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The Road Ahead For Autonomous Vehicles

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PRIMARY INFRASTRUCTURE CREDIT ANALYSTS

Kurt E Forsgren
Boston
(1) 617-530-8308
kurt.forsgren@spglobal.com

Dhaval R Shah
Toronto
(1) 416-507-3272
dhaval.shah@spglobal.com

David L Lum
San Francisco
+ 1 (415) 371 5013
david.lum@spglobal.com

PRIMARY AUTOS CREDIT ANALYSTS

Nishit K Madlani
New York
(1) 212-438-4070
nishit.madlani@spglobal.com

Lawrence Orlowski, CFA
New York
(1) 212-438-7800
lawrence.orlowski@spglobal.com

Key Takeaways

- Growth of fully autonomous vehicles will be influenced by and significantly lag the market growth of electric vehicles, which could approach a 10% share of U.S. light vehicle sales by 2025 (compared to 1.1% today), behind our forecast 25% share in Europe and 20% share in China.
- Under our low disruption scenario advanced autonomous vehicles requiring minimal to no driver intervention could reach a 2% share of light vehicle sales by 2030 rising to 10% by 2040.
- The trajectory of autonomous vehicle growth is complex and unpredictable as it faces hurdles beyond technology and cost.
- If autonomous vehicles and related technology mobility advances develop incrementally and linearly with current industry participants leading the way, we anticipate fewer positive or negative credit implications. However, newer entrants into mobility technology could disrupt a gradual, evolutionary scenario and negatively affect credit quality across various sectors involving transportation infrastructure and supporting funding mechanisms.

Overview

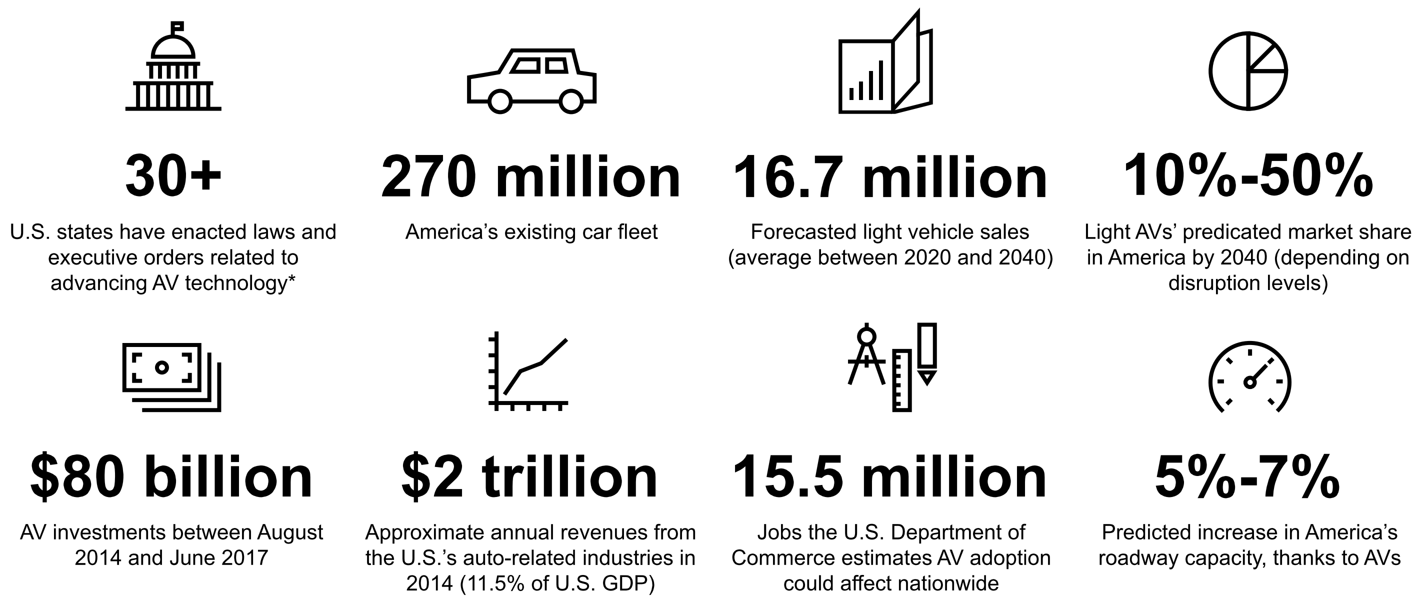
The March 2018 pedestrian fatality by an Uber autonomous test vehicle highlights both the significant technical challenges and limitations associated with this transformative technology as well as the many practical, technical, legal and moral questions requiring resolution prior to the mass adoption of driverless, autonomous vehicles (AVs), still decades away. Full-scale testing of self-driving vehicles without human control—including tractor trailers--is underway in cities globally by a number of companies, and clearly, how people travel has been changing because of rideshare offerings from transport network companies (TNCs) like Uber, Lyft and soon perhaps Waymo. And with the commercial rollout of "hands-free" features on some premium autos this year, the early stages of a transition to autonomous vehicles is underway.

That said, we believe AV penetration will significantly lag that of electric vehicles (EVs) and the variance between our different AV disruption scenarios discussed in this report is very large: our low disruption scenario only foresees advanced AVs (level 4 and 5) with a 2% share of light vehicle sales by 2030 rising to 10% by 2040. However, should the revolution follow our high disruption scenario where AVs comprise a 30% share of light vehicle sales by 2030 and 50% by 2040, the effects on society will be profound and far-reaching. Semi-automated to fully autonomous all electric-vehicles sharing the road – augmented by ride-sharing technologies and TNCs – are likely to alter how cities are designed, grow, and function, affecting where we live and work. AVs will introduce life-saving and ultimately laborsaving technologies while fundamentally altering the movement of people and goods disrupting business models along the way.

In this report, we present our range of estimates of when AVs will arrive, highlight how mobility technology could develop, and how it will change the landscape of infrastructure needs and other sectors over the long term, principally from a U.S. perspective. We intend to use this background commentary as the basis for our next commentary, which will address the potential credit impact on transportation infrastructure assets of these technological advances.

Chart 1

Automated Vehicles By Numbers



*As of March 2018. Sources: S&P Global Ratings, Deloitte, Brookings Institution, The U.S. Department of Commerce.

S&P Global Ratings' View Of Where Things Are Headed

Growth of AVs will lag that of EVs. This is because EVs have inherent advantages due to lower maintenance costs (i.e. fewer moving parts), zero emissions and lower operating cost per mile, which is crucial for fleet operators that will target mass deployment in geo-fenced urban areas. We believe that over the next decade, advancements to self-driving hardware and software implementations will be highly dependent upon the higher capacity and energy stored in an EV battery pack which is also likely to allow much more vehicle design freedom.

