[Ecosystem Brief] VSI AV Ecosystem Infographic 2020

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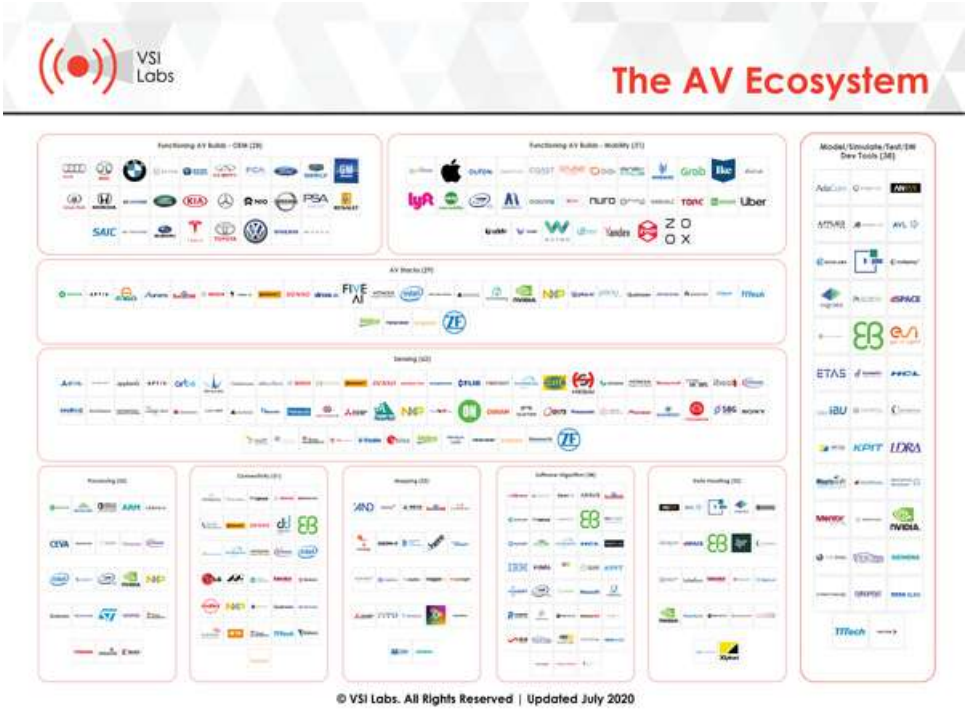
Introduction

Developing automated vehicle systems is a complex endeavor for anyone trying to compete in this space. OEMs and traditional automotive suppliers have been very active through tie-ups, investments, and acquisitions designed to improve their strategic position. Large tech companies are also very active in developing complete platform strategies as well as aggressive investments through their venture funds.

Beyond traditional auto and big tech companies, there are literally hundreds of other companies vying for a piece of the AV ecosystem. Many are startups with fresh rounds of capital, who are feverishly pursuing technology breakthroughs in the areas of sensing, processing, data handling, or software/algorithm. Meanwhile, well-established companies have been entering the AV space from adjacent sectors such as geosciences, robotics, or artificial intelligence, while others are entering from adjacent industries such as aerospace, defense, or logistics.

The purpose of this report is to decompose the current AV ecosystem by looking at the latest version of VSI's infographic, which reflects the major players within the value chain for autonomy. The report provides a high-level analysis of the global AV landscape by explaining each domain of the AV ecosystem.



VSI AV Ecosystem Infographic: The Building Blocks of Automated Vehicles

The AV ecosystem is a vast array of companies both large and small, that offer products and technologies to support active safety (ADAS) and automated driving. Making sense of this complex and evolving ecosystem is an

ongoing task.

VSI has been mapping the ecosystem of automated driving since 2014 and has published the VSI Infographic: AV Ecosystem - The Building Blocks of Automated Vehicles via social media channels since 2016.

