WHITE PAPER

Testing is Critical for Adoption of Autonomous Vehicles

Developments in the autonomous vehicle (AV) arena are accelerating as traditional automakers, along with new players, invest in technology that is driving innovation. While AVs have the potential to improve automobile safety and driving convenience, their complexity requires a rigorous test and verification system to ensure vehicle safety across all types of traffic, road, and weather conditions. Certainly, AVs will use methods based on artificial intelligence (AI), which will enable the vehicles to communicate via telecom service and infrastructure providers.

The underpinnings for AV technology is the connected car concept. Systems communicate with the vehicle about road and traffic conditions, vehicles nearby, and other critical elements of the driving experience. AV technology combines multiple sensors, computers, and software to produce self-driving cars. These cars are already statistically safer by miles driven than that of their human-driven counterparts.

About 94 percent of serious crashes are due, in part, to frequent and predictable driver errors, such as speeding, or driving while impaired or distracted.

Waymo, (formerly the Google self-driving car project), reported only one at-fault, no injury accident at two mph with over five million miles driven in total. Even so, building consumer trust in fully self-driving cars is a challenge. For example, 73 percent of American drivers report they would be too afraid to ride in fully self-driving vehicles, and 63 percent of U.S. adults report that they would feel less safe sharing the road with a self-driving vehicle while walking or riding a bicycle, according to a 2018 American Automobile Association (AAA) **study**[1].

Safety and Other Benefits

While safety concerns are top of mind based on the number of accidents that are caused by driver error, safety improvements usually top the list of potential benefits of AVs. Taking human error out of the driving equation dramatically reduces traffic injuries and deaths.

There are other benefits of deploying AV technology. For example, as the population ages, AV technology offers more access and freedom to senior adults and disabled individuals. Also, there is the potential for new modes of transportation and business models such as fleets of autonomous taxis and shared autonomous cars; which leads to the prospect of greater personal productivity.

1 https://5g.co.uk/guides/how-fast-is-5g/

Overview of Automation

Today, there is a range of automation options to assist drivers, and some are already on the market. To put things into perspective, the Society of Automotive Engineers (SAE) has **established levels of automation**[2] for AVs as shown in Figure 1.

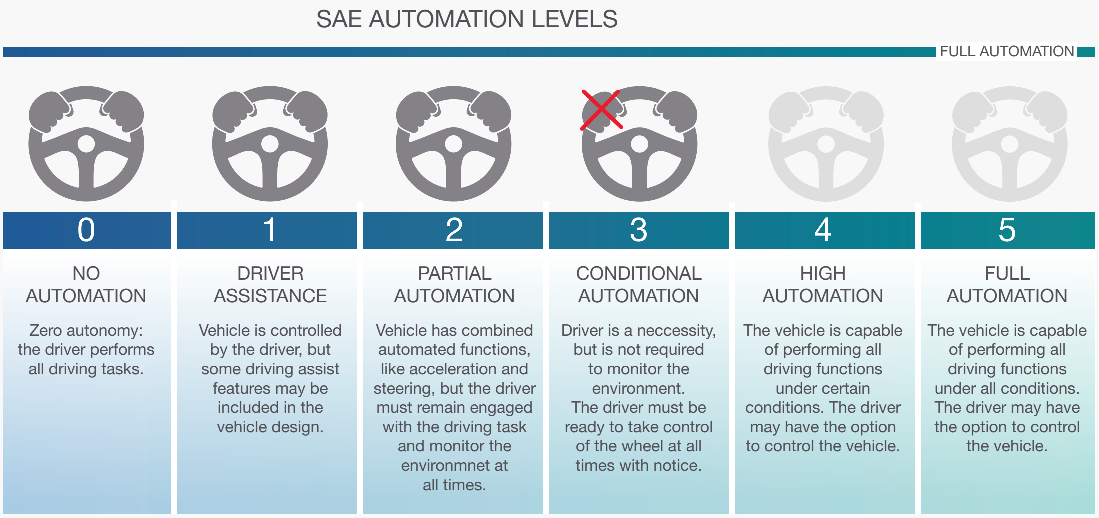


Figure 1. SAE Automation Levels describe the different levels of autonomous vehicle capability

- Level 0 is no automation at all; the driver does all of the work.
- Level 1 adds some driver-assistance features, such as adaptive cruise control and blindspot monitoring.
- Level 2 still requires the driver to drive but offers both steering assistance and speed control features.
- Level 3 automates the driving of the vehicle but still requires the human driver to remain attentive and take control within some specified amount of time.
- At Levels 4 and 5, the AV truly becomes autonomous. For example, Level 4 automated driving limitations to certain conditions such as specific geography or route, weather, traffic type, speed, and roadway. Level 5 represents a no restrictions self-driving car.

