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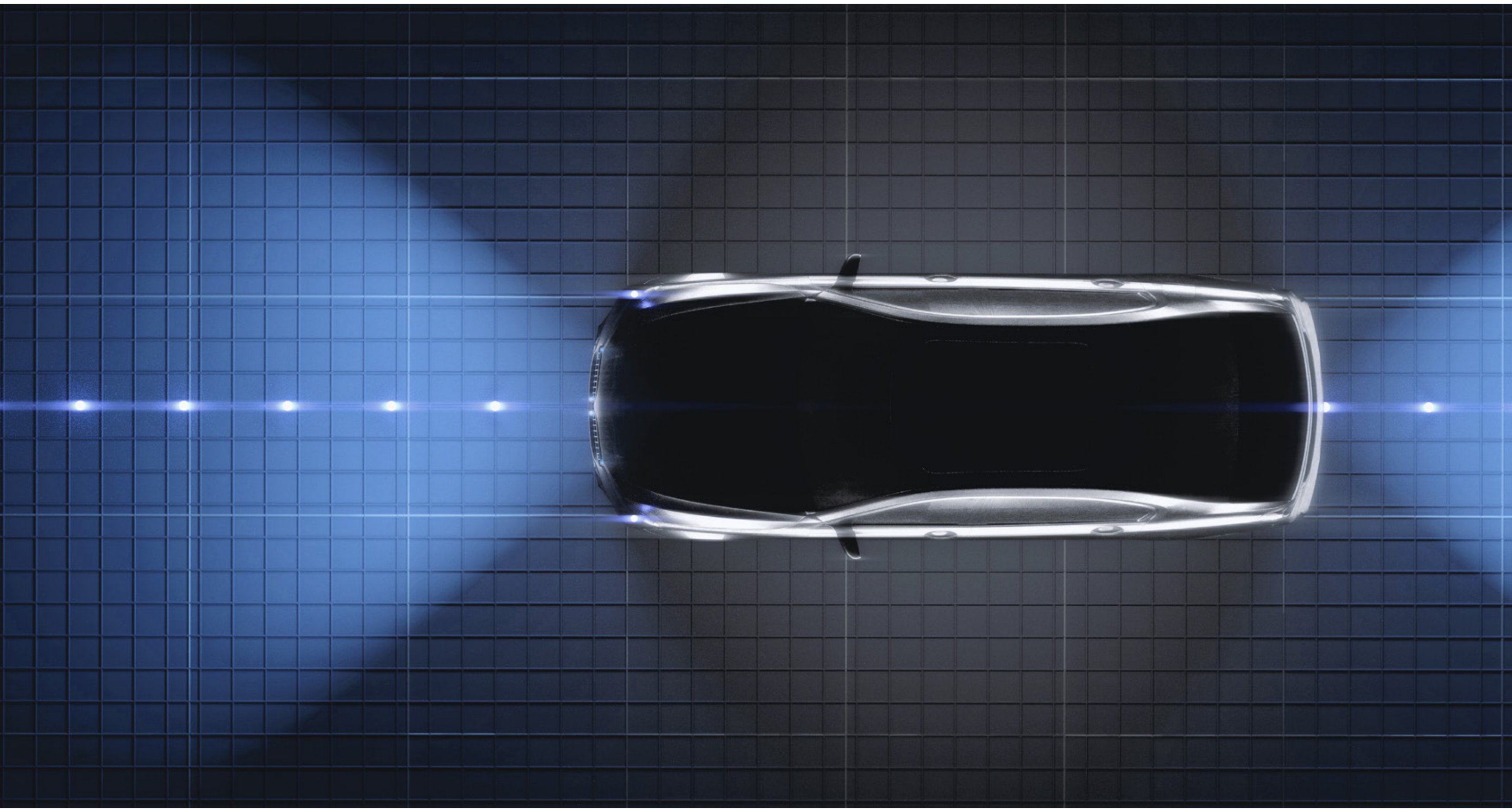
Private autonomous vehicles: The other side of the robo-taxi story

Although private self-driving cars attract less attention than robo-taxis do, our new market model suggests that they could give OEMs opportunities for growth.