***VSI Infographic 2016**: One of the first VSI Infographic published in social media*

VSI Infographic's AV ecosystem map is rather high level, and beneath it lies many categories and subcategories. Thus, VSI has also built an AV/ADS taxonomy for our database records system since 2014. The method for researching the companies and organizations that make up the ecosystem as well as a technical insight into their products and technologies led us to launch a dynamic and interactive infographic generator, Ecosystem Examiner, in 2019, as part of the VSI portal subscription service.

In order to invite broader AV community members, we decided to open the Ecosystem Examiner infographic generator to the public, whose outputs are based on our company-product relational database organized by our product database taxonomy.

While the Infographics in the Ecosystem Examiner represent more than 1,000 companies and over 1,500 products, this VSI Infographic is VSI's selection of only the top AV companies in each domain of the value chain.

VSI Infographic Selection Criteria:

- Companies featured in this infographic are chosen based on theirknown products or evidence of their commercialization strategy. A company operating in stealth mode does not necessarily qualify them to be on the chart unless we know precisely what they are doing and where their capital is coming from. Thus, industry visibility such as media/industry conference exposure is important to be considered, although the companies making the most progress are sometimes the ones making the least noise.
- VSI analysts receive analyst briefings from these companies routinely and gather insights by asking quality questions. Often times, we talk to each and every company in an AV ecosystem domain, enabling us to assess who has a more competitive advantage and strategic prowess. Our in-house lab engineers who perform applied research on AV technologies also help us build more objective and deeper technical insights on the technologies and products of these companies.
- Clarity of strategy, partnership span and ecosystem influence are also considered in selection.

The VSI Infographic is updated regularly (at least once a year) in order to reflect the dynamic nature of the ecosystem: mergers and acquisitions, internal business expansions, the emergence of new domains (e.g., data handling) and the demise of business entities.

Latest Landscape of AV Technology

Let's decompose the ecosystem by examining the companies and their associated categories within the infographic. The following sections discuss the categories, the compositions of each category, and what type of products are included. Based on observed trends in each domain, the leading companies are called out as well.

FUNCTIONING AV BUILDS - OEM

The Functioning AV Builds category represents companies that are buildingcomplete vehicle platforms with AV functionality. This field is also divided into two sub-categories; OEM and Mobility.

The companies that are represented in the OEM category are traditional automotive OEMs that are actively

developing ADAS/AV technologies for their production models. Their end goal is to build their own ADAS/AV vehicles and/or sell them to AV service operators or fleet operators.

To qualify for AV Builds, the OEM may offer automated features at the production level (typically L2 or L2+) and/or are developing L4+ "robo-taxi" vehicles. These are typically separate business units as rarely does an OEM consolidate their automated activities into one group. Furthermore, the L4+ track is typically based on a new mobility service model which has huge implications in terms of timelines and go-to-market strategies.

Most recently, OEMs have pushed hard to come out with new and better L2+ ADAS systems, utilizing improved software algorithms, additional sensors, and more scalable platforms. A few OEMs seem to be interested in showing off L3 reliability from their new systems, while most others are pushing for wider availability of their L2+ systems and adding more ADAS features. On the other hand, most OEMs have slowed down developing robo-taxis and pursuing L4+ consumer AVs.

Tesla and **General Motors** are the early leaders of L2+ systems (Autopilot and Super Cruise, respectively), while most major OEMs started commercializing their L2+ systems. Notably, many Chinese EV startups partnered with major ADAS/AV compute platform suppliers have planned or commercialized these L2+ systems recently.

FUNCTIONING AV BUILDS - MOBILITY

The Mobility category includes companies that are developing and testing complete AVs for future mobility target markets such as the robo-taxi, low-speed automated shuttle, robo-delivery vehicle and autonomous truck. Many companies in this space retrofit current production vehicles and integrate systems from multiple suppliers coupling that with their own self-driving technology stack. Their end goal is to operate AV mobility services for the general public and commercial fleets.

