The road to autonomous vehicles

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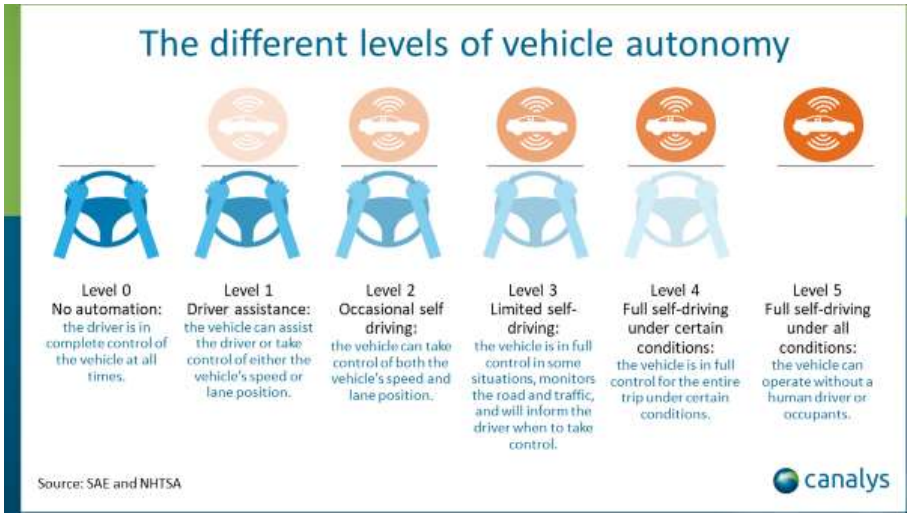
The current state of driving holds some troubling statistics. Cars sit idle for more than 90% of the time. Over 1.2 million people die on roads each year globally. According to NHTSA (the National Highway Traffic Safety Administration in the US), 94% of serious crashes are due to human error. At any given time, around one-third of drivers in major cities are looking for somewhere to park their car. According to Inrix, American drivers spend 17 hours a year looking for a parking space, even though there are more than three parking spaces for each vehicle in the US. Road congestion continues to worsen. According to TomTom's Traffic Index, drivers in Mexico City spend 66% more time travelling than they would in free-flowing traffic – or 227 hours per year wasted due to congestion.

Autonomous vehicles (AVs) are regarded by many as a key element to improving mobility. It will not get distracted, not drive under the influence, not have blind spots, not get road rage, not fall asleep, not speed or pass through red lights. It will have instant reaction times and with vehicle-to-everything (V2X) connectivity, it will communicate with other vehicles, road and city infrastructure, road users and pedestrians to anticipate and know what is ahead, enabling much-improved traffic flow and safer, less congested roads.

The revenue opportunity will grow and with new services, will diversify. This report describes the evolution of advanced driver assistance systems (ADAS) to higher levels of autonomy (as defined below), explains the strategies and launch plans of automotive OEMs and other companies chasing the new services and technology opportunities and describes the role of legislation.



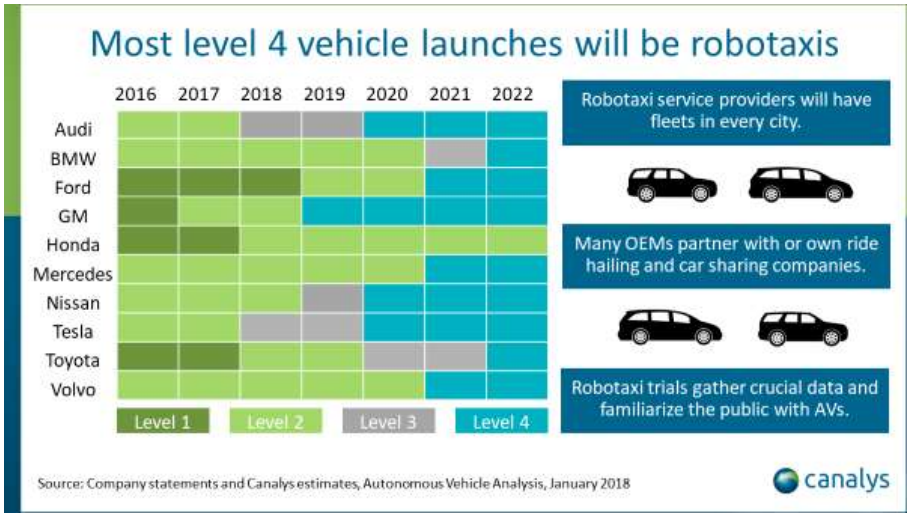
From driver assistance to automated driving – a reality check

