Autonomous Vehicles

Spearheading an Era of Dynamic and Intelligent Mobility

A White Paper by Microsoft and Frost & Sullivan

Microsoft FROST & SULLIVAN

50 Years of Growth, Innovation and Leadership

INTRODUCTION

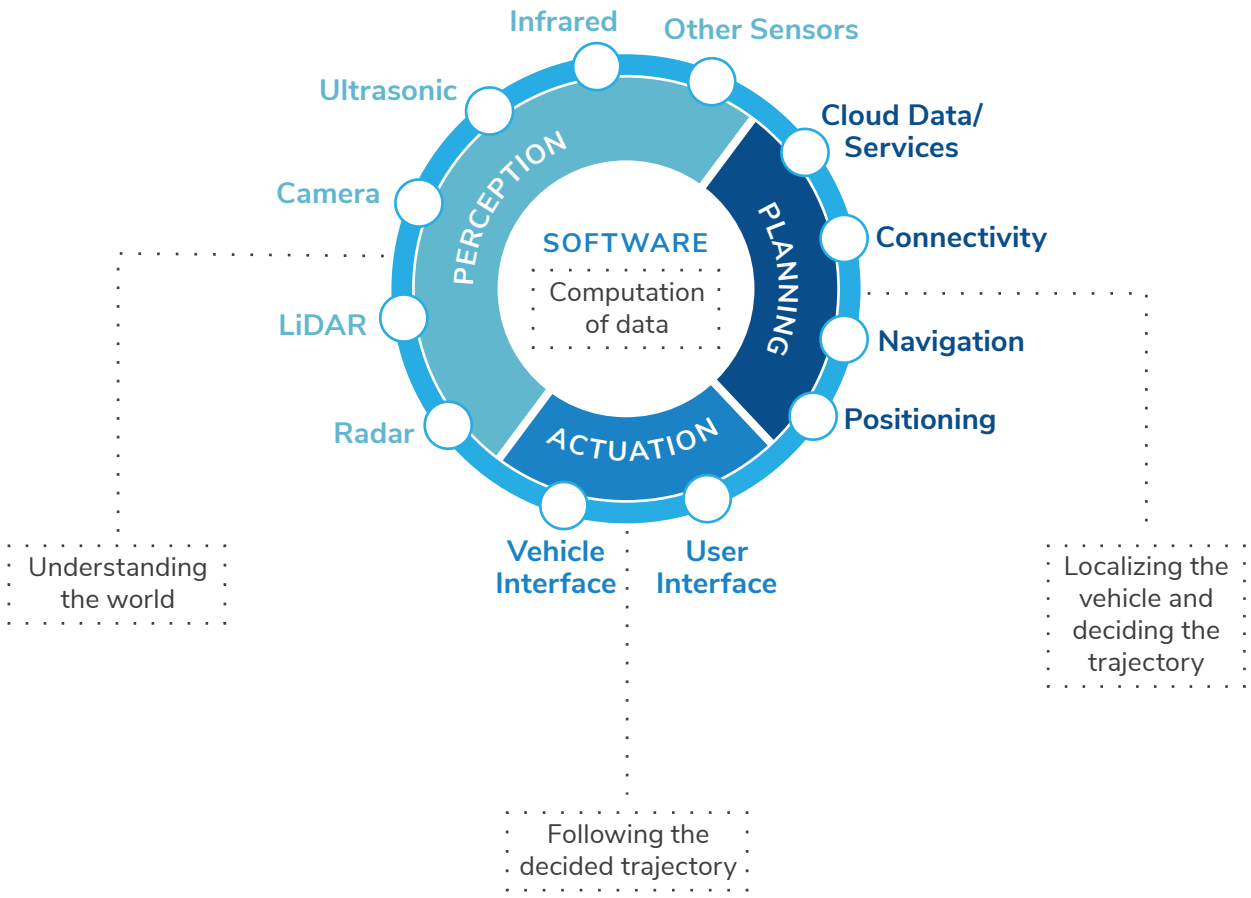
The automotive industry is actively writing the roadmap towards an autonomous future. It's no secret that connected, autonomous, shared, and electric (CASE) technology are expected to transform mobility, giving way to more dynamic, intelligent forms of transportation and new in-vehicle experiences. These advancements are set to redefine driving experiences for consumers. AVs have the potential to reduce travel time, ease road congestion, and deliver more reliable and safe mobility services. Autonomy represents a major quality of life improvement for the elderly, young, and disabled travellers that can access equitable mobility offerings. Self-driving vehicles are to reduce accidents and severity, which help cut down annual traffic deaths and injuries sustained. As drivers in The United States spend 294 hours behind the wheel commuting each year, less time spent in congestion, and more productivity while travelling represent tangible benefits that save time, money, and stress.