EVs could be 10% of the U.S. light vehicle market by 2025. We're including plug-in hybrids along with pure EVs. The comparable figure for 2017 was just 1.1%. U.S. electrification in turn should be well below other key markets, with our estimates for 25% of light vehicle sales in Europe by 2025 and 20% in China (the latter being consistent with the government targets by 2025 under the stimulus provided by the new carbon scheme it will introduce in 2019). This reflects in part a lack of political consensus in Washington on climate change.

The trajectory of AV growth is complex and hard to predict. Whereas EV growth is primarily determined by battery cost developments and supporting infrastructure, AV growth faces many hurdles beyond technology and cost including:

- Legal and regulatory developments: Specific laws will be required as well as regulation around interaction between conventional cars, pedestrians, and AVs. We believe regulatory developments are likely to advance faster in large markets like the U.S. and China, while being delayed in Europe, where reaching a consensus among different governments and jurisdictions could prove more challenging.

All-electric EVs will necessitate a new infrastructure funding model

- Consumer acceptance and human behavior: The initial growth phase of AVs is likely to lead to more congestion, as conventional cars will need to interact with AVs, which also likely will be regulated in a conservative manner. This new dynamic could increase the number of vehicles miles traveled (VMT), and the use of ride-sharing services. There may also be calls for dedicated lanes or roadways to separate AVs and driver-operated vehicles. The behavior of drivers and pedestrians to AVs, which is just beginning to be studied, is difficult to predict.
- Public opinion on safety and liabilities: While AVs will ultimately yield significantly fewer automotive deaths and injuries, it is clear that public opinion will be defined by incidents and casualties during the testing phase. Society may have little tolerance for the inevitable road accidents and fatalities caused by AVs. Equally, how insurance companies will adapt the policies they write to take account of driverless cars is presently an unknown. As AVs become connected to and, ultimately, controlled by automated systems, designing cyber-security measures to protect against potential hacking of crash prevention systems causing them to fail will be an important factor in customer acceptance and critical in assuring public safety.
- Taxation and infrastructure funding: All-electric AVs will usher in upgrades to roadways and the electrical grid and have long-term impacts on employment, travel and traffic patterns, and vehicle ownership. Simultaneously AVs will also necessitate a new infrastructure-funding model and new revenues for some governments to replace diminishing sources derived from gas and sales taxes, car registration fees, fines, parking, and property taxes. Changes in the pace of market penetration of EVs and AVs will affect all these auto-related revenue sources with growing AVs and TNCs likely to influence our current model of vehicle ownership and mobility patterns.
- Demand for semi-automated (level 1-2-3) vehicles will be significant by 2020: We believe consumers will be interested in advanced safety and convenience features. This corresponds to level 1 to level 3 automation levels, which still require driver intervention. Semi-autonomous vehicles currently on the road range from active engagement of the driver (level 1 to level 2) to passive engagement in some driving modes for level 3 as seen on a few high-end autos. We anticipate these vehicles will increase with consumer demand and as costs are reduced with scaled production.
- Full automation (level 4 and level 5) will be a much more challenging phase: Levels 4 and 5 assume full system control (limited or no driver monitoring required) and require advanced artificial intelligence software, real-time high precision 3D mapping, and frequent and timely communication between vehicles and infrastructures. Governments are highly incentivized to reduce traffic fatalities, though whether infrastructure funding to reach full automation will be available remains another question, as studies show that vehicles approaching level 3 capability can achieve 80% of expected level 5 safety at 20% of the cost.

Our U.S. scenarios summarized below suggest three different rates of growth for fully autonomous technology. Even if we currently see the low scenario as more likely given the numerous hurdles ahead, we believe it is important to conceptualize the impact of the higher growth scenarios and its impact on credit quality they could have.

Table 1

Autonomous Vehicles Full Automation (Level 4-Level 5) Growth Scenarios

	Low Disruption	Medium Disruption	High Disruption
Phase I: 2020 – 2030			
Resultant AV adoption rate by 2030 (i.e, AV sales vs total light vehicle sales (%)	~2	~15	~30
Resultant AV fleet share of U.S. car fleet by 2030 (%)	<1	<5	<10
Phase II: 2030 – 2040			
Resultant AV adoption rate by 2040 (i.e, AV sales vs total light vehicle sales (%)	~10	~30	~50
Resultant AV fleet vs U.S. car inventory by 2040 (%)	<5	>15	<35

Key Credit Impacts For Various Sectors

For now, we do not expect AV developments to play any meaningful role in our ratings and outlooks on automakers and suppliers. This is because we believe any large-scale commercial deployment of AVs is significantly more uncertain than EVs and likely several decades away (2030-2040), given the hurdles mentioned above. In the event that driverless AVs make market inroads sooner than expected (and follow the growth of battery electric or hybrid vehicles), it could lead to a sustainable competitive advantage. The rapid deployment of self-driving fleets could help first-movers establish significant barriers to entry, particularly in major metropolitan areas, where penetration of autonomous ridesharing over vehicle ownership is likely to be higher. For now, automakers' investments in autonomous driving have more risk than upside, given the significant deployment of companies' resources toward similar technologies. Autonomous driving won't be disruptive for the auto industry yet, as it depends on regulatory developments. It could affect large markets like the U.S. and China first, but be delayed in Europe, where reaching consensus among numerous governments and regulatory authorities could prove challenging.. (See "Global Auto Industry 2018: At A Crossroad" published Oct. 10, 2017, on Ratings Direct.)

The rapid deployment of self-driving fleets could help first-movers establish significant barriers to entry

Shifting liability from individuals to auto manufacturers – should it occur - will eventually have a major effect on motor insurers, especially the less-diversified personal line insurers. Because of crash avoidance technology, we expect to see declines in both the frequency and severity of claims, significantly reducing costs to the motor insurers. The competitive nature of the personal motor insurance market means that this drop in claims cost would result in a fall in premium rates. (See "Changes In Car Safety And Automation Signal Long-Term Adjustments For Major U.K. Motor Insurers," published Jan. 19, 2016.)

We see growth opportunities for electric utilities if they pursue EVs in a credit-friendly manner and with adequate regulatory support. It could even be a way for utilities to counter the woes of slumping electricity demand by generating additional revenues. (See "Are Electric Cars And Charging Infrastructure Bright Spots For U.S. Regulated Utilities?," Sept. 12, 2017, and "For Slow-Growth U.S. Electric Utilities, Batteries Could Be A Power Booster," Nov. 2, 2017.)