Advanced driver assistance systems (ADAS) are systems to help the driving process. They include adaptive cruise control, lane keep assist, assisted parking, rear/side traffic alert, forward collision warning and autonomous emergency braking. Today warning and alert features are more commonplace than features where the vehicle actively provides assistance. While these features have existed for several years, they have typically only been standard in higher-end vehicles from premium brands. In other vehicles they are available options, often delivered as a bundle in a pack, dependent on the vehicle trim. Level 2 autonomy features are even less common – examples include traffic jam assist from Audi, Personal CoPilot from BMW, Super Cruise from GM/Cadillac, Distronic Plus from Mercedes, AutoPilot from Tesla and Pilot Assist from Volvo. Again, optional rather than a standard feature and limited by model and trim level. However, in Japan, mainstream OEMs Nissan and Subaru have launched level 2 features ProPILOT and EyeSight Touring Assist respectively, with high adoption – proving mass market demand.

The long vehicle launch/planning cycle (still at three to five years), the conservative approach of OEMs and a highly-regulated industry means that annual vehicle refreshes offer a slow advancement in ADAS availability. The benefits are clear but there is a varied availability of features in vehicles today, and most drivers have never experienced them.

Autonomous vehicle launch plans typically feature robotaxis

Automotive OEMs are forced to plan for a future where fewer, but better-utilized cars are on the road. They must decide whether they build for individuals or build for fleet owners. The table below shows when some automotive OEMs will launch vehicles with a higher level of autonomy, based on their statements and Canalys estimates.



The automotive OEMs have gradually increased the ADAS features in their vehicles and some have launched level 2 functionality. Their strategies to get to level 4 and beyond typically involves acquisitions and partnerships:

- Audi has level 2 functionality in vehicles today and has announced the Audi A8 with level 3 automation, using TTTech MotionWise software platform running on a zFAS controller which uses an NVIDIA Tegra K1, including Arm processors and NVIDIA GPUs. Audi is partnering with NVIDIA to use AI in AVs from 2020, while its subsidiary Autonomous Intelligent Driving GmbH will create autonomous driving solutions for the broader VW Group. VW recently announced an AV partnership with Aurora Innovation.

- BMW has level 2 functionality in vehicles today. In 2016 it formed an autonomous driving technology alliance with Intel, Mobileye, Delphi and others and it recently announced that in 2021 level 3 vehicles will be available to buy, and level 4 and 5 vehicles will run in urban pilot programs. More than 7,000 BMW and Mini vehicles are available in BMW's DriveNow and ReachNow car sharing programs in over 15 cities.

- Ford has level 1 functionality in vehicles today, but it will bring AVs to an unspecified test market in 2018. Ford is targeting 2021 for production of an AV for use in fleets. In early 2017 it acquired Argo AI and announced it would invest $1 billion in autonomous driving over five years. The Argo team has grown to around 200 people and it acquired lidar supplier Princeton Lightwave in October 2017.

- GM has level 2 functionality in Cadillac vehicles today. GM acquired San Francisco-based Cruise Automation in early 2016 and tests with Chevrolet Bolts in the city. Like Ford, GM acquired a lidar maker, Strobe, in October 2017 and has partnered with ride hailing companies Lyft and Uber. GM recently announced that it will mass-produce and deploy robotaxis in dense US urban areas by 2019.

- Honda has level 1 functionality in vehicles today, adding features to its Honda Sensing technology suite in the next two years. In 2020, it will launch a level 3 solution for multi-lane highway driving and level 4 functionality in cars by 2025. In late 2016 Honda announced a partnership with Waymo, but no details have been disclosed.