The established norms and business models familiar to legacy automakers are disrupted as cost structures shift, forcing OEMs to explore new roles as service providers. The number of new vehicles sold annually is expected to decrease as the automotive industry moves towards shared mobility business models powered by autonomy. Although some speculate that increased vehicle utilization will incur more vehicle replacement, this has led the industry to acknowledge that profitability in the future will depend on the creation of new revenue streams and business models. Meanwhile, advancements in autonomy have led to or catalyzed developments in multiple adjacent segments such as advanced driver assistance systems, tele-operations technology, and autonomous fleet management platforms. As such, new entrants such as major tech players and start-ups are becoming more prominent in the automotive space. To stay ahead of the competition while preparing for this autonomous future, automotive players must build toolchains that enable collaborate development, validate and manage AV solutions through deep learning, and provide full support through product life cycles.

Established automakers and new entrants alike are turning to technology partners that provide the most innovative and cost-efficient intelligent cloud and intelligent edge offerings to underpin their development toolchains. The overarching technology used to facilitate autonomy can be classified into four categories – perception, planning, actuation, and software. Perception allows the collection and processing of sensor and driving data, such as object recognition and localization. Planning allows AI models to plan and predict paths, avoid obstacles, and control motion. Actuation controls braking, steering, and the human machine interface (HMI).

Software is central to improving and deploying technology of perception, planning, and actuation. Software lays the foundation for end-to-end autonomous development along each phase, from data ingestion and preparation, to training and simulating models, and training and validating. When selecting the best software partner, autonomous developers should consider players that enable integrated toolchains and comprehensive DevOps platforms. Strong partners help foster collaborative development with an open ecosystem and effectively reduce time to market, without directly competing in the automotive or autonomous space.

EXHIBIT 1: FOUR CATEGORIES OF AUTONOMY



EMERGING BUSINESS MODELS

AV technology will bring significant change to traditional automotive business models while ushering in an era of safer, more accessible, cost-effective, and immersive mobility services. The convergence of technologies and consumer changing preferences will create an array of new value propositions in the market. Among the main business models that are expected to emerge and grow in conjunction with autonomy are:

- **Mobility Services:** As it progresses towards full autonomy, the automotive industry is expected to shift from ownership to usership-based business models. Simultaneously, autonomy will help drive the convergence of the various fragmented mobility services that exist today.
- **Vehicle Services:** As sensors and technologies become uniform across the industry, vehicle services will emerge as the differentiating factor. These services are becoming more dominant

than automotive brands themselves and are expected to dictate the shape of future vehicles more than manufacturers.

- **Unlocked In-Vehicle Experiences:** With less time and cognition focused on driving, consumers will have the option to bring the office or home space into their mobility experiences, increasing productivity and comfort.
- **Peripheral Services:** Connected and AV data will be used to develop value-added services like usage-based insurance and predictive maintenance that can be offered to drivers, fleet owners, and mobility service operators.
- **Logistics Services:** New modes and mechanisms across various stages of the logistics chain will improve efficiency by optimizing time and cost of services. Some logistics providers are exploring autonomous delivery bots and drones to supplement traditional delivery services, while others have launched pilots to understand the feasibility of using shared mobility platforms to improve last-mile delivery.
- **Long-Haul Delivery:** Autonomous delivery represents a major improvement in long-haul efficiency, as vehicles can travel 24/7 with no human oversight or need to stop other than refuelling. As the industry continues to face a driver shortage, this space has the potential to yield high returns as shippers can instantly realize cost savings.