AV penetration sufficient to have a profound impact on the infrastructure transportation industry is likely to be far off. However, given the long-term funding and life of infrastructure assets, the variance of long-term impacts of AVs on travel and traffic patterns and vehicle ownership will require careful planning and flexibility to accommodate alternative scenarios. For instance, a highly disruptive scenario could affect some private and public transportation issuers and project financings with long-dated debt maturities or concessions. Impacts on toll roads, airports, and parking enterprises will vary depending on growth of TNCs and the individual AV ownership versus mobility-as-a-service model.

In short, it's generally too soon to say

We anticipate fewer rating changes if the technology develops incrementally and linearly

We do not view the future to be clear enough to adjust ratings today. In the future, any widespread significant credit impact is more likely under the high-disruption scenario because change would be exponential rather than linear. To the extent applications for level 5 AVs are first applied to TNCs, they may have a disproportional impact on public transit and parking enterprises. That is, while level 5 AVs may comprise a small share of overall light vehicle sales, if they largely replace taxis and TNCs, transit providers and parking enterprises at airports could be significantly affected. We anticipate fewer positive or negative credit implications if AVs and related technology mobility advances develop incrementally and linearly with current industry participants and their supporting ecosystem of companies providing parts and technology. Nevertheless, newer entrants into mobility technology could disrupt a gradual, evolutionary scenario and cause a large impact on credit quality for transportation infrastructure and supporting funding mechanisms.

AV 101: How We Got Here

While early prototypes of autonomous vehicles date back to the late 1970s and early 1980s, only in recent years with advances in computer processing speeds have we witnessed accelerated development in automation with the research shifting from academic institutions to manufacturers and technology companies. Indeed, the movement by both traditional auto industry participants and technology companies into AV development has been without precedent in the automotive history. An October 2017 Brookings Institution analysis revealed AV investments announced by all companies including start-ups totaled approximately $80 billion between August 2014 and June 2017; this comprised approximately one quarter of all auto industry research and development investment over that period including spending on vehicles, machine-learning software, operating systems, sensors, navigation and mapping, communications systems to connect to other vehicles, roadway infrastructure, and other core technology.

Automated vehicles (sometimes called semi-autonomous or connected vehicles) are defined as those with fully integrated robotics directed by humans even if no driver is onboard (level 1 to level 3). Most auto manufacturers are advertising the introduction of vehicles with AV features (level 3) by 2020 or sooner. The next phases (level 4 and level 5) are high-to-fully autonomous vehicles which employ artificial intelligence (or embedded intelligence) to operate completely independently (see "Automated And Autonomous Vehicles: The SAE Scale"). The six different levels of autonomy (zero to five) were established by the Society of Automotive Engineers (SAE) International in 2016 and were recently adopted by the U.S. Dept. of Transportation and the National Highway Traffic Safety Administration to help define, categorize, and standardize the growing number of features and technologies being developed, in order to answer the question: "What does self-driving precisely mean?". The SAE standard refers to AVs as "automated driving systems" or "driving automation systems" to capture all relevant technologies.

What are the forces driving this evolution in mobility? Research by Deloitte has highlighted a convergence of trends including:

- Improved batteries for electric vehicles with higher energy efficiency and lower emissions;
- Advances in strong lightweight materials that improve range and passenger safety;
- Expanded wireless networks and connected vehicles that can communicate with each other and developing infrastructure;
- Evolving shifts in consumer mobility preferences with pay-per-use offered by TNCs rather than car ownership; and
- Expanding automated features in autos and related mobile artificial or embedded intelligence technology.

Of course, at the core for this rapid growth is the demand by consumers for safer, more efficient and productive mobility for all that relieves the passenger from responsibilities of driving.

State governments have an important role in facilitating AV implementation, including licensing drivers, registering vehicles, establishing and enforcing traffic laws, regulating motor vehicle insurance and liability issues, and conducting vehicle safety inspections. In reaction to the first pedestrian fatality associated with an Uber test vehicle, some companies temporarily suspended testing. It is likely that the pedestrian fatality in Arizona and future likely fatalities will result in increased regulatory oversight at the state and federal level, slowing development and deployment of AV technology. At one point there were over 40 companies involved in testing almost 300 self-driving cars in California alone – and the state recently revised its regulations to allow AVs without humans to drive on state roads. As of March 2018, over 30 states had enacted laws and executive orders related to advancing the testing or AV technology (see chart 2). In fact, states may take the lead in advancing AV implementation due to their oversight of vehicle inspections and insurance laws, though there will likely be calls for additional controls and regulatory monitoring.

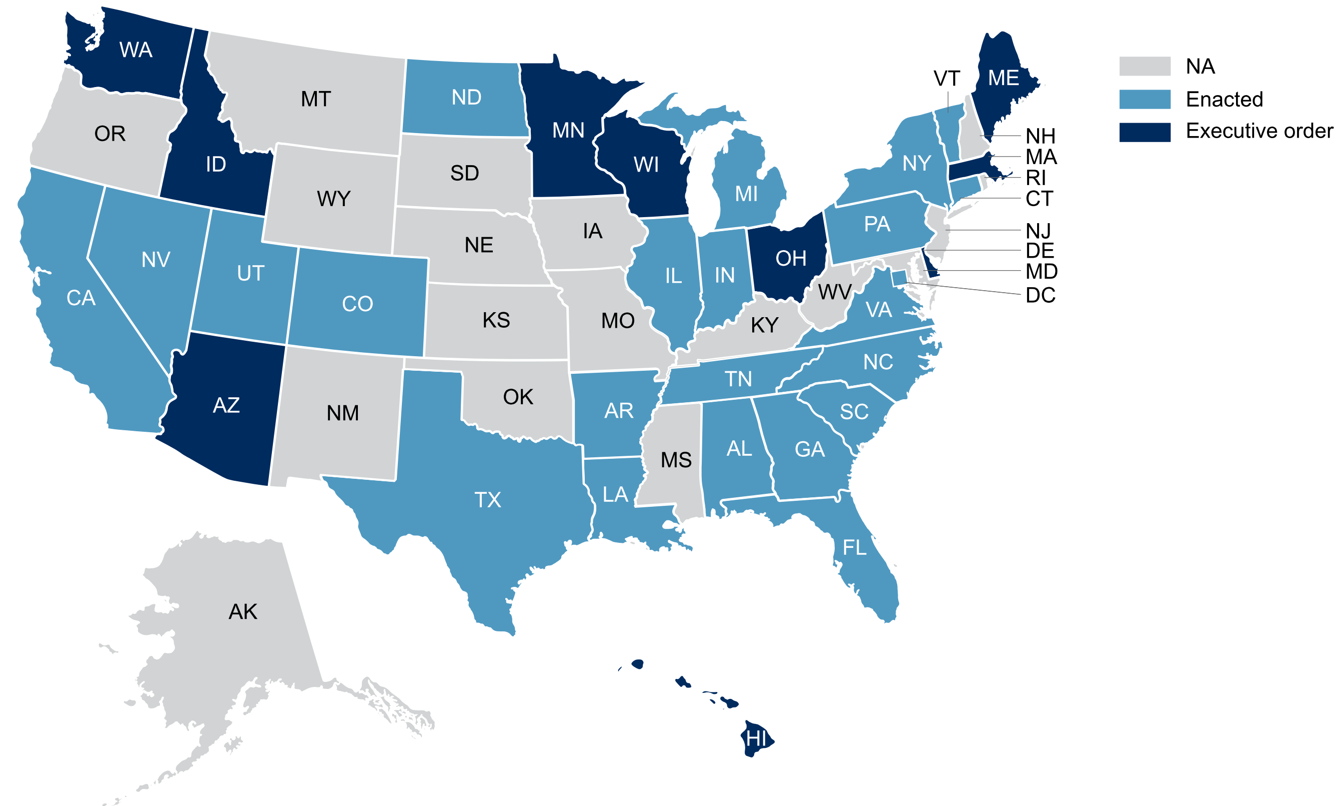
We expect China, with its massive demand, to seize leadership in development and implementation

