY

TECHNICAL EXPERT
Robert Bosch Engineering & Business Solutions Ltd.

GIREESH RAJENDRAN

CO-FOUNDER AND CEO
Steradian Semiconductors

PINAKI LASKAR

DISRUPTIVE INNOVATOR & COGNITIVE TECHNOLOGIST, CEO AND FOUNDER
FishEyeBox

WENSI JIN

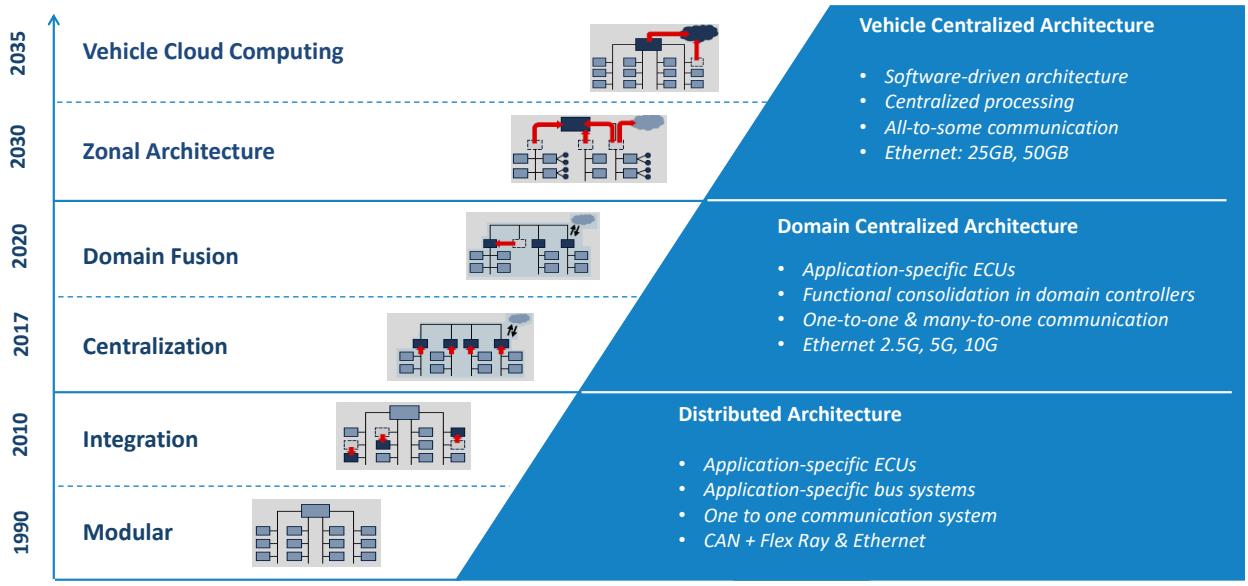
AUTOMOTIVE INDUSTRY MANAGER
MathWorks

OVERVIEW

Several key trends will drive the growth of simulation technologies for AD. Among them, the evolution of E/E architecture from distributed to domain centralized.

Trend 1 – Evolution of E/E Architecture

Ethernet driven centralization of domains is a top priority among OEMs to mitigate bandwidth challenges



Source: Frost & Sullivan, 2021

In addition to such newer, more complex architectures, the volume and complexity of data is also set to increase. It is estimated that a single autonomous vehicle will generate around 4000-4500 GB of data per day.

Meanwhile, the complexities associated with developing, testing, validating and certifying AD systems is also changing the traditional relationship between OEMs and suppliers. OEMs are set to have greater control over the features and IP, unlike in earlier domains, thereby reducing their dependency on single suppliers. Tier 1s, on the other hand, are looking at gaining more system experience to capture a greater share of the business in the AD pie. AD is also seeing several players in the start-up ecosystem bringing innovation and disruption into this rapidly emerging space.

Significant progress notwithstanding, the AD development space continues to face a raft of challenges: integrating different tools and workflows onto a common platform, ensuring the fidelity of simulation tools, accounting for a range of different driving conditions / scenarios, and covering the long tail of edge cases that are safety critical and potentially difficult to simulate or encounter in a physical vehicle. Accordingly, simulation tools for AD are targeted towards enabling ease of creation of all typical driving situations and the multitude of edge cases. At the same time, there has been widespread recognition of the need to build cross-functional competencies among teams working on the multiple technologies that underpin AD.