Key Challenges

AV development requires a comprehensive toolchain, the various components of which seamlessly integrates and work together in harmony. End-to-End workflow management with built-in feedback loops and traceability for automotive certifications are two key challenges automakers are constantly faced with. The other challenges include managing the massive test data generated by AVs, the massive compute needs required to train large sets of data, simulate real-world driving, validation such as software-in-the-loop and hardware-in-the-loop testing and accurate AI model training. AVs generate massive amounts of data during development. On-road trials are necessary to hone the AI powering AVs. Depending on the level of autonomy, AVs generate 20-100 terabytes of data per day. Managing the sheer amount of data requires proper curation to filter and store data at scale and economically. On-site data centers will be hard pressed to handle the storage and technology needs as the volume and permutations of ADAS, autonomous programs, associated simulations and validations increase. Developers must leverage high performance computing to train, simulate, and re-simulate ML models and algorithms. Requirements of Hardware-in-the-Loop (HIL) and Software-in-the-Loop (SIL) testing impose further challenges. Additionally, beyond technology, since developing AV is so specialized and the level of simulation, training, validation, and model building is unique, finding and retaining the right talent becomes challenging.

AV Development & Testing

AVs need to pass rigorous testing and regulatory hurdles before becoming commercially viable. Billions of miles of driving validation are required to certify an autonomous system. Typically, AV testing is done in two parts: digital, simulated testing, and real-world, on-road testing. Simulated models test AVs on virtually constructed environments in which AVs traverse routes surrounded by other vehicles, bicyclists, and pedestrians. This drastically reduces the requirement of on-road miles to gather data for

training purposes while addressing edge case scenarios that are hard to test in real world safely, such as pedestrian navigation on a busy road. Simulations increase the speed of AI training while reducing the cost of real-world testing.

As OEMs transition from basic ADAS to full autonomy, their methods of data ingestion, curation, training, validation and simulation will also need to evolve. Higher levels of automation will require massive amounts of data from sensors and events to be collected and processed. AV development, therefore, requires robust data transfer and processing capabilities. Cloud integration and cloud-based DevOps tools will allow developers to architect a unified data pipeline that reduces development and test cycles and help create an integrated seamless toolchain across the organization. The need for computing capacity is magnified with autonomous development particularly for re-simulation, simulation and training. Significant investments in servers are required to store and process this data on-site. As these workload demands are not always static, these servers would be underutilized when there is light simulation demand, at a fixed expense to the developer and run out of capacity at peak demand creating productivity bottlenecks. Cloud technology solves the challenges of data ingestion, processing, and analysis by offering an economical and scalable solution that meets the on-demand needs of variable workloads with the latest of technologies.

PAVING THE WAY TO AUTONOMY WITH PARTNERSHIPS

Building a Toolchain for Autonomous Development

Developing autonomy is a feat that cannot be accomplish by one single entity. Automakers realize that collaboration is key in creating effective and economical autonomous platforms. Microsoft, with its partner led approach and breadth of assets affords automotive industry players a collaborative, open, traceable, comprehensive and highly customizable toolchain, comprised of first party and third party based secure and hyper-scale solutions

MICROSOFT'S AV EXPERTISE, CAPABILITIES, AND SOLUTIONS

Microsoft's Azure has become a comprehensive platform that augments AV development, offering the means to improve autonomous perception, planning, simulation, and deep learning. It is the foundation of an end-to-end toolchain that developers can utilize to accelerate autonomous development, testing and deployment. Microsoft's ongoing strategic product investments and ever-expanding partner ecosystem further accelerate the research and development of AVs. Microsoft's DevOps tools help developers streamline the workflow and manage traceability over the multiple iterations of development and validation cycles.

Data Ingestion, Storage, and Curation

Microsoft Azure Storage offers a range of capabilities that are resilient, flexible and scalable for the storage of both structured and unstructured data. Microsoft's IaaS and PaaS options provide automotive manufacturers with limitless scaling across global data centers. A comprehensive set of storage and networking solutions for data ingestion of over 100Gbps express route cover both network-based and offline appliance-based scenarios, including edge processing appliances. With multiple options for data ingestion, Azure enables rapid transfer and transform options. Azure provides a tiered storage model across hot, cold, warm and archive that facilitates cost-effective scalability and performance needs of data-intensive simulation, rendering, and validation workloads. Microsoft bolsters product capabilities through independent software vendor (ISV) partnerships to build a broad set of AD capabilities on Azure. These third-party services include labelling for AI training and data management tools that reduce the time spent searching for drive scenarios of interest and curate the data for effective development and validation.