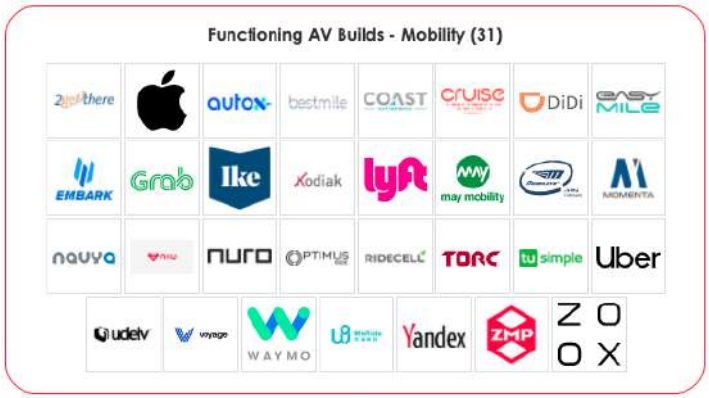
Many of these companies develop full AV stacks in-house with a mobility service operation network in mind, but others may outsource either designing the AV system, integrating the software platform and/or compute platform.

While automotive OEMs (e.g., **Mercedes-Benz** and **BMW**) still put a lot of focus on making self-driving cars for private ownership, non-OEMs believe the fleet-owned robo-taxi model is the right path. Currently, tech giants (e.g. **Waymo**) are set to lead the robo-taxi ecosystem by acquiring capable AV startups at discounted valuation (e.g., **Amazon's** acquisition of **Zoox**) due to the COVID situation and the fact that their technologies still lack revenue generators anytime soon.

Meanwhile, independent startups and regional players (especially in China) are well-funded by automotive OEMs or tech giants to operate independently until the commercialization of robo-taxis. An interesting new player in this space is **Mobileye**, who is set to become a complete mobility provider with the acquisition of Moovit.

Nuro and other robo-delivery AV makers are also getting attention in the COVID era, while low-speed shuttle operations have been slowed down. Still, **Navya, May Mobility, Optimus Ride, Bestmile,** and **Easy Mile** have done many pilot projects in restricted areas and are nearing commercial operations.

Lastly **tuSimple** who's designing an autonomous truck, enabling technologies, and autonomous freight network in the US is partnering with many commercial fleet operators and truck manufacturers. The autonomous trucking industry is also joined by many others startups like **Embark, Ike, Kodiak,** and **Torc** (acquired by Daimler Truck). There is also a recent dropout like Starsky Robotics.



AV STACKS

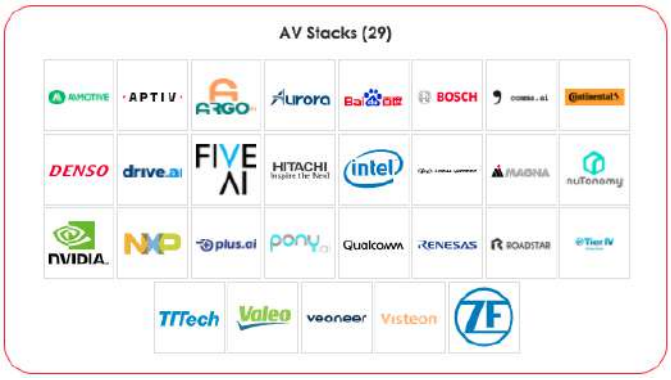
The AV Stacks category includes companies that offer AV full-stack systems, and compute and/or software platforms that can handle the tasks of perception, decision, and control. These companies are developing AV platform technologies to control multiple domains of AV functionality. Most companies in this space also have their own research AVs for testing purposes. Their end goal is to provide their AV hardware and/or software stacks to OEMs and mobility service operators developing functioning AV builds – complete vehicles.

Traditional tier ones used to dominate designing ADAS systems, but in the AV world independently operating **Aurora Innovation, Five AI, Comma.ai,** etc. or vertically integrated/acquired AV startups like **Argo AI (to Ford**/VW group**), Drive.ai (to Apple)**,etc. are the ones leading AV platform development.