THE IMPORTANCE OF SIMULATION

AD requires advanced validation, with a 'safety first' approach at its core. Today, many OEMs, including Daimler, have adopted the simulation route in order to better manage their development cycles and stay on track with the release of more advanced AD systems.

To be successfully implemented in the real world, AD first requires the creation of scenarios that reflect real world complexities such as heavy or light traffic, fast or slow moving traffic, intersections and even crashes. The difficulty is that such scenarios **cannot be easily repeated and tested in the real world**. Thus there is considerable reliance on simulation to recreate these scenarios, along with the extensive deployment of AI and analytics. However, this poses an additional challenge since not all the data required to recreate such scenes are available today; many need to be synthetically simulated.

Recognizing that it **is impossible to test all real world scenarios**, companies like Bosch are working to identify the right scenario, creating and running them in "shadow mode", collecting as much data as possible on those scenarios, and then adding synthetic information into them in order to get better use cases/situations.

For the optimal performance of AD, it is critical to have economically viable, all-weather, robust and precise sensors. Sensor developers need to test their designs under different conditions of environment in order to be sure about the robustness of performance – which is possible only by simulation. This allows them to validate against different weather conditions.

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Simulation is not an end but only the means for successful AD and is a pre-requisite for the introduction of safely tested AD systems.

SUNDARRAJAN RAMALINGAM

Simulation is key to AD and its development.

SHAJU S.

We believe in focusing both on existing core development and deployment where a prototype is deployed and data fed into it to support robust outcomes. Additionally, standardizing situations/scenarios will be crucial since it will provide a common framework, a common language for people to work on.

RAJA DURGESH VIPPARTHY

The only way, in my opinion, to build a simulation framework is to develop infrastructure through data generation. Fixing all vehicles with sensors to create such a database would be very accurate but expensive. Another more cost-effective way would be through synthetic data or sensor output. The challenge here will be to guarantee that it matches the real data.

GIREESH RAJENDRAN

If scenario/scene generation and sensor modeling are key pillars of the larger AD framework, so is human modeling. The concept of AD lies between engineering and intelligence. This explains why, in some cases, while the engineering and math may be correct, the algorithms might not always transfer successfully to real world conditions. Such problems arise because the car is perceived as a machine whereas, in actuality, it is a social object. The reaction of drivers, traffic or pedestrians to machines or cars needs to be considered while developing AD algorithms. This is another area that simulation can cover as physical testing with such diverse driver behavior may be difficult to achieve.

MathWorks summarizes the above factors and emphasizes the philosophy of their investments that covers: a) virtual development without waiting for hardware and vehicle prototypes, b) increasing workforce mobility and, c) ensuring safety certification of the algorithms.

In terms of the first factor, MathWorks has focused on developing scenes and scenarios, sensor models, vehicle dynamics and enabling a ready-to-use framework for testing of AD algorithms in a virtual world. With Simulink, one of the platform tools offered by MathWorks, customers have the flexibility to integrate a variety of tools to enable powerful virtualization.

Moreover, in terms of integration, MathWorks understands that there will always be a continuous stream of new technologies. Recently, for instance, MathWorks' tools were integrated with the NVIDIA simulation ecosystem.

In essence then, simulation will have a key role to play since it is not possible to test all scenarios on a physical prototype. However, an effective simulation framework will require different elements — scenario/scene generation, sensor modeling, and human modeling — to come together in order to promote safe, reliable, and resource efficient testing and training.

Modeling training should not be one dimensional; algorithms should be thought of in terms of being three dimensional or even four dimensional models. In that sense, they are like human modeling, combining the past and the future and bridging the engineering-intelligence gap. Simulation is a major player in the training++ and testing of autonomous vehicles.

PINAKI LASKAR

This is an industry with many moving pieces and so industry standardization becomes crucial. Also, no company can solve all AD simulation problems singlehandedly, so all stakeholders need to work together.

WENSI JIN

THE UNIQUE REQUIREMENTS OF SIMULATION IN AUTOMATED DRIVING

There has been tremendous activity in the simulation space over the past 4-5 years. Amidst the unique challenges faced by OEMs, Tier 1 suppliers and start-ups, the one common theme revolves around how simulation can become more effective? This section, therefore, focuses on the 'what' and the 'how' of simulation in AD.