- Mercedes has level 2 functionality in vehicles today. In April 2017 parent company Daimler and Bosch announced a partnership to launch shared level 4 vehicles "by the start of the next decade". Mercedes has a partnership with Uber to supply it with vehicles, has made investments in other mobility-as-a-service companies and has its own Car2Go car sharing program with 14,000 Mercedes and Smart vehicles available in more than 25 cities.

- Nissan has level 2 functionality in vehicles today. The ProPILOT feature will be available globally in more cars in early 2018 including the Leaf and Rogue/X-trail. Nissan plans to build "commercially viable autonomous drive vehicles by 2020" and it will conduct a small robotaxi trial in Yokohama, Japan in 2018.

- Tesla has level 2 functionality in vehicles today. Its new hardware suite and internally developed software stack is included in all vehicles manufactured after October 2016, with the Autopilot feature an option. Autopilot software is regularly updated over-the-air and greater autonomy functionality will increase when allowed by authorities.

- Toyota has level 1 functionality available today. In partnership with Denso and based on Renesas technology which includes Arm processors, it will launch autonomous driving for highways in 2020. The Toyota Research Institute debuted its latest test vehicle in September 2017 with Guardian and Chauffeur autonomy modes.

- Volvo has level 2 functionality in vehicles today and plans level 4 vehicles for 2021. The Drive Me pilot in Sweden was delayed to Q4 2017 and scaled back from a target of 100 AVs deployed by the end of 2017 to 100 deployed

over the next four years. Volvo set up an autonomous driving/ADAS software company Zenuity in joint venture with Autoliv in 2017. Uber has ordered 24,000 Volvo SUVs but will integrate its own AV software.

Robotaxis will provide riders their first driverless experience

Canalys expects today's ride-hailing and car sharing service providers will be the robotaxi service providers in the future and will become important customers of automotive OEMs as they replace driver-owned vehicles with robotaxis they own and manage. Of the many ride-hailing companies around the world, Didi, Lyft and Uber are the most active in autonomous driving. Didi opened a research center in Mountain View, USA in March 2017 to focus on AI and AVs and has recruited engineers from Waymo. Lyft is partnering with automotive OEMs Ford, GM and Jaguar Land Rover (JLR) and autonomous driving technology providers Drive.ai, nuTonomy and Waymo. Lyft also opened its level 5 engineering division research center in Palo Alto, USA in August 2017. Uber partners with automotive OEMs such as GM, Mercedes and Volvo. It partnered with, and later recruited researchers from the Carnegie Mellon University robotics team in Pittsburgh, USA, creating the Uber Advanced Technologies Center in the city. Uber also acquired autonomous trucking company Otto, founded by former engineers from Google, with whom it is battling in the courts. Between Uber, Didi, and Lyft, the companies have raised over $30 billion.

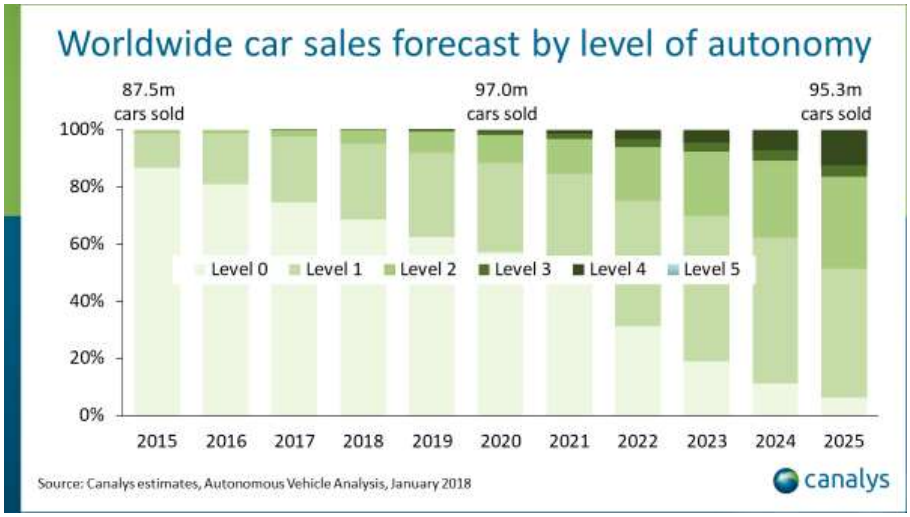
Lyft predicts that in five years robotaxis will provide most Lyft rides. Its gross bookings (before it pays its drivers) in the US were estimated at more than $1 billion for the first time in Q2 2017. It has recently started operating in its second country, Canada. Uber's gross bookings in Q2 2017 were an estimated $8.7 billion, operating in 77 countries, with its two million drivers completing ten million trips every day. 2017 data is not available for Didi but despite lower per-ride fares, with 400 million riders (10x that of Uber), Canalys estimates gross bookings of over $10 billion per quarter.