The automobile industry is rapidly adding features to vehicles at Levels 1 and 2, and there are many opportunities to assist the driver while maintaining the existing model in which the driver actively controls the car. A wide range of sensors (cameras, radar, LiDAR, and ultrasonic sensors) let the vehicle "see" what is going on around it and automatically assists the driver. Many vehicles already offer driver-assisting features such as blind-spot monitoring, backup cameras, automatic high beam headlights, adaptive cruise control, lane-keeping assistance, and automatic braking.

2 https://driverless.wonderhowto.com/news/definitive-guide-levels-automation-for-driverless-cars-0176009/

Some experts express concern about the viability of Level 3 automation, which requires the driver to remain vigilant while the car drives itself for extended periods of time. One important point to consider is under what circumstances a driver needs to take control and how quickly that needs to happen. Audi says its traffic jam pilot feature offers Level 3 automation during traffic back-ups, or when traffic moves at speeds up to 65 km/h (40.4 mph). This system allows the driver to relax during bumper-to-bumper traffic, but requires the driver to take control within 10 seconds of notification.

Levels 1 through 3 can improve automobile safety, but Levels 4 and 5 are required to deliver additional potential benefits including mobility improvements for disabled and senior adults, increases in personal productivity, and new transportation models. This makes Levels 4 and 5 the ultimate goal of most AV program to leave the driving to the car.

Level 4 is a natural precursor to Level 5 and limits the operational design domain (ODD); the AV is autonomous under certain specific conditions. For example, a Level 4 AV may only handle specific types of roads — limited access highways, HOV lanes, AV-only lanes, rural roads, or closed campuses. There may be restrictions depending on visibility; there is no AV action in extreme weather. Another constraint might be specific infrastructure support for AVs or roads that are pre-mapped.

Deployments are likely to be local or regional. Hitting 100 percent coverage of all scenarios is difficult. It's not too hard to get to 95 percent, but the last 5 percent is challenging; so reducing the ODD has a significant impact. For example, an early Level 4 use case might be an autonomous taxi service in a confined, well-mapped area with known streets, lower speeds, extreme weather to deliver the minimum required visibility. Another possible first deployment is long-haul cargo trucks limited to specific, known routes.

Level 5 automation poses the challenge of handling every possible driving situation. Due to the scalability of software-enabled systems, Level 5 automation enables the vision of replacing the average driver with the most capable software-defined driver in the world.

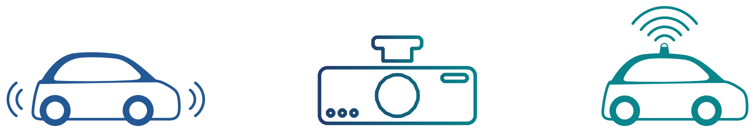
> "Perhaps the most obvious challenge in a fully autonomous vehicle is that the whole point is for the driver to no longer be actually driving the vehicle. That means that, by definition, the driver can no longer be counted on to provide control inputs to the vehicle during operation."
>
> *– Koopman and Wagner*

Sensor and Communication Technologies

A combination of new technologies working together makes AVs possible — sensors, computing power, smart software, communications, and navigation. AVs use sensors to see the world around them, just like human drivers. Perhaps, better than humans because they can see in all directions simultaneously.

AVs use four main types of sensors to monitor the driving environment:

- Vision with cameras
- Radar detection and ranging system (RADAR)
- Light detection and ranging (LIDAR)



	Radar	Camera	LIDAR
Technology	Detection – distance (range) and motion (velocity and angle) by radio waveforms	Recognition, classification by images	360-degree 3D view by laser light
Application	• Adaptive cruise control • Automatic emergency braking systems • Blind spot detection • Parking assistance	• Traffic sign recognition • Lane keep systems • Parking assistance • Blind spot detection • ACC, AEBS • Surround view • Rear collision warning • Cross traffic alert	• Emergency brake assist for pedestrian, crash imminent braking, mapping

Figure 2. Autonomous vehicles use an array of sensors to see the driving environment.