Intel/Mobileye, Nvidia, Qualcomm, NXP and some tier ones (**Hitachi, Denso, Bosch, Conteinental, Vaelo, ZF, Magna,** etc.) lead the supply of AV compute platforms or ADAS/AV domain controllers. Qualcomm for example, announced the Snapdragon Ride platform enabling levels of automated driving at CES 2020.

Rather than licensing individual software components, AV SW platform suppliers usually provide onboard software (algorithmic SW, framework SW and operating system), off-board software and data infrastructure (data processing, operations, mapping, maps).

Meanwhile, several companies (e.g. **Baidu, Tier IV, Apex.AI**) in this category open source their software/ framework and are calling for participation and collaboration across the industry to share knowledge and to contribute to their open-source AV software repositories. Some companies do this to generate revenue from other sources such as selling the data they collected (e.g., **Baidu**).



SENSING

The Sensing category is the largest category, to no surprise. Sensing is a large piece of the AV stack and the components here include all formats from sensor signal/image processing ICs to optics components and antennas, to complete sensing modules.

Although not shown in our high-level infographic, the sensing category is further defined by sensor types including RGB camera, radar, LiDAR, ultrasonic, IR/NIR (or thermal), GPS/GNSS, IMU (Inertial Measurement Unit) and INS (Inertial Navigation System) devices.

Among the many functions, sensors are used to detect the 3D environment around the vehicle as well as other actors in the scene including vehicles, pedestrians, and even animals. For example, vision sensors are ideal for classification of objects as well as scene segmentation, while radar provides the best object tracking (the exact movement) of other vehicles.

Many Robo-Taxi application challenges are being covered by different technologies in LiDAR (wide field of view and short-range LiDARs), while the main use case of LiDAR like highway pilot applications in consumer vehicles seem to be near production-ready by a few major LiDAR companies.

There are more companies that have already solved the main use case / most common applications (roof-mounted or forward-facing), while this ultra-wide, ultra-high-resolution, short-range LiDARs are filling in a gap in main sensing, blind spots, or an edge case, and there are more likely Robotaxi companies who are farther along in development or mature in the development phase. For example, **Waymo** is far along in development and they use the Honeycomb LiDAR which is similar to these ultrawide, ultra-high res, short-range LiDARs.

Lots of LiDAR startups are acquired (e.g.,**Blackmore, Strobe**) by vertically integrated companies (e.g., Aurora Innovation and Cruise Automation, respectively) who want to internalize all necessary components and IPs. Other successful startups are working with tier ones/OEMs to prove out the commercial viabilities of their technologies (e.g., AEye, LeddarTech, Aeva, etc.).

In the radar world, aside from renowned radar chipset makers (e.g.**Texas Instrument, Infineon, NXP**,etc.) and tier-one incumbents (**Aptiv, Continental, Bosch**), HD/imaging radar startups (**Arbe Robotics, Echodyne, Uhander, Metawave**) are emerging with unique antenna designs for creating data much more similar to LiDARs than traditional radars which lack vertical resolutions.

GPS positioning is vital for AVs because they require absolute location, but GPS by itself does not provide the precision necessary, so many AV developers rely on enhanced GNSS receivers that rely on ground-based transponders to improve GPS accuracy down to a few centimeters.

Another sensor vital to AV functionality is Inertial Measurement devices (IMUs). When coupled with wheel odometry, IMUs can predict the AV's position through dead reckoning, especially in areas where GPS signals are compromised. INS devices typically come with both GPS and IMUs, along with positioning engine and correction services. Major suppliers include **Trimble, Swift Navigation, OxTS, Novatel/Hexagon**.

Lastly, thermal cameras are an important sensor for higher levels of AVs (e.g., robo-delivery Nuro R2 has a thermal camera) and could also become more popular in L2/L3 ADAS vehicles (e.g., **FLIR** testing AEB-P system with VSI Labs).

PROCESSING

The Processing category includes companies that offer processing logic orlicensed IP. The processor technologies and types represented in this domain typically include digital signal processing (DSP), field-programmable gate array (FPGA), graphics processing unit (GPU), microcontroller, and a system on a chip (SoC). There are also application-specific integrated circuits (ASICs) which are essentially customized instruction sets coupled and optimized for a specific computing function. This category would also include processors optimized for computing and AI-based inference model.