This article was written collaboratively by members of McKinsey's Center for Future Mobility and Automotive and Assembly practice: Georg Doll, Eike Ebel, Kersten Heineke, Martin Kellner, and Charlotte Wiemuth.



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In the past few years, autonomous driving (AD) has generated sizable interest. The buzz started with a wave of bold announcements by tech companies and automakers about their plans to launch vehicles with conditional and high automation. These declarations proved premature, however. After investing several years and billions of dollars in R&D—and enduring some highly publicized autonomous-vehicle (AV)-related casualties—automotive players have delayed or retreated from their initial pronouncements; plans for vehicle launches have been postponed or scaled back. Many OEMs cite technology issues and insufficient regulations for autonomous driving when they explain their change of plans.

Despite these early setbacks, there have been some important success cases involving vehicles with AD capabilities, and they represent a huge opportunity to transform mobility. Road safety would increase as AD systems reduced collisions caused by human error, and drivers would have more time to relax in vehicles rather than focus on the road. Many companies recognize AD's enormous potential and are forging ahead. But in addition to technological hurdles, they face many uncertainties, including those related to the COVID-19 pandemic, the exact regulatory requirements that will be established, and customer willingness to pay. These could affect both the availability and adoption of AD features.

To provide greater clarity about how the AV market could evolve, McKinsey developed a detailed mobility-market model that covers more than ten modes of transport. Our model includes data from upward of 2,800 cities and rural areas in more than 110 countries. Among other things, the model projects miles traveled, light-vehicle sales, installed vehicles (or parc), environmental impact, and the size of the value pools for private and shared transport through 2030. Recently, McKinsey updated the model to include COVID-19's impact on the adoption of AVs.

Using insights from the mobility-market model, we created future AV scenarios that will help OEMs, suppliers, and investors make decisions about their opportunities. After describing general trends, we focus on our findings about the private AV market—a segment that typically attracts less attention than shared robo-taxis do. By our definition, the private AV market comprises all vehicles not used for AV ride-hailing services. We believe that this private market could open new opportunities for OEMs, especially in the premium segment.

Autonomous driving will change the automotive game

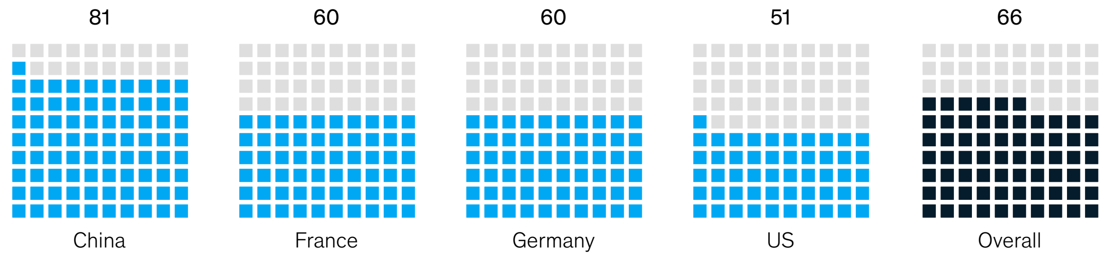
AD will be a game changer in the automotive industry. For one thing, it is becoming a key buying factor for customers: a recent McKinsey survey of 1,000 people in China, Europe, and the United States, for example, showed that roughly 60 percent of respondents in each region would switch automotive brands to get a vehicle with better AD features. Despite some degree of dilution when customers move from consideration to purchase,

Autonomous driving represents a huge opportunity to transform mobility. Road safety would increase, and drivers would have more time to relax in vehicles rather than focus on the road.

Exhibit 1

Many premium buyers, especially in China, are willing to switch car brands to obtain better autonomous-driving features.

Willingness of premium-segment buyers to switch for better autonomous-driving (AD) features,[1] %



[1]Question: Is AD going to be a key buying factor for premium customers in the future?
Source: McKinsey Future Mobility Survey 2019

this finding illustrates the current perceived importance of AD features (see the ACES[1] 2019 survey for details).

Among premium customers, the 2019 McKinsey Future Mobility Survey (Exhibit 1) indicates that the willingness to switch OEMs for the best AD features is significantly higher in China (81 percent) than in the United States (52 percent) or Europe (about 60 percent in France and Germany). Chinese customers may be less loyal to brands in general and more interested in technology. Premium customers also show a significantly higher willingness to switch, since they value the latest technology more than other segments do.