Functional Safety

AD has amongst the highest levels of functional safety requirements. The safety of traditional systems was often evaluated by standards such as ISO26262 which has served the industry well so far, but falls short of newer technologies like Machine Learning, newer processes of development like Continuous Integration (CI) / Continuous Development (CD), and testing that doesn't meet situational requirements.

Accordingly, newer standards like Safety Of The Intended Function (SOTIF) assess whether an intended safety functionality has performed successfully in the absence of faults, thereby improving AD safety. This marks a departure from traditional functional safety standards which focus on minimizing the risks resulting from system failure.

Simulation systems will also have to keep pace of the developments in certification and provide tools and workflows to ensure that developers meet certification demands.

Scenes and Scenario Creation

A unique aspect of advanced driver assistance systems (ADAS) is to test algorithms in different scenes and scenarios using multiple actors which is difficult to do with real vehicle prototypes. The need to validate millions of kilometers will mean engineers have to quickly create scenes and variations and put the algorithm under different conditions to be able to test safety and correctness. In line with this thinking, MathWorks recently acquired a company called VectorZero, which makes an interactive tool editor called RoadRunner that allows scene creation for ADAS simulation. While most organizations have some tools to create scenes, RoadRunner is able to do this with significantly lesser effort which increases the productivity and efficiency of simulation. It also can import a variety of formats and export the scenes to most popularly available simulators, making it very versatile.

The RoadRunner Tool

RoadRunner is an interactive editor that lets users design 3D scenes for simulating and testing AD systems

Source: MathWorks, 2021

Replicating Real World Reality

Trust is another tenet; whether simulation can be trusted completely. Simulation needs to emulate the real world as far as possible. This aspect plays out in real world scenarios in simulation, configuring sensor models close to the real world and parametrizing the vehicle dynamics. Organizations focus on how real world data can be brought into simulation in order to make it more reliable.

Edge Cases

Another requirement is to simulate edge cases in simulation. Edge cases are scenarios that play out with low probability in real life but when they do may prove fatal. These are very difficult to recreate with physical prototypes and essentially rely on simulation. Simulation frameworks must allow for the

> There are many problems: system integration, system fidelity, corner cases, learning from the environment…this is a huge risk in the context of trusting simulation results and safely releasing the system into the market.
>
> **SUNDARRAJAN RAMALINGAM**

creation of such edge case scenarios and how algorithms behave in these scenarios.

Real world data offers scenarios that highlight edge cases. The challenge here lies in extracting scenarios from the cloud and running intelligent analytics to create a catalogue of events. In terms of safety, at some point, such catalogues will be published as open source. Currently, however, the real essence of differentiation between safety + and safety ++ levels for OEMs centers on how such catalogues can be extracted, tabled and the circumstances under which they can be invoked.

So far, the data collected and mined by OEMs from their fleets operating across different markets has yielded volume/quantity but not quality. The use of quality data should be used, therefore, to continuously improve simulation in order to drive performance enhancements in AD. Also, while safety will remain a top priority, it is unlikely that safety systems will be updated every week. Accordingly, every aspect will need to be taken into account before introducing systems into the market.

Data Collection

While there is consensus that data collection is critical, the main challenge lies is having a common database for all the data that is collected as every OEM has its own way of gathering data. The need here is to create a standardized structure for data collection processes. At forums like Pegasus, for example, stakeholders work collaboratively to standardize the structure to collect data.

In contrast to larger companies like Mercedes-Benz and Bosch, start-ups like FishEyeBox have adopted a different approach to data collection models. Lacking the resources to collect millions of TB of data only to find that the result is not working on the road, they have chosen instead to focus on achieving more active learning; where there is less but more accurate data made available rapidly so that feedback can be generated in real-time, allowing for more sustainable costs of operation.