The U.S. Department of Transportation (DOT) and the National Highway Traffic Safety Administration (NHTSA) released guidelines for federal AV policies in September 2016. While the guidelines were just that (i.e., not regulations), they did establish a foundation for stakeholders to work in tandem to advance public policy around the topic. Later, in September 2017, the DOT released a new guidance document entitled "A Vision for Safety 2.0," which supersedes the prior policy. The new policy further clarifies and delineates federal and state roles, with the federal government maintaining responsibility for regulating vehicles and states regulating the human driver. It also sets a framework for developing safety accountability measures to ensure that safety standards remain a top priority. However, the guidelines remain exclusively voluntary and do not lay out a timeline for future regulations.

Chart 2

States With Enacted Autonomous Vehicle Legislation

Over half of U.S. states have cleared the way for some type of autonomous vehicle legislation

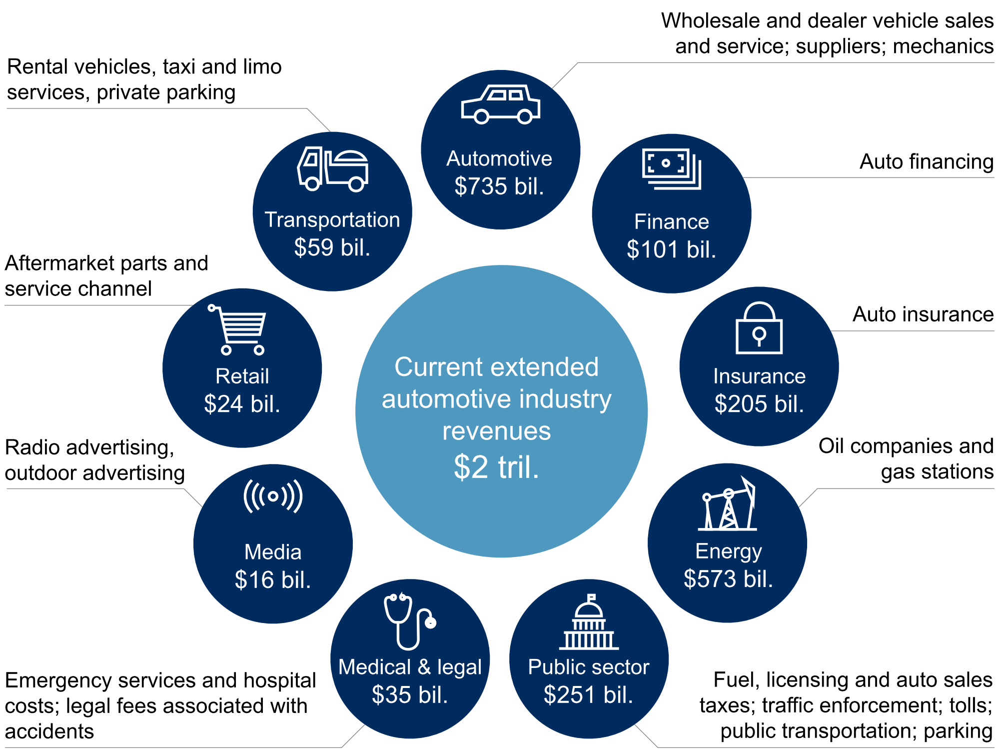


Source: S&P Global Ratings.

Chart 3

Reach Of Automotive Industry Revenue

The U.S. auto sector generated $2 trillion of annual revenue in 2014 – 11.5% of US GDP



Current revenue represents 2014 figures or earlier if data not available. Sources: Deloitte analysis based on IBISWorld Industry Reports, HIS, DOT, US Census, EIA, Auto News, TechCrunch.

AV Implementation As We See It

We believe the arrival of AVs is inevitable; however their adoption across the globe will be slow and fragmented based on the type of vehicle as well as demographics, congestion issues, development of regulations and policies as well as supporting AV infrastructure. Unsurprisingly, growth in most developing countries will lag developed countries. And while the regions with significant technology concentration (the U.S. and some European countries) have an early lead, we expect China, with its massive market demand, to catch up and seize the leadership in developing self-driving cars and related technology as well as implementing relevant supporting infrastructure. This is largely due to China's controlled economy and central government mandates regarding electric vehicles and innovation – autonomous cars were named as one of the key sectors in its "Made in China 2025" initiative – as well as a higher public acceptance of data and technology compared to the U.S.

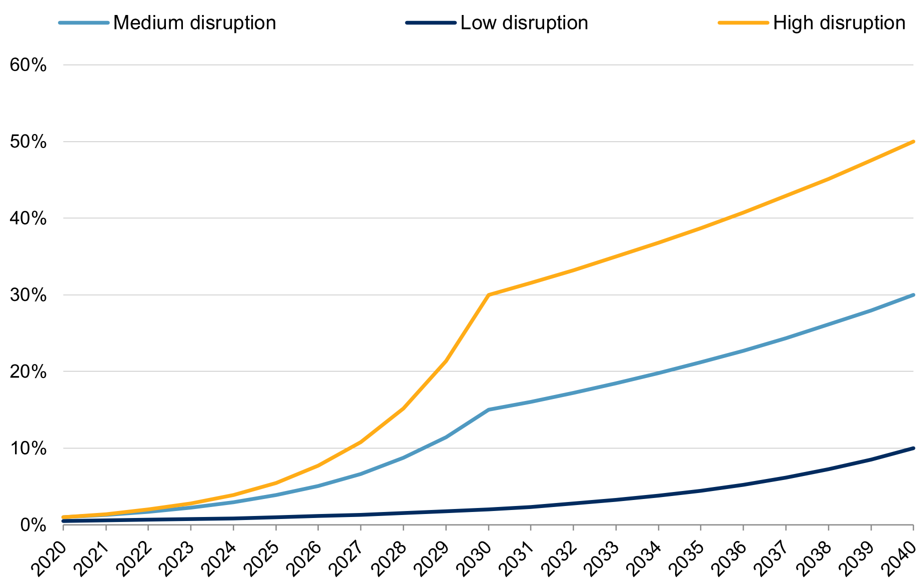
Our low-medium-high disruption scenarios for the U.S.