Our ACES survey suggests that most customers would hesitate to buy autonomous vehicles that do not allow the driver to take control. They were, however, keen to use AD in many other situations. Customers rank driver-assistance features and conditional AD capabilities in traffic jams and on highways as more important than AD in urban areas because they see traffic jams and monotonous highway driving as major pain points. Preferences vary by country or location, of course. In China, for instance, traffic jam–assist features are more important (and useful) than a highway pilot that can drive cars at up to 130 kilometers an hour.

Although the private AD market is promising, OEMs and other stakeholders face many uncertainties. In the near term, the COVID-19 pandemic could have a significant impact on technology projects in the automotive sector: the development of some AD features will be delayed as OEMs and investors scale back funding for innovation to focus on day-to-day cash management. (Some AV testing was temporarily suspended early in the pandemic, for instance.) These delays will probably stall the development of AVs for months rather than years. Over the longer term, however, AVs may gain traction as both consumers and public officials come to realize that they can support physical distancing.

There is also some long-term uncertainty because AD regulations are still evolving. Although the UN Economic Commission for Europe's working party 29 (WP.29)[2] and several governments are actively drafting legislation for highly autonomous driving, the exact requirements for highway pilots (HWPs) and urban autonomous driving remain unclear. Furthermore, the shifting AV landscape has compounded uncertainty within the industry and

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[1] Autonomous driving, Connected cars, Electrified vehicles, and Shared mobility.
[2] The World Forum for Harmonization of Vehicle Regulations (WP.29).

among stakeholders (such as insurance companies and regulators) about how much AD they can expect in the foreseeable future.

Understanding the autonomous-driving world

Before we delve into AD use cases, it will be helpful for us to explain AD's capabilities. The most useful classification may come from the Society of Automotive Engineers (SAE), which has established levels ranging from 0 (no automation) to 5 (full automation) to describe the capabilities of automated driving (Exhibit 2). Private AVs may eventually include models with partially automated driving functions, such as advanced driver-assistance systems (ADAS), as well as high automation.

The SAE levels describe only the abstract capabilities of vehicles. Industry stakeholders have identified very specific use cases for the settings in which AD might be used, as well as constraints imposed by vehicle speeds or functions. The customer features and technologies of these use cases do not exactly align with the SAE levels. In fact, these differences are responsible for more precise divisions within the SAE definitions; for instance, SAE Level 2 can be broken down into two segments: entry-level capabilities, such as adaptive cruise control with lane centering, and advanced ones, such

Exhibit 2

The Society of Automotive Engineers has divided autonomous vehicles into levels based on their capabilities.

Six levels of automotive automation defined by the Society of Automotive Engineers (SAE) and information on use cases for each level

Use case: Focus of the current analysis; Out of scope of current analysis; focus of the Mobility Market Model

		Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	Use case
Advanced driver-assistance systems (ADAS)	**0** No automation	Human driver	Human driver	Human driver	N/A	
	1 Driver assistance	Human driver and system	Human driver	Human driver	Some driving modes	
	2 Partial automation	**System**	Human driver	Human driver	Some driving modes	ADAS Level 2 entry ADAS Level 2 advanced
Autonomous driving (AD)	**3** Conditional automation	**System**	**System**	Human driver	Some driving modes	Level 3 highway pilot Level 3 traffic-jam pilot
	4 High automation	**System**	**System**	**System**	Some driving modes	Level 4 highway pilot Level 4 highway/ urban pilot
	5 Full automation	**System**	**System**	**System**	**All driving modes**	Level 4/5 vehicle on demand in controlled areas (robo-taxi) Level 4/5 vehicle on demand (robo-taxi 2.0)

Source: Society of Automotive Engineers

as supervised hands-free driving on highways. Some use cases require capabilities associated with a number of levels. The following list shows the most relevant SAE levels for AD, along with some use cases:

— *Level 2 entry (sometimes also referred to as L2+ or L2 hands-free).* Vehicles with these capabilities have basic ADAS that can steer, accelerate, and brake. Such systems usually use cameras and radar sensors, and drivers must typically have their hands on the steering wheel. The system will remind drivers if it does not detect steering action during a brief period of time.

