EXECUTIVE SUMMARY

Autonomous Vehicle Market Forecast: Demystifying the $50 Billion Opportunity

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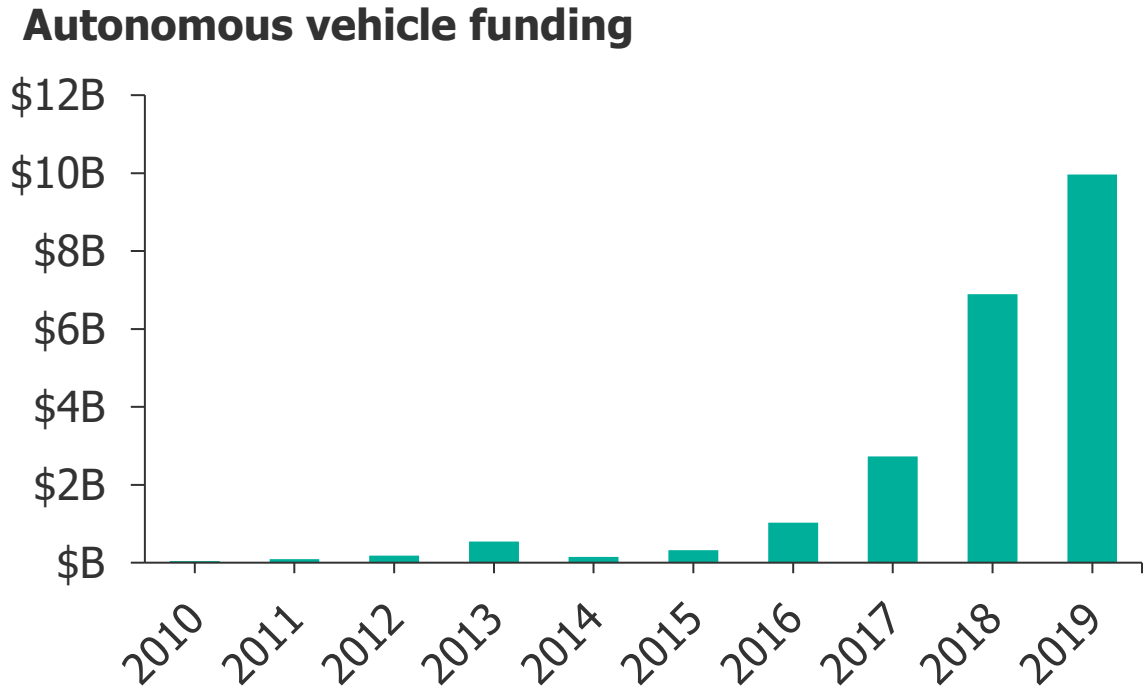
The commercialization of self-driving cars would be the biggest technological advancement of the auto industry

Autonomous vehicles (AVs) hold the potential to be a disruptive change in the automotive industry, fundamentally changing the operation of a vehicle to enable new use cases, not just for personal vehicle ownership but in commercial applications like ride-hailing (so-called robotaxis) and trucking.

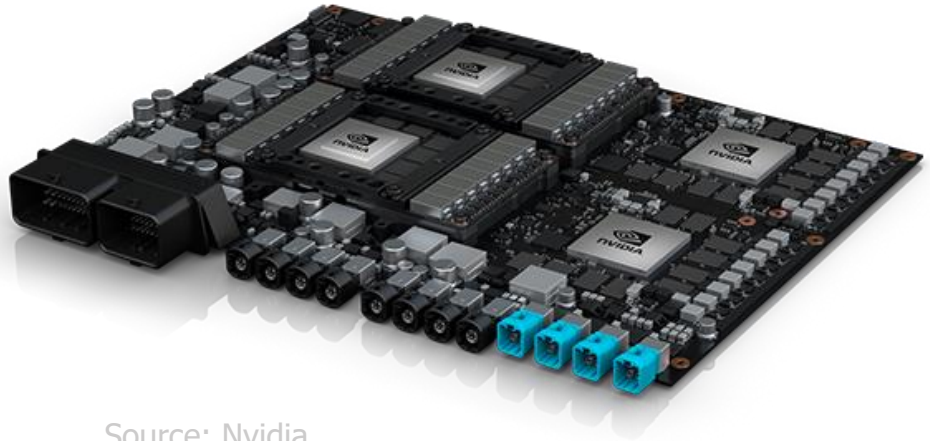
After an initial period of inflated expectations and billions of dollars in funding, many AV developers have missed deadlines for commercial milestones. This has largely been because training the AI systems to properly deal with highly unlikely scenarios or "edge cases" is an extremely difficult problem. As a result, the market landscape has been shaken up, with key players targeting different and sometimes niche applications, business models, and geographies. In this report, we set out to capture the full picture of AV development and what it means for future AV sales and adoption.