Vision systems use image sensors that require processing to extract useful information. Radar sensors operate at 24 GHz short range, or 77 GHz long-range positioned in the front or back of the vehicle to monitor traffic and obstacles. They can detect objects over a range of a centimeter up to a few hundred meters. Ultrasonic sensors are useful for detecting objects close-up close-in for parking and other activities.

A lidar sensor uses a pulsed laser to detect objects, usually with higher resolution but shorter range than radar. Lidar is a less mature technology and is generally more expensive. Lidar's higher resolution can provide a much more complete view of the vehicle environment and be used to discern between different types of objects.

Wireless communications play an important role with AVs by enabling vehicles to exchange information with other vehicles (V2V), pedestrians (V2P), or roadside infrastructure (V2I). Often, these are available in vehicle-to-everything (V2X). These communications channels provide essential information to the AV, including notifications of traffic congestion and road hazards. Two critical competing communications approaches are dedicated short-range communications (DSRC) in the 5.9GHz band, and cellular V2X using future 5G capability.

Navigational aids, such as the Global Positioning System (GPS), is integrated with AV technology. GPS enables routing of AVs from one location to another, but it can also work in conjunction with detailed maps to improve autonomous driving, the location of driving lanes, and traffic signals.

Strict Testing is Critical to Gain Acceptance

All new technologies face barriers to adoption and AVs are no exception. Because of the safety issues involved, adoption of AVs will initially encounter resistance by many consumers. A recent **survey of drivers in the US**[3] found that 63 percent of U.S. drivers report feeling afraid to ride in a fully self-driving vehicle; an actual decrease from an earlier survey.

Public opinion, familiarity, and trust play a significant role in the consumer's willingness to adopt AV technology. Consumer perceptions are likely to shift over time, as AV technology is proven and becomes more familiar. AV testing is critical to validate self-driving cars are safe enough to be on the road. Adoption of Levels 1 through 3 is happening incrementally as automakers add more driver assistance features to their vehicles. Levels 4 and 5 represent a bigger challenge because the driver is removed from the system, leaving the AV to drive on its own.

Validating a Complex System in a Complex Environment

All systems have a non-zero failure rate, so while you would like to design an AV that never makes a wrong decision, the real question is how good does it have to be? You expect that an AV design will perform better than the average human driver. The industry is grappling with how good is good enough; and how will you know that level of reliability is achieved.

A recent **research report**[4] by the Rand Corporation concluded that:

> Autonomous vehicles would have to be driven hundreds of millions of miles and sometimes hundreds of billions of miles to demonstrate their reliability in terms of fatalities and injuries.

While referring to the number of miles driven may give us a sense of how much testing needs to take place, it is not a reliable metric for describing the robustness of the testing. A mile of test on a limited-access rural highway is a lot different than a mile in a complex urban environment. Specifically, you must ensure testing of critical edge cases — challenging scenarios that only rarely occur in normal traffic but may be deadly when they happen.

The same report admits that existing methods of testing and validation are likely inadequate:

> Developers of this [AV] technology and third-party testers will need to develop innovative methods of demonstrating safety and reliability.

3 https://newsroom.aaa.com/2018/01/americans-willing-ride-fully-self-driving-cars/
4 https://www.rand.org/pubs/research_reports/RR1478.html

Experience with complex systems for both hardware and software includes quality and reliability standards from the start. Attempting to take a weak design and test your way to quality does not produce top quality results.

An effective validation program starts with a test strategy that considers the operation of the entire system. Electronic and software-based components have been a part of modern vehicles for many years, so the auto industry has experience designing and verifying system reliability. Current test strategies use a layered approach with verification done at various levels of abstraction in the system. Figure 3 shows a common approach is the V development model that connects design requirements and specifications for testing at each level of the system.