— *Level 2 advanced.* In this category, vehicles are equipped with features (such as Tesla's Autopilot and GM Super Cruise) that allow drivers to take their hands off the wheel for longer periods where that is legal. But even with this degree of freedom, drivers must always monitor the systems and road. In addition to cameras and radar sensors, Level 2 advanced systems typically include driver-monitoring cameras, highly accurate maps, and a central and high-performance ADAS computer. The borders between these systems and Level 3 ones are somewhat blurry from the customer viewpoint. For instance, although the technologic capabilities of Tesla's Autopilot put it squarely within SAE Level 2, some customers use its Level 2 advanced features to enable hands-free driving and reduce the amount of time needed to monitor streets—something the SAE associates with Level 3.[3]

— *Level 3.* Several OEMs are now testing Level 3 systems, which will probably serve as bridging technologies replaced by Level 4 ones as soon as they become available. Level 3 traffic-jam pilots (TJPs) and HWPs are likely to be the first use cases tested because they involve fewer "corner cases" (encounters with intersections or pedestrians). That reduces complexity, though vehicles are moving at high speeds. TJPs, which help cars autonomously navigate crowded roads, will be followed by HWPs in which vehicles navigate crowded situations at higher speeds. In both use cases, drivers must be prepared to take control at short notice. Level 3 TJP regulation is addressed by the automated lane-keeping systems (ALKS) regulation proposed by WP.29. Level 3 HWP systems might face additional challenges securing legal approval for several reasons, such as the complexity involved in quickly transferring responsibility to the driver if a system reaches its performance boundaries. (Drivers do not have to monitor conditions constantly in vehicles with Level 3 systems but must be able to take control rapidly.) In addition to all Level 2 technologies, these systems will probably include LiDAR[4] sensors, enhanced sensor fusion (combining sensor data from several sources to reduce uncertainty), and redundancy in control units and actuation.

— *Level 4 highway pilot.* These systems contain all Level 3 technologies and have additional AD capabilities that allow vehicles to operate safely in emergencies: for instance, they can stop autonomously in emergency lanes. Drivers therefore will not need to assume control at short notice when the vehicle is in charge and will be able to take their eyes off the road to engage in more extensive side activities. Within the private AV space, we expect Level 4 systems to focus initially on highway driving.

— *Level 4 urban pilot.* These systems not only make it possible to drive autonomously in urban areas but can also operate independently in emergencies. Few owners of private cars will seek vehicles with Level 4 systems for inner-city driving, since the costs will remain high through 2030. Vehicles with these systems could be in demand as robo-taxis, however.

— *Level 5.* Vehicles with these systems can drive autonomously in all situations. They will not be technologically or commercially available for the foreseeable future, because there are unique situations in which a human driver must

[3] This may not be legal in all areas.
[4] Light detection and ranging.

The future of autonomous parking

One subject of great interest is autonomous parking. The earliest mainstream attempts to implement it occurred in congested Japan in the early 2000s. Today, there are two main self-parking use cases:

— *Autonomous parking on streets.* Level 2 parking features, such as self-parking with human monitoring, are already available. Level 3 or 4 features that do not require human monitoring might be the next step, launching first in safe environments on private property before debuting in public areas.

— *Autonomous parking in garages.* For safety reasons, the first attempts to crack this use case are likely to occur in secluded parking garages. Society of Automotive Engineers Level 4 features will probably use hardware adapted from the driving features of Level 2 advanced autonomous vehicles. There are three different options for implementing this use case:

- having smart cars without sensors in the infrastructure
- having cars use sensors and processing power embedded in the infrastructure
- following a hybrid model with some sensors and intelligence in the cloud and some in the vehicle

More advanced features will enable cars to park autonomously in hybrid garages that have pedestrian traffic. The evolution of autonomous parking in garages is difficult to predict because it depends on many factors, including the support of infrastructure owners and operators. Initial discussions with parking-garage owners reveal that many of them do not see autonomous parking as a strong business advantage. They are therefore reluctant to invest in the necessary hardware or to create secluded areas in their garages that would accommodate fully autonomous parking—the chicken-and-egg problem.

take control (for instance, driving on unmapped roads or in extreme weather). Attaining Level 5 capabilities will be extremely difficult. Further, Level 5 systems are much more expensive than Level 4 ones but do not significantly increase the benefits for end customers. That limits the commercial potential of these systems.