Given significant uncertainty surrounding consumer acceptance and proactive intervention by regulators and government, we have developed three SAE level 4 and level 5 AV disruption scenarios for the U.S. – low, medium, and high – based on assumptions outlined in table 2 and illustrated in charts 4 and 5.

Chart 4

Autonomous Vehicle Adoption Rate Forecast (2020-2040) - AV Share Of Total Light Vehicle Sales

AV adoption faces many barriers and uncertainties

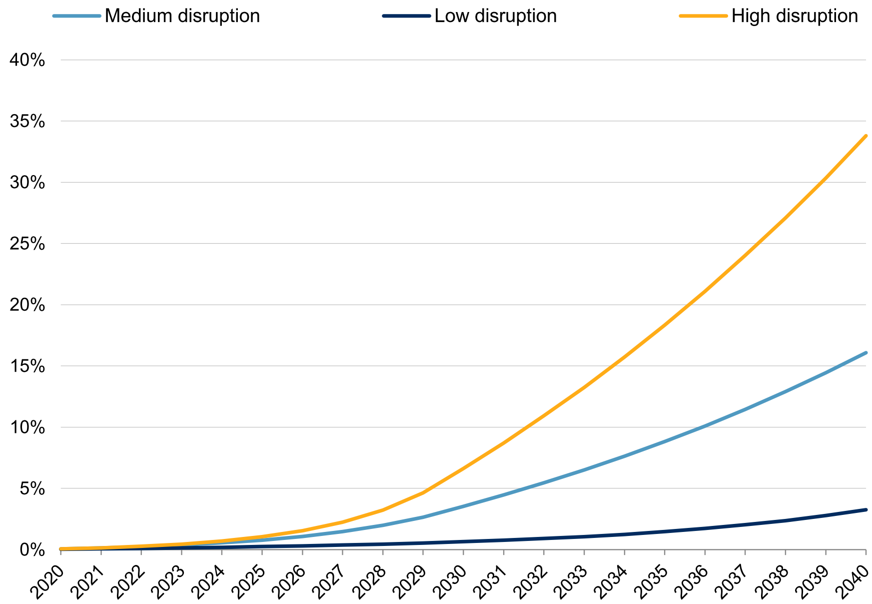


Source: S&P Global Ratings.

Chart 5

Autonomous Vehicle Mix (2020-2040) - AV Share Of Total U.S. Fleet

With 270 mil. vehicles on the road today, turning over the U.S. fleet will take decades



Source: S&P Global Ratings.

Table 2

Assumptions Behind AV Implementation In U.S. (SAE Level 4 And 5)

Low vs medium vs high disruption scenarios

	Low Disruption	Medium Disruption	High Disruption
Estimated 2017 U.S. Car Fleet size	270 million at the end of 2017		
Average annual Light Vehicle sales and growth forecast (2020 – 2040)	About 16.7 million or about 1% annual growth rate (our simplified assumption to develop AV sales and adoption rate forecast)		
Scrappage rate (defined as annual vehicles retired from use as a % of light vehicle sales)	Steady at around the last four years (~70%) and no government incentives for AVs	82% based on historical average since 1990	Accelerated due to substantial government incentives for AVs; 95%
L4-L5 Fully AV Adoption: Two Phase Implementation As We See It			
Phase I: 2020 – 2030			
AV Technology			
- Safe and Reliable Technology Advancement	Incomplete to slow	Gradual; accelerated towards the end of the decade	Fast and Complete
- AV Price premium reduction/cost savings from lower fuel costs or insurance	Very Expensive or insignificant costs savings due to nascent technology, no government incentives, and high insurance costs	Expensive with gradual decline in AV prices, low government incentives, and high insurance costs	Marginal Premium with rapid decline in AV prices, high government incentives, and lower fuel and insurance costs
- Government Incentives	None	Low	High
- Electric vehicle technology growth and adoption	Low	Moderate	High
Government/Insurance Regulation and Policies, and Related Infrastructure Development	Slow/Delay	Gradual/moderate	Accelerated
Growth in ride/car sharing	Low to Moderate	Moderate to High	High to Significant
Consumer Acceptance	Limited	Moderate	High
Resultant AV Share of Light Vehicle Sales (i.e. adoption rate) by 2030 (%)	~2%	~15%	~30%
Resultant AV Fleet Share of US Car Fleet by 2030 (%)	<1%	<5%	<10%
Phase II: 2030 – 2040			
AV Technology			
- Safe and Reliable Technology Advancement	Gradual	Fast and Complete	
- Price/cost	Expensive	Declining premium/improving costs savings	
- Government Incentives	Low to moderate	Moderate to high	
- Electric vehicle technology growth and adoption	Slow to moderate	Accelerated	**Continuation of Phase 1**
Government/Insurance Regulation and Policies, and Related Infrastructure Development	Gradual/moderate	Accelerated	
Growth in ride/car sharing	Moderate	High	
Consumer Acceptance	Limited to Moderate	Moderate to High	
Resultant AV Share of Light Vehicle Sales (i.e. adoption rate) by 2040 (%)	~10%	~30%	~50%
Resultant AV Fleet Share of US Car Fleet by 2040 (%)	<5%	>15%	<35%

US Car Fleet Size is calculated as Existing US Car Fleet Size + New Vehicles Sales - Scrappage Rate.
Scrappage Rate means cars retired from use and it is calculated as annual vehicles retired from use as a % of light vehicle sales.
Source: S&P Global Ratings.

AV growth may depend on capturing the ride-sharing economy

As shown, we forecast a very wide divergence between the low- medium-high disruption scenarios. This range reflects the variables in table 2 that influence two key inputs to our U.S. forecast: (1) AVs as a share of light vehicle sales, including assumptions regarding individual vehicle ownership versus joint or fleet ownership of AVs (under a shared mobility model); and (2) AVs share in the overall U.S. fleet, including assumptions regarding the conversion rate of the U.S. fleet to electric from internal combustion engines (ICEs) and vehicle scrappage rates.