Within the context of automation, these processing technologies are used for the areas of perception, localization, prediction, planning, control, AI inferencing, connectivity, security, and safety. Most of the major semiconductor companies in the automotive industry offer solutions (i.e., nodes) for the various domains within active safety and autonomous control. Some silicon providers provide physical chips while others may offer licensable instruction sets for some custom configuration.

Within the context of processing, the demands required from an AV are similar to gaming computers where millions of pixels (or data points) must be processed in real-time. Therefore, processing methods often require massively parallel architectures where multiple streams of data can be processed in parallel.

Graphic processing units (GPUs) are a popular choice for handling this type of computing environment. These architectures are also well suited for processing AI-based algorithms. Some companies refer to this type of processing as accelerated computing, where the processor is designed to handle parallelized processing tasks.

Many companies in this category also appear in AV Stacks as an AV Compute platform supplier, while this category highlights more component-level players, for example, suppliers of neural network (vision) accelerators (ASIC or IPs only) such as **Almotive, Ambarella, Horizon Robotics**, etc.

CONNECTIVITY

This category used to be Data/Connectivity in the previous versions of VSI Infographic, but the players for data processing and management solutions for AV development will be tracked separately in the "Data Handling" category. Instead, this new Connectivity category includes companies that offer hardware/software solutions that support the movement of data along the in-vehicle networks or via wireless networks outside the vehicle. Some of the companies are Tier 1 suppliers that make connectivity modules (i.e. gateways or connectivity controller/ECUs) that can handle the data traffic, compressing/decompressing or encrypting messages where needed. Others in the space produce network interfaces and switches that may be a component within the network architecture of the vehicle.

Moreover, companies that make external communication modules such as V2X devices and telematics control units (TCUs) are also included in this category. These companies are a vital member of the data connectivity stack as future AVs must communicate with other vehicles and infrastructure. Furthermore, the AV must maintain connectivity to service providers and monitoring centers for various applications including the maintenance of vehicle software assets (Over the Air Software update), or remote teleoperation. Tele-operation companies included in this version of VSI Infographic are **Designated Drive**r and **Phantom Auto**.

MAPPING

Mapping assets used for automated vehicle functions are vital for performance and safety. Maps for AVs are highly detailed and include a precision lane model so the vehicle can operate when lane lines are not visible or are covered by environmental elements. Furthermore, Maps for AVs contain landmarks and other physical

structures from which the AV can localize against. Lastly, mapping assets contain other data including speed limits, curve warnings, lane closures and the like.

This category includes map companies that provide digital map data for AVs. These map companies harvest, process, and update map data and provide them to OEMs and other AV companies. Some of the companies provide full maps-as-a-service while others offer mapping-as-a-service.

It is clear that maps for automated vehicles are gaining in importance to enhance the safety or control the operational domain from which that vehicle can operate within. The Level "2+" category typically adds mapping assets including lane level intelligence and/or localization markers.

The companies here can be grouped in three categories as below:

1) Big 4 (**HERE, TomTom, Zenrin, NavInfo**) who are ADAS map global leaders, HD lane model regional leaders with end-to-end mapping operation capabilities.