Of course, other AD capabilities and potential use cases also exist (see sidebar, “The future of autonomous parking”).

At the 2020 Consumer Electronics Show, the industry appeared to shift temporarily away from highly autonomous driving features—the SAE Level 3 and Level 4 performance levels—and instead embraced partially automated driving at advanced Level 2. These systems are more reliable and satisfy customers by allowing hands-free driving, backed up (within the boundaries of the law) by an alert driver.

The enablers of autonomous driving

The diffusion of AD depends on two factors: the availability of technologies and the customer’s willingness to adopt specific use cases. Regulatory requirements can heavily influence both.

The availability of technologies

Automakers around the world have announced ambitious goals for launching vehicles with Level 3 and Level 4 features. Unfortunately, they have already significantly delayed or rescheduled many of their initial plans. The latest announcements indicate that the first Level 3 highway systems will hit the market at some point from 2021 to 2024. Two to three years later, companies will probably upgrade their vehicle systems to Level 4. If uncertainty persists at the start of production, however, many target dates will probably slip. Technological challenges and regulatory issues are likely to account for most of the delays.

For several reasons, the COVID-19 crisis could also delay the availability of AD features. OEMs and suppliers, for example, are reviewing their investment projects and reducing spending to limit cash outflows. AV start-ups could face funding hurdles. The full effect of the COVID-19 crisis is still unknown, so it is not yet represented in our model.

Customer adoption

When OEMs and other stakeholders create strategic plans for AD, they must consider different scenarios, since customer adoption overwhelmingly depends on difficult-to-predict factors such as safety benefits and convenience. Consumers, for example, will be more willing to pay for AD systems that free up time otherwise spent driving. But the exact value of this time will depend on the side activities that drivers undertake while their vehicles are under autonomous control.

McKinsey's Future Mobility Survey shows that customers highly value relatively simple side activities, such as the ability to have more concentrated discussions or to look out the window briefly. Highly distracting side activities, which are only possible with Level 4 systems, account for only a small share of what consumers want to do (Exhibit 3). Level 2 advanced systems already enable 25 to 40 percent of all potential side activities, which helps explain their current success and bodes well for their future. The exact percentage varies with regulations and typical driver behavior in different countries.

Customer adoption will also depend largely on the cost of vehicles, since AD features will probably remain expensive. While we expect OEMs to pay system-component costs for Level 2 advanced features in the range of $1,000 to $2,000, Level 3 systems could cost up to $5,000 or more for hardware and software licenses at the time of system launches on top of all required safety-systems. Their costs are high because Level 3 systems require additional sensors, sensor–data fusion, stronger computing power, and redundancy in actuation. Consumer sticker prices will probably end up significantly higher because of the OEMs' development costs and dealers' markups.

The high prices suggest that AD features will be introduced in a top-down cascade, starting with large vehicles from premium OEMs and moving down over time to the mass market and low-cost OEMs. Typically, customers considering a high-price premium sedan or SUV show less price sensitivity for optional features than customers buying value products or smaller cars.

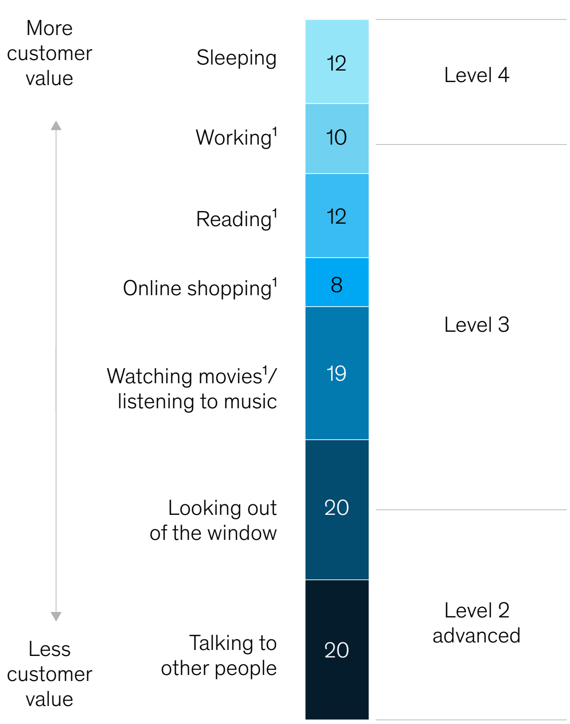
Impact of regulations

The regulatory environment will shape the adoption of AD features, especially those for driver assistance. Additional safety features will probably become mandatory and commoditized in response to EU