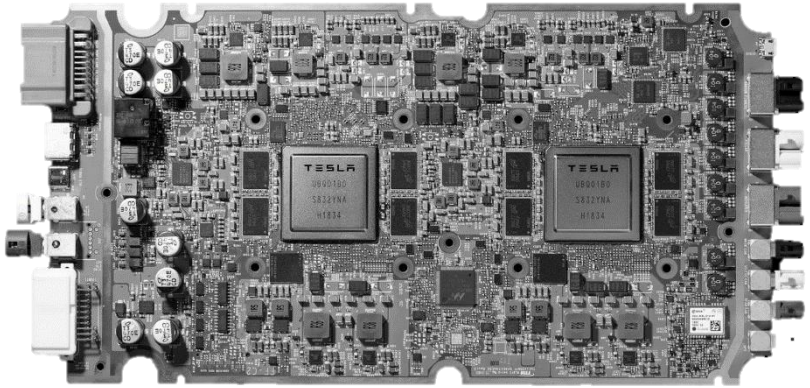
Increased levels of autonomy also require increased computational power

The increased use of deep neural networks in autonomy stacks requires large amounts of processing power, typically provided by industrial computers made up of GPUs and custom AI chips. These computers can add thousands of dollars to the cost of the AV hardware stack. The fastest way to improve the overall performance of perception, prediction, and planning algorithms in the AV software stack is to use bigger and higher-performing computers.

However, higher cost, weight, and power consumption are all trade-offs that come with a larger computer. That is why companies like Nvidia are releasing new computers every couple of years with improved performance for a given power consumption and size. Some AV companies, such as Tesla and AutoX, are vertically integrating and building their own self-driving computers.



Source: Nvidia

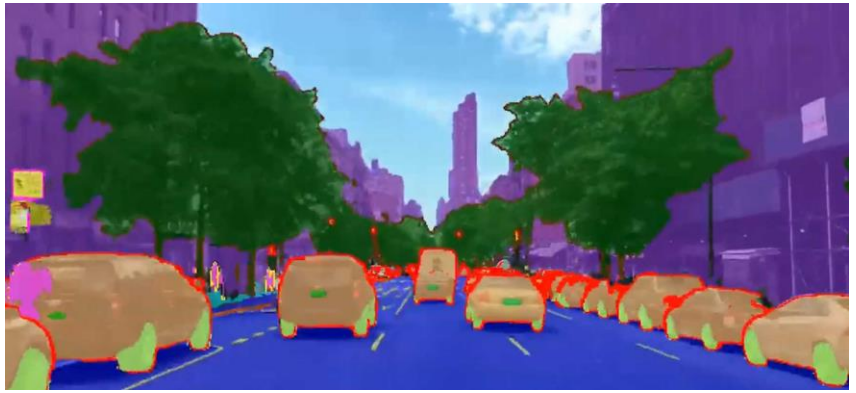


Source: The Verge

Improvements in algorithms and data collection will help better utilize the sensors and computers in AVs

Given the long development cycles of vehicles, it can take years between when a new sensor or computer is announced and when it is included in a production vehicle. That's why algorithmic innovations are equally important. New approaches to perception algorithms, such as Helm.ai's Deep Teaching technique, use unsupervised learning to remove the need for human data labelers.