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> There is enough information and data available across the various players in the industry which can be modified to create corner cases. Here, synthetic scene generation has an important role to play wherein scenarios are created completely synthetically or where data from a video/sensor file generated by mounting signals and running the vehicle for a few miles can be leveraged to propose some scenarios which were not encountered.
>
> **SHAJU S.**

> Unless there is a standard language whereby data can be collected, used and then reproduced, then it will not be possible to compute it.
>
> **RAJA DURGESH VIPPARTHY**

> What is really needed is a model of active learning which would be helpful not just for the automotive industry but across domains. What is also critical for AD is to bridge the gap between engineering and intelligence by drawing from multi-disciplinary sources in order to enable the vehicle to understand the micro interactions/interference that occurs between humans.
>
> **PINAKI LASKAR**

Driver Behavior

The way cyclists, pedestrians, and car drivers interact with vehicles vary. To gain a deeper understanding into these dynamics, lessons from anthropology, sociology and psychology need to be incorporated into the AD domain. Accounting for these behavioral variations through algorithms will require innovative, out-of-the-box approaches.

Accuracy of Sensor Models

In the context of active learning, sensor networks need to be trained to help smart cars "see" better and, thus, drive safer. This means camera-based or radar-based systems have to be able to identify the right set of obstacles or objects based on the images being received.

Sometimes sensor output in a simulated environment changes in a real world setting because of the multiplicity of car parameters that can influence sensor output, much beyond what can be modelled in a simulation timeframe. Here, while some companies are focusing on simulation or synthesized data to ensure it is as good as real data, others are concentrating on building the product itself.

One approach is to slice out the most critical test cases and then "parameterize" the collected data which becomes the basis for simulation. This provides a starting point, making that scenario more reliable to begin with. Parameterization allows for the spinning of new scenarios from the base, enabling a much richer set.

WENSI JIN

Our focus is on creating an infrastructure to generate the data, a database on which to design the product and to gradually migrate to the simulation infrastructure from MathWorks (or a similar company) when it reaches a point where the synthesized data is as good as the real data. This will make the product cycle go faster and make it much more economical to develop. Until that point, however, the principal reliance will be on real data.

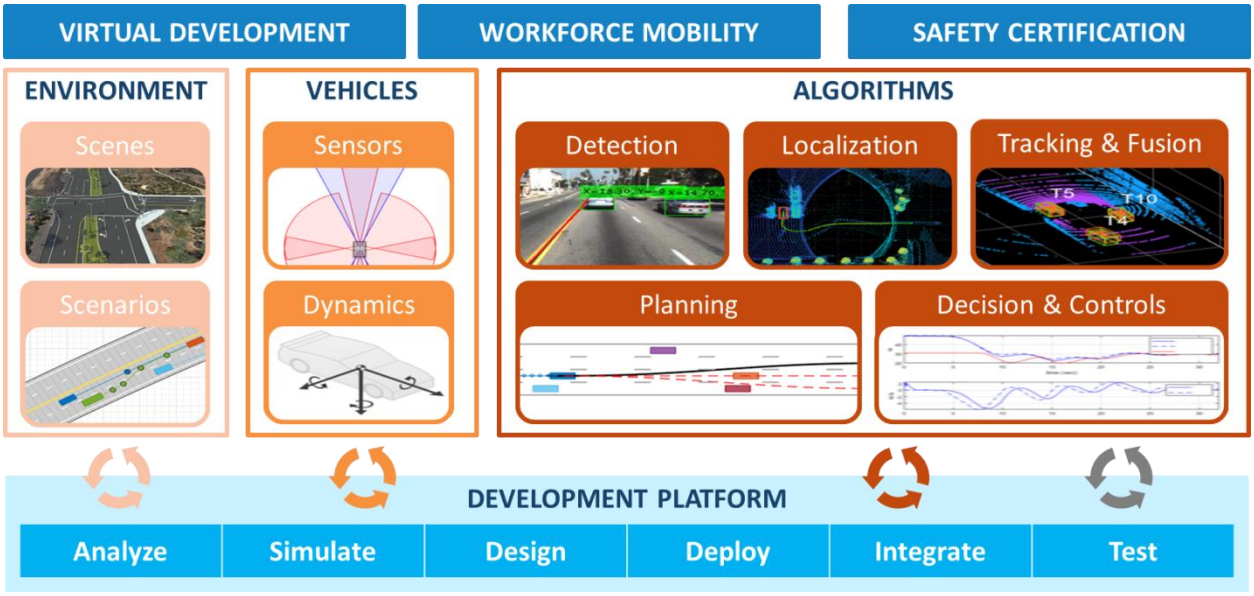
GIREESH RAJENDRAN

BUILDING THE COMPETENCY OF TEAMS WORKING ON AUTOMATED DRIVING

In no other domain of Automotive Engineering do we find such diverse skillsets coming together. Today, ADAS stacks are developed by teams with skills ranging from AI (perception) to advanced model predictive control (controls) to engineers working on techniques like SLAM (localization).