Exhibit 3

Respondents expressed interest in engaging in multiple side activities while the autonomous-driving mode is active.

Preferred activities of drivers while autonomous-driving (AD) mode is active, % of total time



[1]Could be feasible with Level 3 if done through human-machine interface; potentially requiring Level 4 if own device is used.
Source: McKinsey Future Mobility Survey 2019

OEMs and regulators are still struggling to define systems and requirements that will allow the first vehicles with Level 3 and higher features to hit the road.

regulations or New Car Assessment Program (NCAP) testing. These safety systems require almost the same hardware that most Level 2 capabilities do and could see strong growth.

Although Level 2 advanced features have already proven their worth on the street, OEMs and regulators are still struggling to define systems and requirements that will allow the first vehicles with Level 3 and higher features to hit the road.

Modeling private autonomous-vehicle trends

As part of the larger McKinsey Center for Future Mobility (MCFM) effort to understand trends, we created a multidimensional model that uses some inputs from the mobility-market model, such as total yearly vehicle sales. It can predict AD adoption under different scenarios through 2030 and also effectively sizes value pools for incumbent automotive players, such as suppliers and OEMs.

In addition to automotive companies, our model data is relevant to adjacent organizations such as city authorities, insurance providers, or real estate developers, all of which will play crucial roles in planning the infrastructure for AVs.

The model includes nine different scenarios that depict varying degrees of customer adoption and technology readiness. In this article we focus on three of the scenarios: the most conservative case, the base case, and the most bullish case, each resting on different assumptions. For instance, our base case assumes that further delays and unexpected technological glitches will not prevent technologies from reaching the market. The conservative scenario assumes that regulators will be reluctant to issue approvals and that technologies may hit obstacles during development.

Our scenarios also make various assumptions about the rate at which people shift their vehicle preferences from private cars to other mobility modes, the potential impact of COVID-19, and the subsequent recovery of mobility. Our model outputs include detailed information on the adoption rate for private AVs. Potential data cuts include vehicle segments, geographies, and OEM archetypes.

What's ahead for autonomous driving

In the base scenario, the total number of ADAS and AD systems will rise over time, and demand will vary by level. Excluding robo-taxis, the share of new private vehicles with Level 2 entry systems will reach 47 percent by 2025, and an additional 12 percent will have Level 2 advanced ones (Exhibit 4). The Level 2 entry level systems will become commoditized from 2022 onward as regulations and requirements for voluntary safety tests change.

After 2025, the number of new vehicles sold with Level 2 advanced or higher systems will grow by about 10 percent annually in our base case, while higher levels of AD will replace Level 2 entry systems. Eventually, demand for vehicles with Level 2 advanced systems will outpace demand for those with Level 2 entry systems, causing the market share of vehicles with Level 2 entry systems to dip to 39 percent in 2030. Overall, 64 percent of vehicles sold that year will have some AD Level 2 or higher features.