Simulation tools like RightHook's are used to generate synthetic data, lowering the need for data captured on real roads. These simulation tools were highly leveraged during the COVID-19 pandemic, when lockdowns prevented AVs from operating on public roads. As it becomes increasingly difficult to capture unique data (either real or simulated), AV developers are starting to utilize data marketplaces, such as Deepen's Safety Pool. These shared data pools will allow AV developers to collect data related to "edge cases" that they may not have captured themselves.



Source: Helm.ai

Source: Cruise

There are many factors at play in the regulatory environment for AVs and ADAS

Standards

Industry standards organizations are just beginning to develop evolving standards for automated vehicles and their subcomponents. This includes ISO 262626, which addresses system failures and faults, and UL 4600, which looks more at how the system will deal with environmental factors that are hard to predict.

Legislation

Legislation at local, state, and national levels often deals with the requirements for AVs to operate on local roads. They mandate things like requiring a safety driver, speed limits, and geofencing. Some require data sharing and formal licensing for any operator that wants to put an AV on the road.

Type Approval

Just like regular cars, AVs require type approval before a certain model is universally allowed on public roads. Since most government organizations have not created AV-specific standards for this, AV manufacturers need to apply for special waivers before their vehicles are allowed on roads.

Mandates and Incentives

Government mandates are an effective way to quickly increase the inclusion of a safety feature in a vehicle. In the near term, this will mostly affect ADAS rather than AVs. Generally accepted safety ratings organizations can have a similar effect on the inclusion of features without requiring government mandates.

See more in our insight, Regulatory landscape for autonomous vehicles

ALL REGIONS

Market Forecast

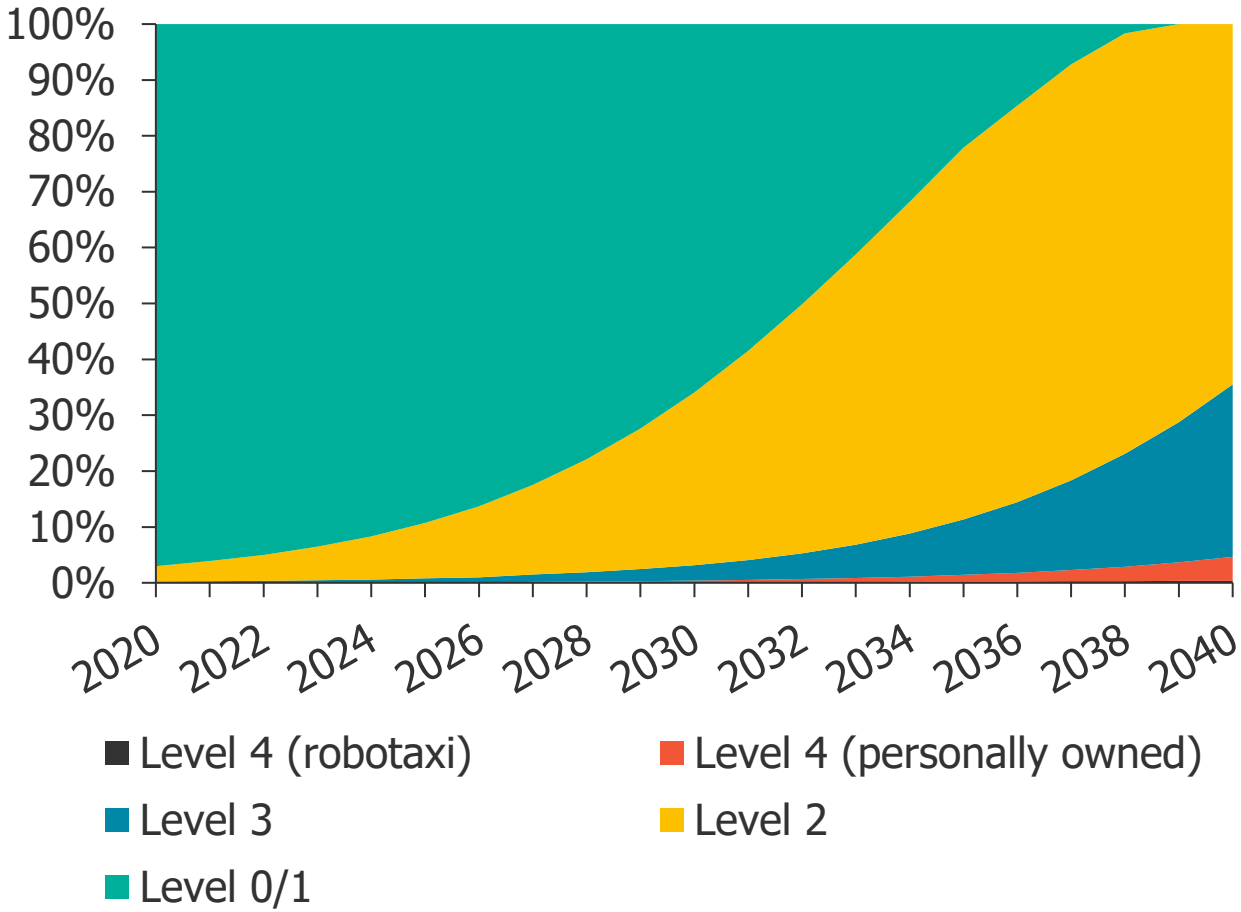
AV market share, 2020	3%
AV market share, 2040	100%