High Performance Compute Services

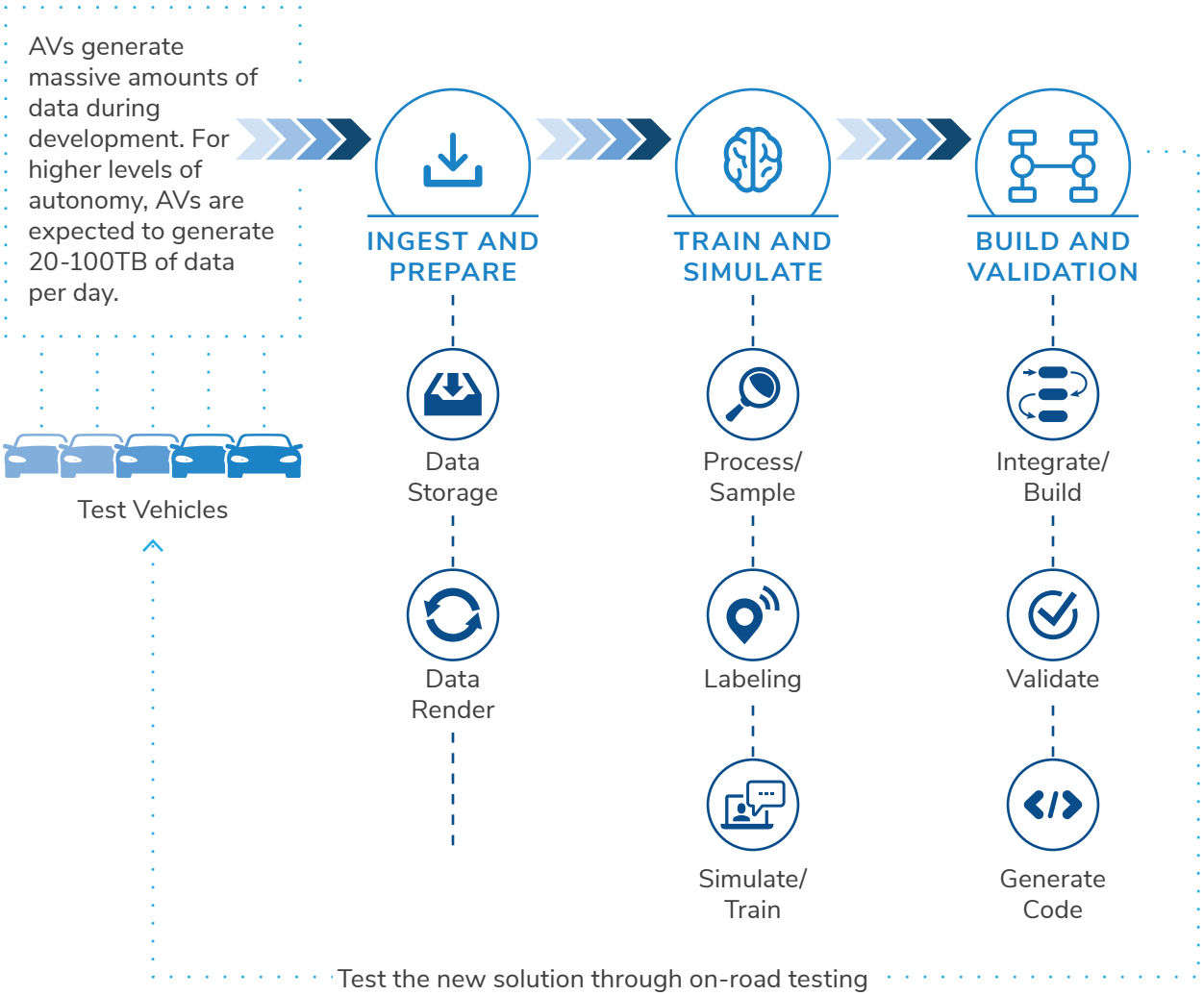
High Performance Computing (HPC) uses a computer network based on central processing units (CPUs) or graphics processing units (GPUs) to solve complex mathematical tasks. Microsoft Azure's high-performance computing and deep learning portfolio consists of four integrated solutions that support end-to-end product and autonomous development workflows: Cloud Workstation, Cloud Rendering, HPC Simulation and Analysis, and Deep Learning and AI Training. These solutions dramatically reduce the amount of time to train, teach, and deploy updated autonomous models, effectively accelerating go-to-market time. Azure HPC enables engineers to quickly convert sensor data pulled from test fleets into simulation data sets, thereby enabling the concept "drive millions, train billions." Microsoft's powerful computing resources enable automotive manufacturers to run simulations on any solver or simulation platform, integrated with an existing scheduler. Engineers can execute large parallel and batch compute jobs at scale on-demand to get results faster and shorten validation timelines. Azure's unique InfiniBand networking capabilities provide high throughput and low latency, enables engineers to run multi-node jobs. Driving innovation within AI is a top priority for Microsoft. Robust support for containers, along with a commitment to support all major deep learning, DL, frameworks (such as Torch, Caffe, TensorFlow, CNTK, and Chainer) makes Azure a flexible platform for deep learning. Moreover, with software tools like Azure Cycle Cloud AI training, running jobs at scale can be run as a PaaS-style managed service.