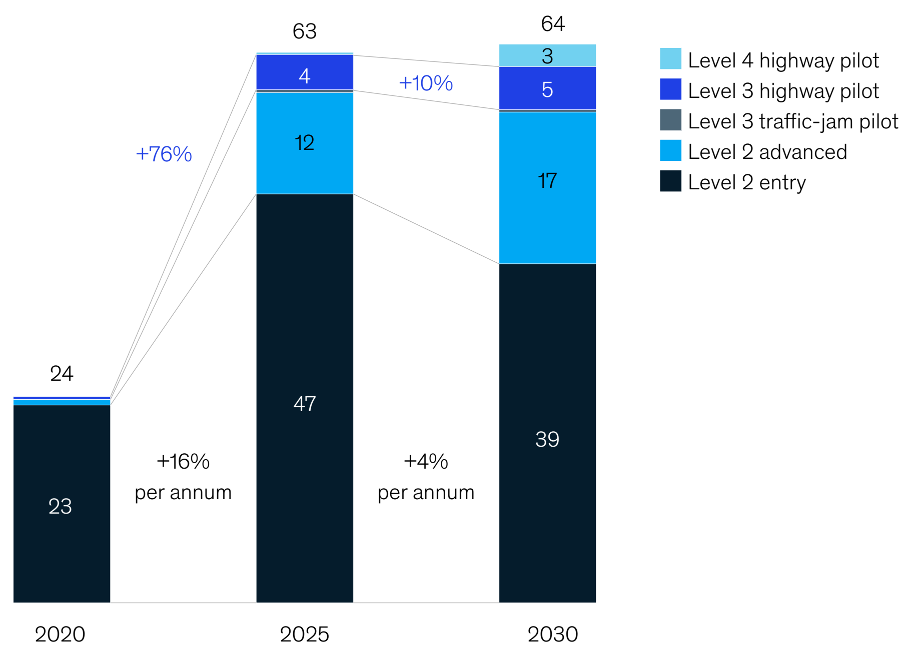
Our model also suggests that Level 3 TJP and Level 3 HWP solutions could serve as bridging technologies until more advanced systems become available. About 5 percent of vehicles sold in 2030 will have these solutions in our base case. As we noted earlier, Level 3 use cases will not gain traction until OEMs resolve the complex issues of quickly transferring responsibility to drivers when systems reach their performance boundaries.

Finally, our base case also suggests that Level 4 HWP applications will have a market share of 3 percent in 2030, primarily in large vehicles from premium OEMs and mass-market leaders.

Exhibit 4

Level 2 features will be the main growth driver until 2025.

Vehicles by autonomous-driving (AD) features, % of total vehicle sales



Note: The base case assumes medium levels of technological disruption and customer adoption.
Source: McKinsey Center for Future Mobility

Of course, a different picture emerges from the projections for our other scenarios. In our most bullish one, customer interest is high, technologies become available early, and 75 percent of vehicles sold in 2030 will have Level 2 or higher features (Exhibit 5). Of these, 14 percent will have Level 3 or higher technologies. However, in our most conservative scenario, with low customer interest and late technological readiness, only 43 percent of new vehicles will have Level 2 or higher systems, and the number with Level 3 or higher systems will be minimal. The conservative scenario will become more likely if the COVID-19 crisis continues and the path to the next normal takes longer than expected.

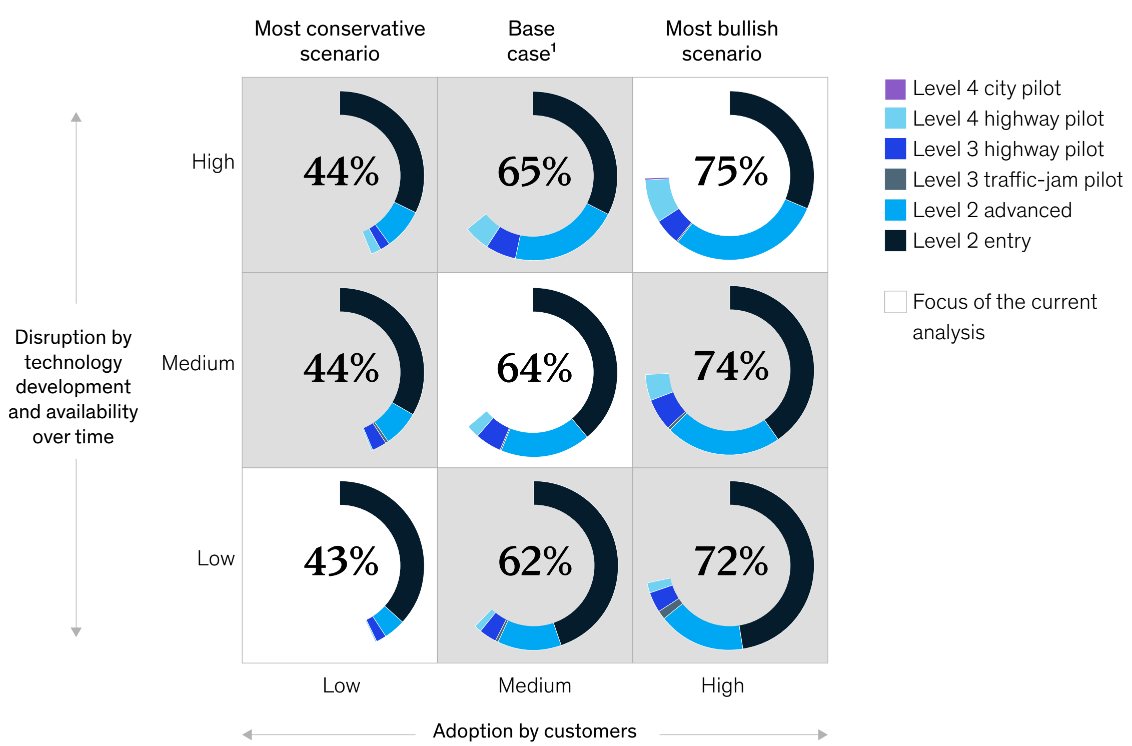
In our scenarios, the number of new vehicles with higher-level AD capabilities, especially those with Level 3 or above systems, may seem small at first glance. But these are total global vehicle sales, including all emerging markets and all OEM and vehicle segments. Additionally, the long development and production cycles for these vehicles will prevent a higher penetration rate.