Although today the market share of autonomous vehicles (including Level 2 through Level 4) is just 3%, Lux expects that by 2040, all vehicles sold will at least include a Level 2 autonomous driving system. Much of this growth is attributed to Level 2 systems, which by 2040 will still be the most popular autonomous vehicle system, with Level 3 systems being the second most popular.

Within higher-priced vehicles, we expect much faster adoption. For example, for vehicles with a base MSRP greater than $70,000, adoption of Level 4 autonomy is expected to be greater than 35%, with all remaining vehicles adopting Level 3 systems.

Autonomous vehicle technologies

Market share (%)



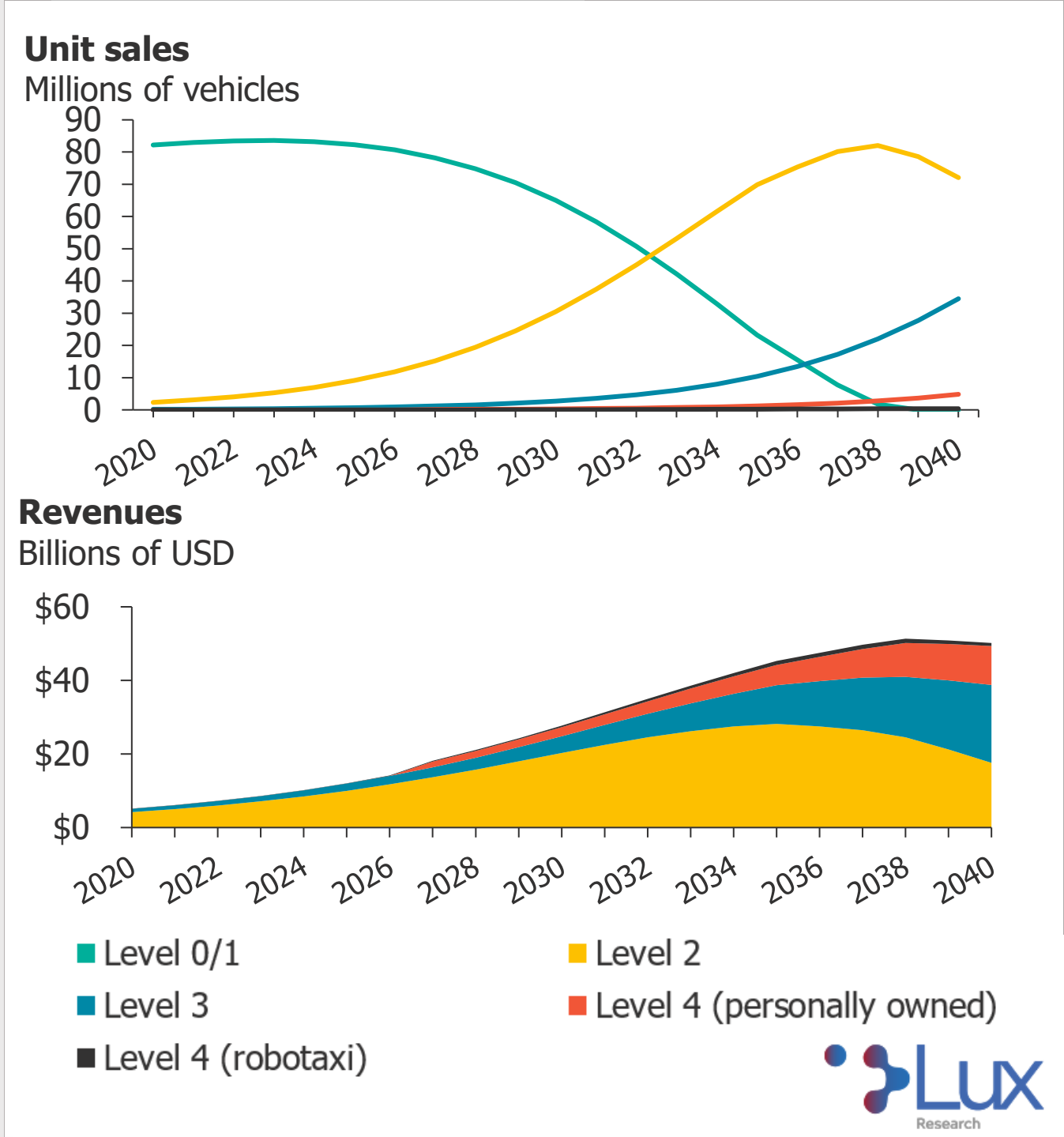
ALL REGIONS

Market Forecast

Market size, 2020	$5.6 billion	2.6 mil. units
Market size, 2040	$50.2 billion	118.7 mil. units
CAGR	11.6%	21.1%

Lux's analysis suggests that the last year a nonautonomous vehicle will be sold will be 2039. After that, due to low costs and possible mandates, revenues are expected to initially decline as AV costs continue to