Under our medium disruption scenario, we estimate that the SAE level 4-5 AV market share of new light vehicle sales will continue to expand to 15% by 2030 and up to 30% by through 2040s. However, with over 250 million vehicles on the road in the U.S., turning over the U.S. fleet alone would take multiple decades, so our medium disruption scenario projects SAE level 4-5 AVs at less than 5% of the total U.S. fleet by 2030 and around 15% by 2040.

Additionally, we formed different qualitative assumptions to guide our low-medium-high disruption scenarios regarding the pace of change of AV technology, government regulation/insurance and related infrastructure, growth in ride sharing and consumer acceptance. Specifically:

Technology for AVs has been dramatic and we assume differing rates of advancement, economies of scale affecting price of technology and vehicle operating costs, and government incentives. Based on a Victoria Transport Policy Institute study correlating the adoption of autonomous vehicle technologies to other vehicle technologies (airbags, automatic transmissions, navigation systems, etc.), the conclusions were longer-term adaption rates than one might expect. Automakers (OEMs) and regulators will need to address cyber security issues for safety and data protection purposes.

Regulation, insurance, and infrastructure development will develop at different rates and are outside control by OEMs and tech companies. The NHTSA estimates human error causes approximately 94% of accidents and 35,000 fatalities a year, but AVs will require significant regulatory oversight at all levels of government. Insurance companies now have to assess how their standard policies will translate to AVs but some estimate liability under full SAE level 5 automation may follow the car manufacturer rather than the individual, reducing costs. To recognize the full benefits of driverless vehicles will require the installation of smart infrastructure, including expanded telecommunications to provide wireless internet connectivity and mobile network access for continuous vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) capabilities to control things like headways, speed, and accident avoidance. There will be a need for electric vehicle charging infrastructure. According to a October 2017 report by Goldman Sachs, the broader utility industry itself will require more low-voltage distribution including new transformers to prevent overloads, electrification of parking bays, grid digitalization to allow for smart charging, and grid upgrades to support higher loads to occur between 2025 and 2050 (or when electric vehicle penetration reaches between 5% and 25%).

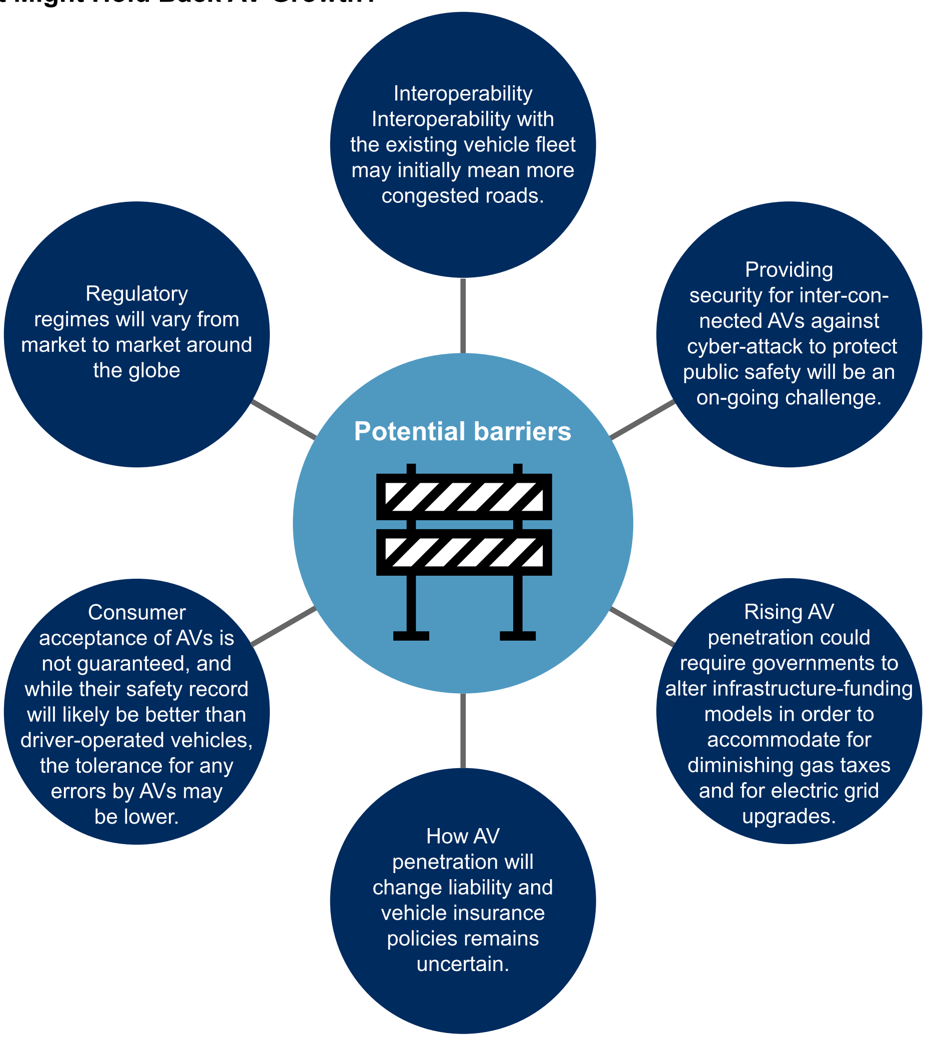
Beyond technology, regulation and infrastructure development, the growth in ride- and car-sharing and consumer acceptance will ultimately drive the growth of AV sales and adoption rate. AVs will likely be first introduced as robo-taxis by TNCs which will operate under a highly regulated and dedicated environment. Growth in ride- and car-sharing will lower the total costs of vehicle ownership for consumers and will further influence the adoption rate of AVs. Some proponents of AVs believe that driverless cars will reduce vehicle ownership by more than 40% and each shared car could replace around 10 or more cars on the road. Some studies are predicting that 25% of global miles traveled by 2030 will be shared and therefore AVs growth would depend on its capture of this sharing economy. However, it remains to be seen if most

Americans will give away vehicle ownership and accept vehicle sharing culture.

Consumer acceptance presents the final but the biggest hurdle in the growth of AVs. Consumer opinion on self-driving cars has lagged the technology development and many consumers may be hesitant to put their lives in the hands of a robot. Moreover, some studies reveal that consumers are not willing to pay extra for electric or autonomous vehicles. Incidents such as fatalities will hurt the technology's image in consumers' minds and lead to a push for more federal and state regulations.

Chart 6

What Might Hold Back AV Growth?



Source: S&P Global Ratings.

More Evolutionary Than Revolutionary Change With Electric Vehicles Being Key

Fundamentally, our key inputs of AV sales and share of U.S. fleet are influenced by the two different approaches of OEMs and other industry participants regarding the viability of AV technology and expected consumer behavior.