An analysis that focused on the premium OEM segment, which covers roughly one-tenth of total global vehicle sales, would look completely different. In our base case for the premium segments, the model projects significantly higher AD feature penetration, reaching nearly 100 percent for Level 2 entry and higher as soon as 2025. In that year, roughly 20 to 30 percent of new premium car sales could have Level 3 or higher TJPs. (Level 3 HWP features would still be rare.) In 2030, Level 4–equipped vehicles could represent roughly 20 percent of premium-vehicle sales.

Exhibit 5

Our most conservative and bullish scenarios show different rates for the adoption of automated-driving systems.

Scenarios for sales of vehicles with autonomous-driving (AD) capabilities, % of total



[1]The base case assumes medium levels of technological disruption and customer adoption.
Source: McKinsey Center for Future Mobility

Especially for large vehicles, which have high base prices, the premium paid for AD features is not a deal breaker for car buyers. We therefore expect premium OEMs to focus on two areas. First, they will attempt to equip many vehicles with Level 2 advanced systems early on to increase market penetration. (Over the longer term, they will also install these systems in less expensive, smaller premium cars.) Second, to achieve higher levels of differentiation, OEMs will compete to offer the most advanced AD features in their flagship vehicles.

Positioned to differentiate

Several implications for OEMs and suppliers emerged from our modeling and industry discussions:

— *Premium segment.* For this segment, Level 2 advanced AD features are increasingly becoming a differentiator, and they will be even more important in the future. Eventually, premium OEMs will also differentiate their vehicles through Level 3 and Level 4 features, especially those that allow drivers more free time during traffic jams or highway driving. It is therefore important for premium OEMs to make their systems more sophisticated and to introduce innovations with each new major platform launch.

— *Mass-market leaders.* These OEMs may decide to increase AD features if they have strategic alliances with premium OEMs that give them access to Level 3, Level 4, and higher features. Otherwise, they may make a more limited investment in Level 2 systems.

— *Mass-market followers and low-cost OEMs.* These segments must invest in ADAS technology to meet regulatory requirements and achieve five-star NCAP ratings. They probably will not pursue advanced AD features over the short and medium terms.

— *Suppliers.* These companies must deliver different component systems to different customer segments. That includes low-cost systems for all vehicles, which allow them to achieve good safety ratings, and high-end systems with additional distinctive features, mainly in the premium-vehicle and large-vehicle segments. Overall, the market for AD features is a huge opportunity for suppliers of both hardware and software, but they will need to manage the challenges of system maintenance and upgrades.

The disruption AD creates will probably have seismic consequences for incumbent automakers and suppliers. They need to understand both how the market could roll out under different scenarios and the use cases for private and shared AVs alike. A flexible model that considers various scenarios may provide the necessary insights.

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