fall and 100% adoption of autonomous vehicles has been achieved. Although our analysis shows a slight decline in revenues from 2039 to 2040 due to market saturation (all vehicles have at least a Level 2 system) and declining system costs, this is expected to grow once again in the future as the market share of Level 3 and Level 4 systems increases.

Despite many companies focusing on applying Level 4 vehicles to robotaxis, a small addressable market relative to personal vehicle ownership means that segment results in fewer L4 sales compared to private vehicle ownership.



Years of pilot programs are still required before robotaxis are adopted at a large scale

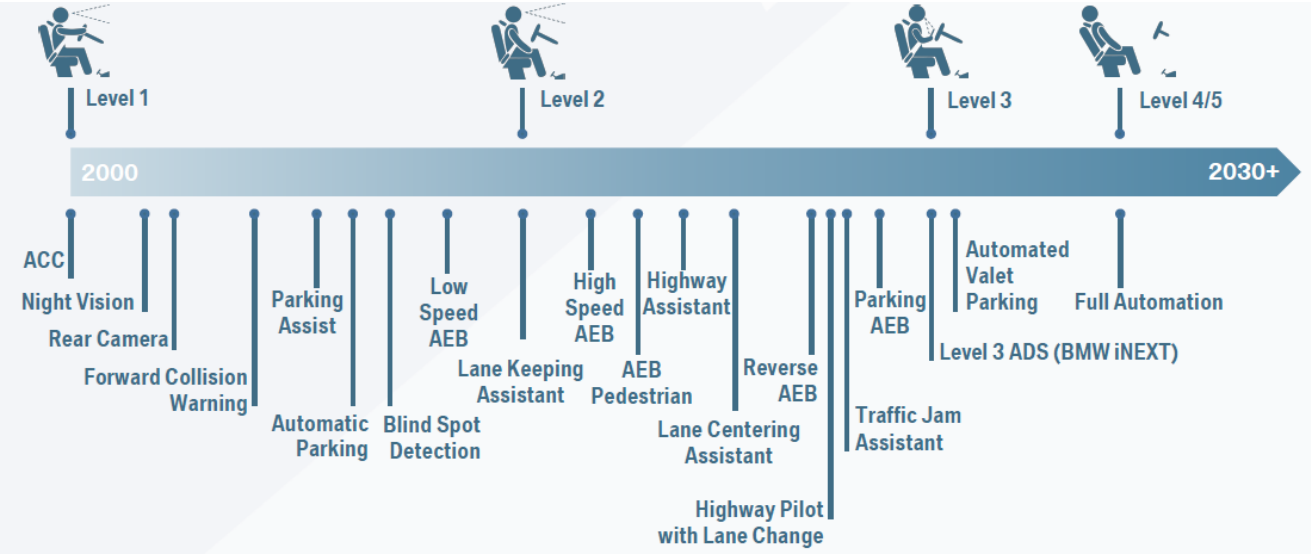
Dozens of pilot programs for robotaxi and last-mile delivery services have been completed over the second half of the 2010s. Waymo made history by offering the first revenue-generating driverless rides to members of the public in 2020. This milestone came more than three years after the company began offering trial rides with safety drivers in the Phoenix, Arizona, area.