As a simulation tool developer working with various organizations, MathWorks understands that organizations have the need to train engineers in niche skills and a second challenge is how these individual teams can discover and work with adjacent domains. For e.g.: How does a perception engineer understand and discover the localization or controls domain. MathWorks' investment philosophy has been to help companies build competencies across multi-functional teams with disparate skill sets.

Representation of the AD Simulation Framework



Source: MathWorks, 2021

So how does MathWorks provide support in Workforce Mobility? MathWorks helps customers address the emergence of new disciplines like sensor fusion by creating specialized toolboxes that work as add on blocks on the base development platform of MATLAB, Simulink and Stateflow. Reference examples shipped with the product help algorithm developers with a baseline, rapidly bringing engineers up to speed on newer developments, thereby avoiding the need to start from scratch. In essence, therefore, MathWorks has supported customers and industry to lower the barriers for engineers in simulation and algorithm development.

REGULATIONS, HOMOLOGATION AND LIABILITY

Any discussion on safety in the AD domain will necessarily include homologation. How do safety and homologation fit into the simulation ecosystem, particularly since some agencies prescribe simulation as part of the homologation process?

The laws for assisted driving are clear because the driver is in control. However, regulation for L3 conditions or automation where there is the possibility for driver hands-off or eyes-off for a certain amount of time, are still in development. Many OEMs, including Daimler, are in ongoing talks with regulatory authorities to explore the requirements needed for L3 certification. Self-certification is one route but brings its own set of challenges.

Today, a rule-based system governs AD. However, humans work on intuition not rules, which means that a rules-based system will work perhaps only 80% of the time and even less in countries like India where intuition dominates. In this context, engineering must be welded to intelligence to promote improved outcomes.

This apart, one of the most unique challenges will be to validate AI algorithms.

Validating something on the basis of simulation or proving that a certain AI algorithm was tested in simulation will be challenging. This is as yet an unsolved puzzle but stakeholders are working to define a robust system wherein the simulation and validation of an AI system can be authenticated.

SUNDARRAJAN RAMALINGAM

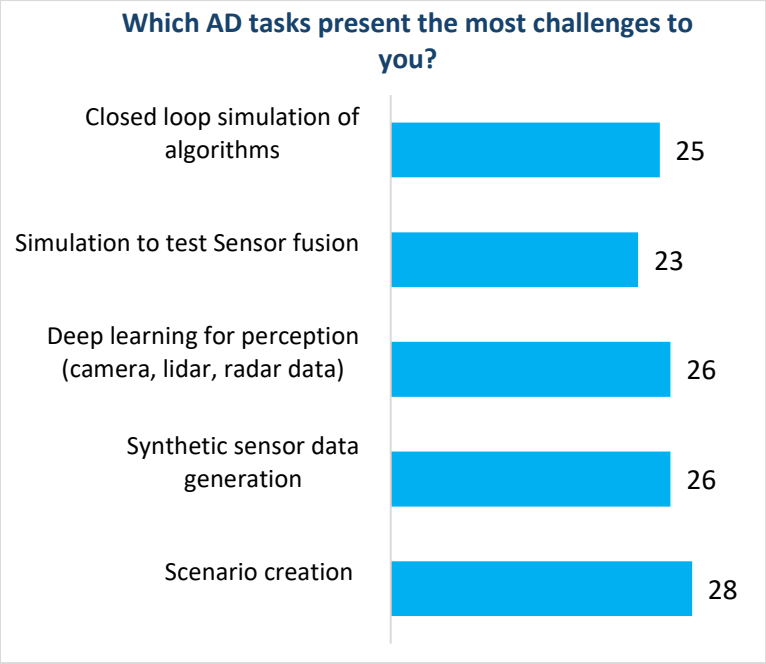
We are very far away from figuring out what will happen in a real scenario involving an autonomous vehicle. Simulation will help but I don't think one can tell a regulatory board that we have 100% simulation, so can you stamp it.