At one end is the evolutionary approach or a continuation of existing trends where OEMs increasingly add features into vehicles requiring the driver to take full or partial full control under certain circumstances (SAE levels 1 to 4). Alternatively, the revolutionary approach of other OEMs and technology companies is one where AVs leap directly to full automation (SAE level 5) with no steering wheel or pedals. The basic premise of the revolutionary approach is that a reliance on the driver to take control of a vehicle when necessary – especially after a period of inattention – is dangerous. In our view, the path to AV implementation will include both approaches, likely more evolutionary than revolutionary, but with a roadway operating environment where driver-dependent and fully automated AVs co-exist and slowly gain market acceptance in different regions (urban versus rural, for example) and applications (personal versus commercial) affecting AV sales and overall fleet mix.

Our key inputs of sales and share are influenced by two different industry approaches

The evolution of all-electric vehicles (EVs) also affects our two key inputs. Similar to the evolutionary versus revolutionary approach to AV implementation, OEMs such as Ford and tech companies such as Uber are initially building off a battery linked to ICE hybrid powertrain alleviating range anxiety and resulting in higher asset utilization (less battery charging time). For instance, for autonomous vehicles that target goods delivery or shuttle pooling applications, we believe hybrid powertrains could be relatively more cost effective, due to more advantageous cycle times.

Other OEMs and tech companies like Tesla, General Motors, and Waymo are going the all-electric route as their core business strategy. We believe the trajectory of AVs will track EV penetration as technology improves. Advances in electrical architecture will be needed to provide the power not only for vehicle propulsion but also to perform complex computations to guide the vehicle in real time. Adapting AV technology to an EV, as opposed to adapting it to a hybrid vehicle, would appear to be a more efficient solution, albeit at a higher cost. Moreover, emission regulations are expected to prod conversion to EVs. We see the extent of government subsidies, reduction in battery costs, and advancements in battery density as the important considerations in future AV sales and the fleet mix.

What Will Our Scenarios Look Like?

We see two phases of AV implementation overlaying our low-medium-high disruption scenarios, which describe the pace of change.

Phase 1: 2020 to 2030

We anticipate introduction of fully autonomous vehicles by the early 2020s, but the market will be small, vehicles will be expensive, and there will be limited applications (e.g., some types of commercial trucking, shuttle buses, etc.) and locations (e.g., dedicated lanes, controlled campus settings, certain states, etc.) where they are permitted. The consumer market will grow and be dominated by semi-automated vehicles (SAE levels 1 to 3) with a driver behind the wheel or ready to take the wheel), but we believe there will likely be some fully driverless (SAE level 4) vehicles on the road by 2023.

We anticipate faster implementation of range-limited taxi and last-mile extensions of transit operated by TNCs with some fully autonomous SAE level 5 vehicles and some trucking by 2030, resulting in an increase in urban traffic movements and congestion. This will in turn increase the need for roadway capacity and parking demand, adding complexity to infrastructure planning as urban congestion overwhelms traditional transit.

Phase 2: 2030 to 2040

We see fully autonomous vehicles and shared mobility begin to comprise about 20% to 30% of the urban roadway network. The integration of fully autonomous vehicles (SAE level 5) for commercial use (parcel and long-range trucking) and transit purposes will further expand and we anticipate further growth by mobility-as-a-service companies. As infrastructure develops and market penetration expands, AVs will spread from metro areas to densely populated suburbs and then to rural regions. Advances in V2V and V2I technology will allow for platooning (vehicles traveling closely together, safely and at high speeds) and vehicles traveling with reduced headways, increasing roadway capacity in some corridors. This will involve re-purposing of urban real estate currently used for roadways and parking for other uses, especially under an accelerated pace of transformation (i.e., our high disruption scenario). AVs represent 50% of new car sales by 2040 and about 35% of the total U.S. car fleet.

As infrastructure develops, AVs will spread from cities to suburbs to rural areas

What Broader Changes Might AVs Bring?

From replacing human drivers to changing travel patterns and car ownership patterns, the transition to AVs will usher in broad transformations to transportation infrastructure and society as a whole. While not an exclusive list, we discuss some the major changes below.

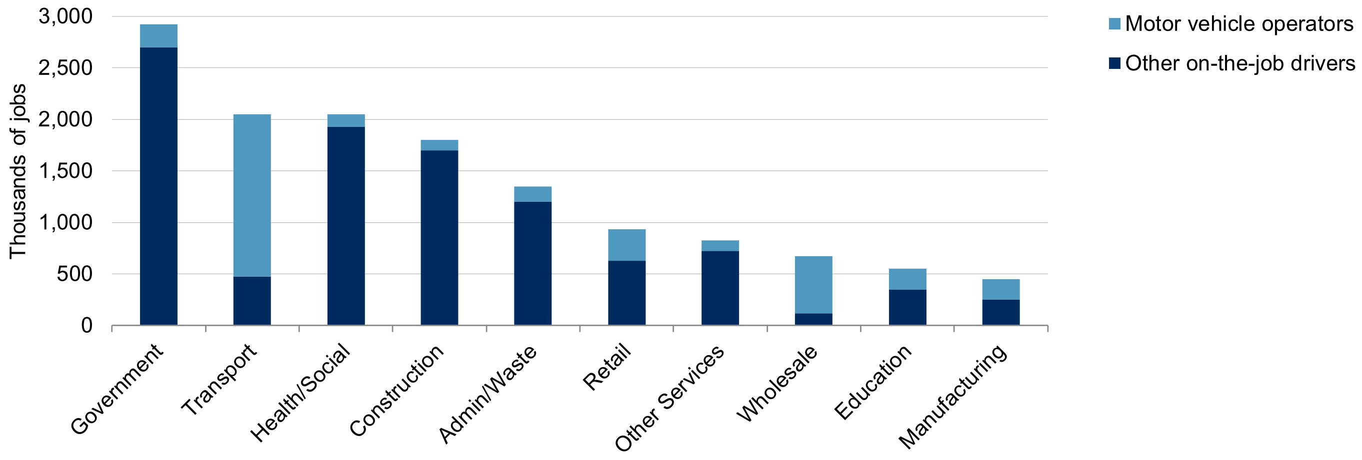
Significant employment impacts are likely down the road. An obvious impact is how AV could displace a portion of the workforce whose primary job is behind the wheel. The U.S. Department of Commerce estimated in August 2017 that 15.5 million U.S. workers had jobs that could be affected by AVs—about 1 in 9 workers. About 3.8 million jobs, mostly in the transportation and warehousing sector, were classified as vehicle operator jobs where AVs would replace the driver. Another 11.7 million workers were driving and also providing or delivering services in the construction, waste management, health care, and government sectors (see chart 7). The American Trucking Association, however, predicts a shortage of 75,000 drivers by 2024 because of the high average age of drivers and a limited employee demographic pool—only 5.8% of truckers are women.