While AV testing started out in suburban areas like Phoenix and Silicon Valley, most of the demand will be in the same urban locations that attract ride-hailing services. Other robotaxi companies like Cruise and WeRide are just starting pilot programs with driverless cars in more complex urban areas like San Francisco and Guangzhou. We expect a few cities to transition from pilots to full revenue-generating services in 2023. At that point, expect the number of driverless vehicles in those cities to scale from less than 100 to 1,000 or more.

Source: Business Insider

Automakers face unique challenges moving from Level 2 to Level 3, and eventually to Level 4

Most automotive OEMs have scaled back plans to mass-produce L4 vehicles and instead have focused on the near-term opportunity in L2 and L3 vehicles. While some L2 features are starting to make their way into nonluxury vehicles, the path forward for L3 will be more complicated. Due to a high reliance on HD mapping and regulatory certifications, releasing an L3 vehicle involves many more stakeholders. In addition, the autonomous system needs to know if the vehicle is currently within the bounds of its ODD. That's why OEMs like BMW have released detailed safety reports that explain exactly how their L3 system will handle certain situations. In a way, the transition from L3 to L4 will be easier for OEMs, as they'll largely rely on the learnings from robotaxi deployments. By the 2030s, when personally owned L4 vehicles start to ramp up, datasets from hundreds of cities will allow those vehicles to have less restrictive ODDs. This is one reason why it's important for OEMs to have early partnerships with those involved in robotaxi services.



Source: BMW Group

Four key factors to monitor that will impact the outlook for autonomous vehicle adoption

Given the early stage of autonomous vehicle development, small changes today could accelerate or set back the industry by years down the road. There are a few factors that we will watch closely over the next few years that could very well change the trajectory of AV adoption.

1. **AV Fatalities** – The pace of rolling out AVs is a fine balance between safety and being early. The high-profile fatality involving an Uber AV in 2018 set back the company's testing by a couple of years, one of several factors that led it to fall behind competitors. Future incidents could sway public perception, forcing developers to achieve an even higher standard of confidence before deploying an AV.
2. **Car Ownership** – In our model, we did not consider the macrotrends related to car ownership, but emerging trends like micromobility and ride-hailing may very well lead to a decline in personal ownership of vehicles. Look for the areas with the highest density of people who don't require cars to commute to work to lead this trend.
3. **Validation Tools** – There are currently no common tools used to validate whether an AV system meets any potential standards that would allow it to operate on public roads. AV developers mostly self-assess their progress, which makes it difficult for regulators to make decisions. A common tool, test, or set of metrics could help accelerate regulatory decisions.
4. **System Cost** – It's difficult to forecast the rate of cost decrease for AV systems, as new types of sensors, computers, and algorithms are integrated into new systems constantly.

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