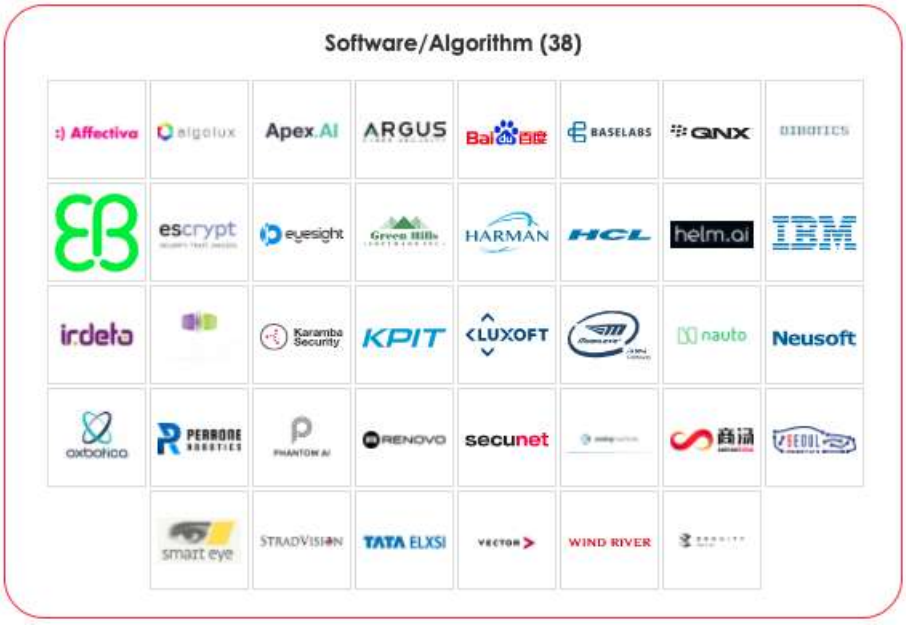
2) HD Map startups such as **Deepmap, Civil Maps, NetraDyne, Camera, Atlatec**, who are focused on mapping-as-a-service software licensing or map change detection algorithms or pilot projects on urban driving.

3) Regional coalitions (**Dynamic Map Planning** of Japan and **Ushr** of North America).

Among the companies in this category, two companies do not exist anymore due to acquisition – Lvl5 (by DoorDash) and Mapper (by Velodyne).

SOFTWARE/ALGORITHM

The Software/Algorithm category is very broad and includes companies which offer operating system, middleware, run-time software, application software, and AI inference model. Among the onboard software suppliers, many are the suppliers of operating systems and middleware, while others are specialized in AV framework software.



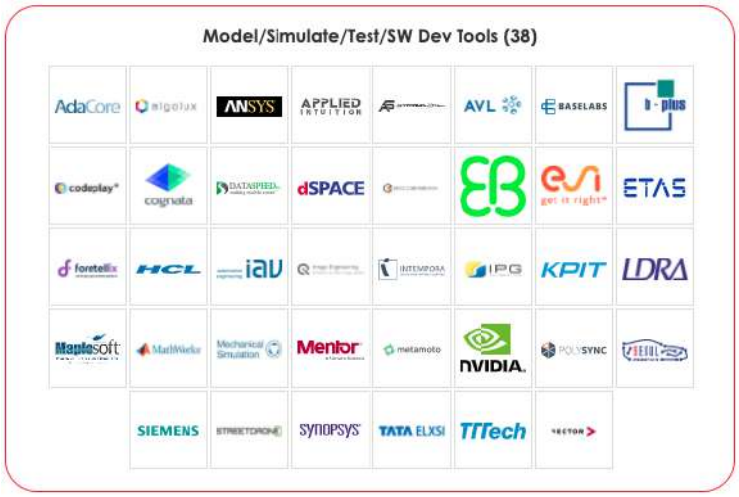
Unlike AV software platform players in the AV Stacks category, some of these companies tend to license individual algorithmic software or application software such as ADAS perception software (e.g., **Helm.ai, Seoul Robotics, Stradvision, Phantom AI**, etc.), driver monitoring applications (**Nauto, Affectiva, Eyesight, Jungo, Seeing Machines, Smart Eye** etc.), and security solutions (**escrypt, IBM, Secunet, ir.deto, Karamb**a, etc.)

Some engineering service firms (e.g., **KPIT, HCL, Tata Elxsi**, etc.) have accumulated its software development experience with PoC projects for their clients and have come out with licensable software components.

Software development tools are generally not part of the software category and are included in the tool domain. Software companies that offer software development tools generally provide what is referred to as a software development kit (SDK) where the developers are responsible for making their own run-time applications.