Simulation, Training, and Validation

Azure aids AV development by enabling a cloud-based simulation platform which allows automakers to run thousands of tests in a virtual environment based on data collected from real-world driving situations or from synthetic scenarios. As developers validate driving models executed in virtual test environments, they will be able to build autonomous systems faster, increasing the speed at which these models are enhanced.

EXHIBIT 2: MICROSOFT CAPABILITIES

Microsoft's solution is spread across the vehicle data pipeline, from data ingestion till testing and validation



Microsoft adds significant value and creative solutions to the individual stages of the workflow of Re-simulation, Training, Software-in-the-Loop (SIL) and Hardware-in-the-Loop (HIL) through industry leading first party capabilities and collaborative third-party solutions on Azure. As customers target higher levels of autonomy, the growing complexity of software & model management across versions and variants is causing many to realize that the key to shorter sprint cycles are not faster GPUs to accelerate training job run times, but process efficiencies delivered by a software layer of abstraction that enables developers, data scientists, and test engineers to collaborate on a shared platform. A comprehensive Continuous Integration/Continuous Development (CI/CD) pipeline built with a combination of Azure DevOps, Azure Machine Learning, Azure Data Factory, & Azure Databricks helps deliver such a platform. A tight integration across these tools and strong workflow management

capabilities will deliver a seamless experience to customers across data, code and models and enables resource optimized autonomous vehicle development.

CONCLUSION

AVs have the potential to revolutionize mobility and improve quality of life if autonomous developers can effectively overcome development challenges. As the roadmap to full autonomy is still being written, getting to that destination safely, expediently, at a reasonable cost will require collaboration and a deep partnership network. Hurdles such as stringent testing requirements and regulation are only the beginning. Autonomous developers are tasked with properly storing and curating data before training and simulating models. This end-to-end cycle depends on robust software development capabilities, which in many cases is outside of automakers area of expertise. As such, automakers partner with tech companies to architect, develop, validate and integrate software that provides traceability and automotive regulatory compliances like ISO26262.

When selecting a partner for autonomous development, consider those with wide partnership ecosystems and proven expertise across various industries. Microsoft empowers their partner's autonomous development workflow with open framework solutions that help with data ingestion, storage, curation, training, simulation, and validation. Autonomous developers that partner with Microsoft also benefit from a comprehensive Azure DevOps tools that assists in developing and integrating software in their end-to-end workflow. Furthermore, as the race towards full autonomy intensifies, collaborators don't fear a conflict of interest or IP loss as Microsoft does not compete against OEMs to develop AVs or provide end mobility services. As the industry gears up to embrace new business models based on AVs and innovative mobility services, expect Microsoft partners to be at the forefront pioneering exciting growth opportunities.

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NEXT STEPS

- Download Frost & Sullivan's **Global Autonomous Market Outlook** report for further information on autonomous vehicles
- **Learn more** about accelerating autonomous vehicle development with Microsoft solutions
- **Schedule a meeting with our global team** to experience our thought leadership and to integrate your ideas, opportunities and challenges into the discussion.
- Interested in learning more about the topics covered in this white paper? Call us at 877.GoFrost and reference the paper you're interested in. We'll have an analyst get in touch with you.
- Attend one of our **Growth Innovation & Leadership (GIL)** events to unearth hidden growth opportunities.

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