Car sharing providers, many of which are owned by automotive OEMs, have fleets of vehicles across cities available for the public to use on an hourly or daily basis. BMW, Daimler and GM who own DriveNow/ReachNow, Car2Go and Maven respectively, all have plans to replace those vehicles with robotaxis in the future. Volvo has a car sharing fleet in Sweden called Sunfleet on which it will base its new mobility strategy. Ford and VW run ride-pooling services Chariot and Moia respectively. nuTonomy is already running AV, ride-hailing pilots in Boston, USA with Lyft and in Singapore with Grab, while Waymo has an early rider pilot in Chandler, USA. Uber launched a pilot in Pittsburgh in 2016. All pilots maintain an engineer in the vehicles and give rides to members of the public – helping them and other road users become accustomed to the technology.

Every mobility-as-a-service provider needs to manage the vehicles in their fleets, the software and the app to ensure high service availability, minimum wait-time and maximum vehicle utilization – and every city is different. The fleet is a collective body – the movement of one vehicle has a direct effect on all the others. Intelligence determines which vehicle serves each customer, what pooling opportunities there are and the route the vehicle should take. The provider must have vehicles in the right place at the right time – predicting demand, aware of events taking place and weather conditions. Valuable data and experience is being gathered by fleet owners today, providing them the intelligence to become key to solving the mobility challenges that cities around the world face.

Shifting from owning to sharing vehicles

In 2017 car sales in mature markets such as the UK and the US declined. Longer term, on a global basis, Canalys forecasts that fewer cars will be sold in 2025 than in 2020, largely due to the impact of robotaxis on car ownership, particularly as urbanization increases.



Autonomous driving platforms will help the laggards catch-up

Several automotive OEMs hope to launch their first level 4 vehicles in early 2020, which means many other OEMs will be late and will need an alternative plan to accelerate their time to market. One possible solution is offered with autonomous driving platforms which are being developed by several alliances, joint ventures, start-ups and major technology companies. Start-ups such as Argo AI, Cruise Automation and nuTonomy have already been acquired, as mentioned, while other start-ups such as AImotive, Aurora Innovation, Drive.AI, FiveAI, JingChi, Optimus Ride, Oxbotica, PolySync, Renovo, Voyage, Zoox and many more are getting vehicles on the road to test their solutions.

Some of the other companies with autonomous driving platforms available or in development include:

- Baidu started the Apollo project in 2017. Apollo is an open autonomous driving software platform for partners to develop systems through hardware platforms, especially for China. Many of the 70 partners are international OEMs, tier-one suppliers and technology companies.
- DENSO has licensed the Arm Cortex-R52 processor to design automotive semiconductor device reference platforms with the highest levels of functional safety possible, as required for autonomous driving systems.
- Intel formed an autonomous driving technology alliance with BMW, acquired partner Mobileye and the alliance has since added Fiat Chrysler and tier one suppliers Continental, Delphi and Magna as system integrators.