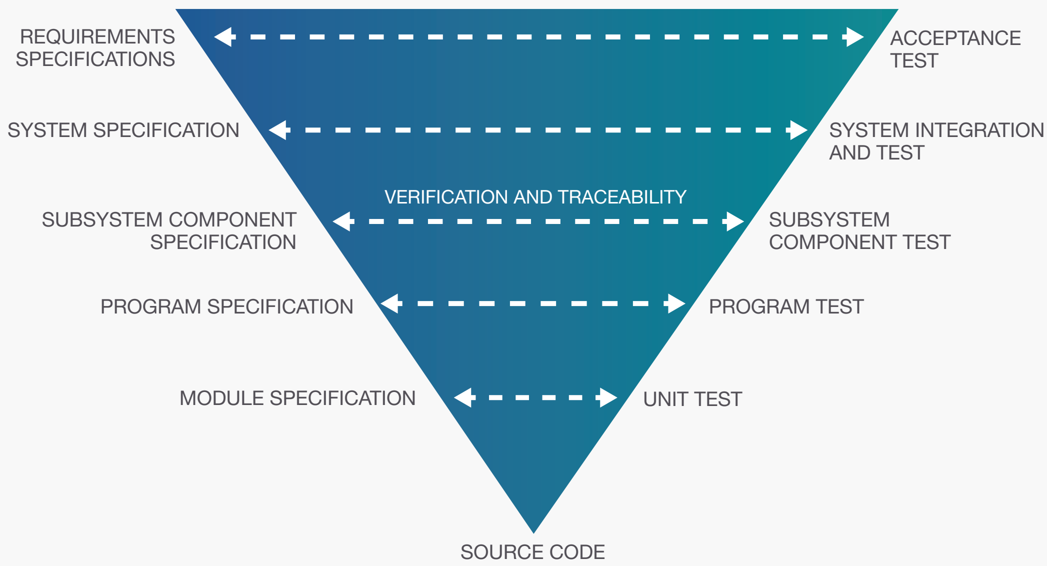


Figure 3. The V development model maintains verification and traceability at all levels of the system.

ISO 26262 is an international standard for the functional safety of electrical and electronic systems in production automobiles. This standard uses the V development model to ensure that the entire system functions properly and maintains a high level of safety. Each component in the system has an assigned automotive safety and integrity level (ASIL) with “A” being the least stringent level and “D” being the most stringent level. It is a risk-based safety standard, where the risk of hazardous operational situations is qualitatively assessed, and safety measures are defined to avoid or control systematic failures and to detect or control random hardware failures or mitigate their effects.

System Level Verification

Testing vehicles under a wide range of environmental, road, and traffic conditions is the ultimate test of AV system performance. Ideally, this would cover every conceivable driving scenario to ensure the AV can handle them. Public road testing by AV companies has received much publicity because it is visible to the general public. This type of road testing is invaluable because it exposes the vehicle to a wide range of real-world scenarios. AV companies also use private test tracks which offer a controlled and repeatable environment but with less variation in test scenarios. Virtual test tracks are emerging as a critical tool for generating a variety of repeatable test scenarios at a reasonable cost.

Simulated driving conditions will undoubtedly play a significant role in the test strategy for AVs. Because sensors and actuators send and receive digital data, their sensed world is captured and replayed as digital streams of data. A virtual representation of the AV, complete with virtual sensors and actuators, is tested in a virtual world driven by the same software as the real-world autonomous vehicle. As the vehicle operates in this environment, models replicate what the vehicle “sees” in the real world. This virtual testing methodology recreates the AV driving scenarios and can be “driven” for millions of miles at a lower cost while offering more repeatable results compared to actual road tests.

Testing and Documenting Reliability to Break the Trust Barrier

Consumers already see the potential value in AV technology — safety improvements, convenience, and greater mobility — but they have concerns about the overall safety of this new technology. Experience in using AVs will help build consumer confidence as long as the industry develops a solid safety track record. To build this track record, robust test and verification systems are needed.

We need to apply systems engineering design principles throughout the ecosystem. AV manufacturers are developing the robust design and test strategies to prove their technology while delivering reliable vehicles. Vigorous testing of these complex systems is critical to verify their safety and will determine whether AVs are safe enough to be on the road.

While none of this is going to be easy, the AV industry must continuously innovate and find new ways to test and validate systems. Keysight Technologies has decades of design and test experience and is working shoulder-to-shoulder with AV leaders to break the trust barrier and win consumer confidence.

Learn more at: www.keysight.com

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