RAJA DURGESH VIPPARTHY

Audience Poll Question 1:

Which AD task presents the most challenges to you today? Scenario creation edged out the other options—Synthetic sensor data generation, Deep Learning for perception, Simulation, and Closed loop simulation—by a small margin.

The Role of Middleware and Standard Interfaces



In 2020, Tata Elxsi and artificial perception pioneer AEye announced the successful completion of RoboTaxi, Tata Elxsi's in-house concept demonstrator vehicle developed using AEye's iDAR™ platform and Tata Elxsi's autonomous stack. Against this backdrop, an important question is whether AD simulation tools can be bought off-the-shelf or whether specific tools or applications based on certain use cases need to be developed?

In terms of the role a simulation tool provider would play in middleware development, MathWorks indicates that there are two aspects to consider. First, the more straightforward, middleware on the vehicle to which the simulation has to connect. The second is the simulation middleware itself. This gets tricky because of the profusion of different simulation tools. This is where standards such as OpenDRIVE and OpenSCENARIO will play a crucial role. Standards such as FMI/FMU are also allowing engineers to connect different pieces of simulation.

> While there are tools available for simulating AD scenarios, they don't necessarily cover all the scenarios. One of the challenges is the choice of sensor configuration and that is what Tata Elxsi targeted while developing Autonomai. It created a middleware platform which was configurable; allowing the OEM/Tier 1 supplier to choose the sensor configuration they wanted to put on their vehicle, interface that with the middleware platform, thereby enabling them to develop further AD algorithms on top of that.
>
> **SHAJU S.**

> From a tool vendor point of view, what we can do is make sure our interface is exposed so that it can be connected relatively easily with any other middleware tool that wants to connect with it. Meanwhile, the formation of standards like FMI will support tool exchanges to which providers will need to adhere. The tools have to generate some artifacts being generated by other tools, for example, open drive format or open scenario format, for which compliance will be required. So there are multiple different answers: the API, the tool interface, the tool-to-tool artifact exchange would all help.
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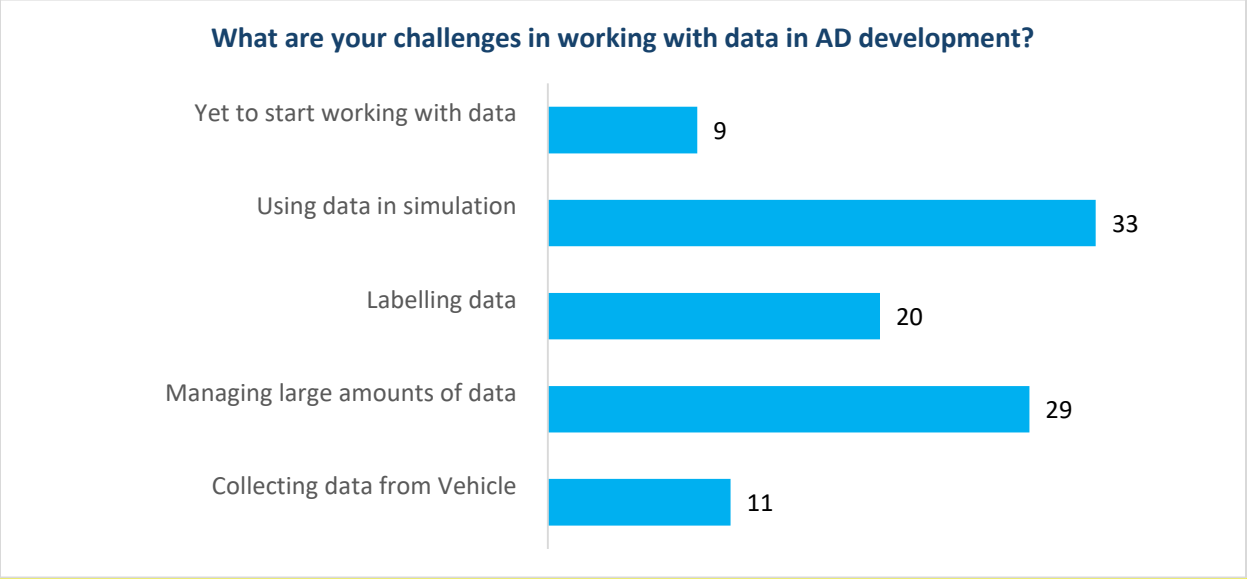
> **WENSI JIN**