- NVIDIA works with dozens of companies relating to autonomous driving including OEMs Audi, Mercedes, Toyota and Volvo. The NVIDIA DRIVE platform software supports autonomous application development on NVIDIA DRIVE PX AI car computer hardware which includes Arm processors and NVIDIA GPUs.
- NXP Semiconductors announced the NXP S32 platform for connected, electric and autonomous vehicles in October 2017. 8 of the top 15 car makers have already adopted the NXP S32 platform for upcoming models. Based on scalable Arm solutions, the automotive computing architecture will enable faster deployment.
- Renesas introduced the Renesas autonomy Platform in 2017. Its suite of solutions includes the R-Car system-on-chip for infotainment and ADAS which is based on Arm.
- Waymo, formerly the Google self-driving car project, sources vehicles from Chrysler. Waymo has driven more miles on public roads in autonomous mode than any other company and is the first to offer rides with no human in the driver seat.
- Zenuity expects to have its solution available in 2019, with no exclusivity to joint-venture co-founder Volvo.

Legislation can make, break, or delay the introduction of autonomous vehicles

Governments are issuing guidelines, drafting rules and making amendments to existing Acts, but passing law relating to an already highly regulated industry, where safety is of paramount importance, is complicated. In an already highly regulated industry, AVs need legislation in place to allow them on the roads for testing, and later to be deployed. While Baidu in China and Tesla and Uber in the US have used an ask for forgiveness, rather than ask for permission approach, for the good of the global industry and for public safety, laws need to be in place.

The US has a patchwork of state-by-state legislation surrounding AVs. California has been the most active with 47 companies issued with a permit to test vehicles on public roads, while neighboring Arizona and Nevada, which are also active, have different rules and a change of license plate is required across the state line. However, progress is being made at Federal-level. In September 2017, the Department of Transportation (DOT) released an Automated Driving Systems 2.0: A Vision for Safety repot with Voluntary Guidance containing twelve priority safety design elements which solution providers are encouraged to follow. Also in September, the SELF-DRIVE Act passed the House of Representatives improving NHTSA's ability to adapt federal safety standards, while in October 2017 a Senate Committee approved the AV START Act. If passed, it will enable a uniformed framework for AV testing and deployment. Automotive OEMs will be exempt from existing safety standards, based on a maximum production volume of 15,000 vehicles in the first year, 80,000 in three years and no limit in the fourth year. States will have control over registration, licensing, insurance and safety rules. NHTSA would oversee the vehicle design and manufacture. The bill, which pertains to cars, not trucks, also requires OEMs to develop cyber-attack protection. The bill will go to the senate floor to be voted on before it is combined with the bill passed by the House of Representatives and then sent to the President to become law.

Australia, China, the European Union and Singapore have all announced their own guidelines relating to AVs. The "Guidelines for trials of automated vehicles in Australia" were approved by Australian ministers in May 2017 – states and territories can implement locally. In November 2017, the Chinese government announced it will develop national regulations for testing on public roads, which is not permitted yet, even though Baidu's test vehicles have hit the roads of Beijing. At least five Chinese companies are already testing in California. The European Commission initiated a

"Letter of Intent" signed by 27 EU Member States plus Norway and Switzerland that aims to increase cooperation in connected and autonomous driving testing, particularly at cross border sites relating to data transmission, connectivity, safety and liability. There are many EU funded projects across the region. Passing law across Europe in this area is complicated, politically sensitive and will take time, thus some member countries, including Germany and the UK will attempt to push ahead on their own. The Singapore government has long encouraged R&D in AVs. Amendments have been made to the Road Traffic Act for testing, design and construction rules, including the requirement to capture and store sensor data and video footage from the vehicles.

Japan wants to promote AVs in the run up to the 2020 Tokyo Olympics and have robotaxis operational at the event. In April 2017 the National Police Agency unofficially approved draft rules for testing on public roads while being monitored remotely by an operator, local police chiefs will decide whether the testing can take place.

The stakes are high

Every major automotive OEM and tier one automotive supplier has an AV strategy, and many OEMs will become mobility-as-a-service providers or close partners of those providers. Some of the world's largest technology companies and dozens of start-ups and universities are also heavily involved in AV research and development. Governments, both at the local and national level, are drawing up legislation. Robotaxis will launch in cities in the next two years, changing how people get around and impacting car ownership. Vehicles will be better-utilized, delivering people and goods in a safer and improved way for the environment, and they will flow more efficiently through less-congested streets. Passengers can be more productive and more entertained in AVs and arrive at their destination more relaxed. The stakes are high, the road is long, but the race is on.

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