MODEL/SIMULATE/TEST/SW DEV TOOLS

The Model/Simulate/Test/SW Dev Tools category includes companies that offer software development tools for algorithms, code generation, development environment/kits, network/signal analysis, and debug/compilation. There are also companies that offer tools for simulation, modeling, prototyping, recording/examination, and validation/verification.



These development tools are vital for designing sophisticated AV systems. Modeling comes into play early in the development cycle followed by various stages of simulation to test the performance against a virtual environment where scenes, actors, sensors, and physics can be modeled. Some of the simulations offer the ability to test individual components, while others are used to test the performance of algorithms.

The latest trend is that big international companies internalize AV development tool assets by acquiring smaller/specialized companies. For example, **dSPACE's** acquisition of **Intempora** and **Siemens** merger with **Mentor** and **Tass International** are evolving from renowned end-to-end "ADAS" testing and validation companies to full-stack "AV" development tools company.

Simulation software and testing system suppliers continue to prove their solutions as important toolchains in AV development, especially in the COVID economy. Newly added companies include **Applied Intuition**, **AVL**, and **Foretellix**.

Lastly, as the vehicle architecture changes to centralized computing platforms embracing OTA software update capabilities and safety redundancy, developing platforms for vehicle architecture compliant with standards such as Adaptive AUTOSAR becomes important. **Vector, ETAS,** and **Elektrobit** lead this supply chain.

DATA HANDLING

This is a new dedicated category for data processing and management companies. Data Handling companies include data storage/logger suppliers, data logging/management/annotation/visualization tool companies, testing automation tool suppliers, and data annotation service companies. The data logging/management/annotation/visualization tool companies only include tools that manage massive data from environmental sensors and create sensor fusion algorithms for ADAS and AV application development, rather than tools for small-sized data (position, sensor/vehicle bus signals, and other measurement data) processing and test management.

Companies specializing in data annotation have become critical to the autonomous driving ecosystem and value chain. Such companies can provide quality training datasets from the raw data AV companies collected, who want to develop and commercialize algorithms based on labeled datasets as quickly as possible.

The recent acquisition of data annotation company**Understand.ai**, **dSPACE** is closing the loop of the entire data management toolchain – from data collection to algorithm training and software validation. Data annotation and related training and validation data is likely in demand from dSPACE customers working on AVs, so now the company has even more products and services to sell. Other annotation services companies have been bought recently also, such as **Uber** acquiring **Mighty AI**.

Data logger or more sophisticated automotive development computer suppliers (**Crystal Group, Intrepid Control Systems, Quantum, Xylong,** etc.) also become critical in the AV development processes. Especially these data storage and ruggedized computers made for harsh vehicle environments are increasingly in demand.

Autonomous vehicle development and deployment requires the ability to collect, store, and manage massive amounts of environmental data, high-performance computing capacity, and advanced deep learning techniques, along with the capability to do real-time processing in the vehicle.

Amazon and Microsoft are becoming very important players of the AV ecosystem, as they not only provide massive data storage and efficient ingestion tools into the cloud, but also offer powerful computing resources, ML/AI algorithm development framework and simulation/validation environments in the cloud along with their AV development toolchain partners.

Also, there are several independent data management platform and cloud-based validation toolchain suppliers (**Elektrobit, Intempora, Renovo**, etc.), who may provide more specialized and systematic solutions along with the big IT cloud solution companies.

Conclusions

AV technologies are worth trillions when you look at the big picture. Every company from technology, telecommunications, data center, IoT, transportation, and commerce is looking to capture a piece of future automated vehicle technology and the mobility trends behind it. Therefore, understanding the AV ecosystem is important for companies and organizations that are involved or trying to enter the AV market.

To capture this fast-moving and growing market, VSI offers its Ecosystem Examiner, where users can create custom infographics for all product categories out in the market, powered by VSI's ADSAS/AV product taxonomy. The VSI Infographic on the other hand represents VSI's selection of top AV companies. Any changes to the AV industry landscape will be dynamically updated every year.