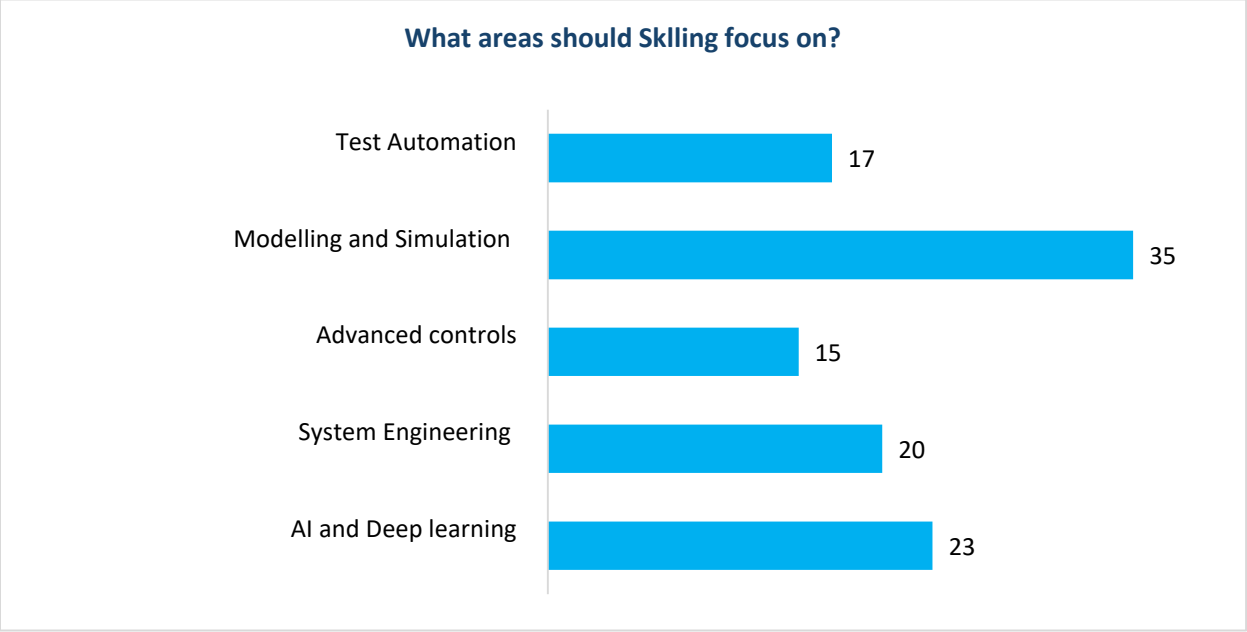
Audience Poll Question 2:

What are your challenges in working with data in an AD development scenario? The majority of the audience chose data and simulation.



Audience Poll Question 3:

What areas should skilling focus on? Modeling and simulation emerged as the top choices.



CONCLUSION

The panel discussion spotlighted several key themes in simulation and AD. The consensus was that the end goal for all stakeholders will be to make simulation reliable and trustworthy. This, in turn, depends on the ways in which data is collected, used and parameterized; the effective leveraging of real life driving conditions into simulation in order to develop new scenarios. And while simulation techniques evolve, the need to train engineers and develop an understanding of different skills and domains in AD is also equally important.

Key Conclusions and way forward

Simulation will be key to the development of Automated Driving

The need for verification and validation is fueled by safety, certification and increasing complexity

Autonomous systems will generate a lot of data and industry is looking at how this data can be used

The opportunity for India is high with the multitude of tech centers, engineering services and upcoming start-ups

The future is "Software Driven" which, in turn, is driving transformation in the auto industry. To solve the AD challenge, partnerships and collaborations will be required.

Source: Frost & Sullivan, 2021

In addition to the need to standardize structures and frameworks for data collection, collaboration between simulation tool providers, OEMs and suppliers will be critical to fast-track developments in new tools, homologation, regulation, testing, validation, and certification.