AVs can also displace insurance agents and adjusters, auto body repairers and mechanics as well as unskilled or semi-skilled jobs related to vehicle parking and traffic enforcement.

Chart 7

Driving-Related Jobs By Industry

About 15.5 mil. U.S. workers -- 1 in 9 of all workers -- have jobs potentially affected by AVs



Source: Derived from Economics and Statistics Administration data (2015)

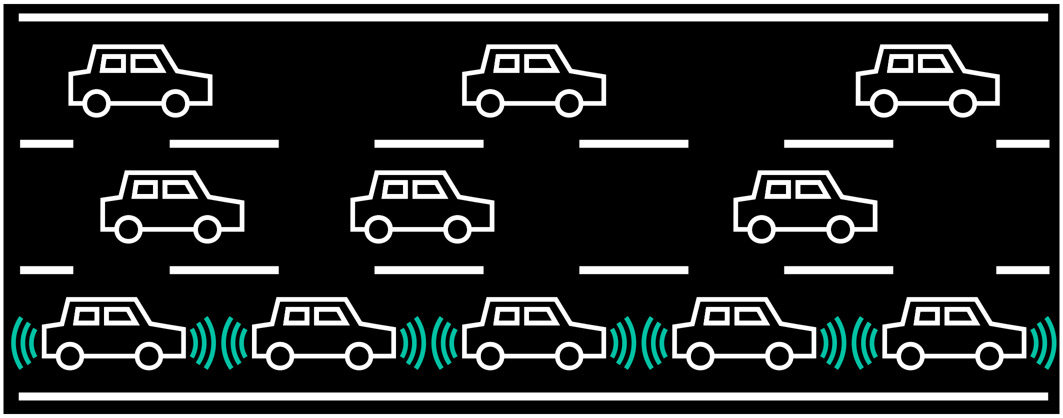
On the other hand, by improving safety or reducing travel times, AVs may complement the functions of workers in some affected businesses and ultimately increase the demand for them. Even with advanced, semi-automated vehicles—particularly for some commercial vehicles carrying valuable cargo (e.g., school buses)—the presence of a human co-pilot will be likely or necessary to handle other portions of the job. Thus, in our view, the wide-scale replacement of sizable portions of the labor market is not imminent and any related impacts on employment will be gradual.

Roadway capacity and travel will evolve over time. The proliferation of AVs will affect travel behavior and traffic patterns. Smart vehicles communicating with other vehicles and roadway infrastructure can use real-time traffic data to anticipate what is ahead, make better route choices, and synchronize speeds to use shorter headways. All of this should result in better use of infrastructure, less vehicle flow breakdown, and less congestion. For example, advanced autonomous safety features promise to eliminate incident-related congestion caused by human error, which is estimated to account for about 25% of all traffic congestion.

However, these favorable effects will not be immediate. Initially, driverless vehicles will have little impact, although operational efficiencies will improve as market penetration increases. The full array of benefits is not likely to materialize until 2030 at the earliest, when a significant share of vehicle travel is autonomous. We expect that lane capacity could increase by up 5% to 7% by 2030 to 2035 with an increase in platooning (see chart 8).

Chart 8

Autonomous Vehicles Will Expand Roadway Capacity
Roadway capacity could increase by 5%-7% with platooning



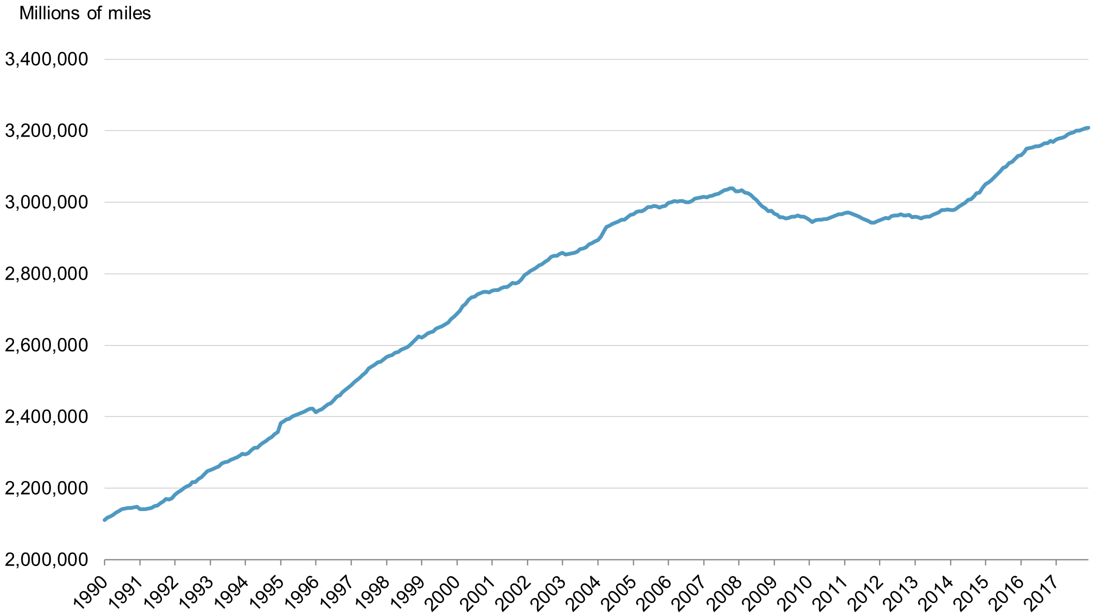
Source: Transurban.

The consensus is that significantly more AVs on the road will mean more vehicle miles traveled (VMT). With the removal of costly human drivers and insurance for TNCs and for some trucking, and the addition of more travelers who otherwise might not drive, like the elderly, we are likely to see a lot more cars and truck on the road. Since 2000, VMT in the U.S. has grown at a compound annual rate of about 0.7%. We expect VMT to rise as drivers become more comfortable with AVs and the vehicles' cost falls. Some studies predict a 5% to 20% increase in VMT when AV market penetration hits 50% (see chart 9).

All told, we expect that passengers will experience more reliable travel times, increased convenience, and reduced stress. They will make more frequent and longer trips as travel becomes easier and less burdensome. Depending on market characteristics, toll facilities and managed lanes could provide a uniquely controlled environment for autonomous vehicles, producing benefits for users and non-toll paying vehicles operating in general purpose lanes. Previously mobility-constrained people will be able to travel in unmanned cars. And people will use their cars more. AVs can lend themselves to continuous operation with on-demand business models, including delivery services, ridesharing, and public transportation. We also expect ridesharing to become more prevalent.

Chart 9

Moving 12 Month Total Vehicle Miles Traveled
AVs are expected to increase vehicle miles traveled as more vehicles take to the road



Source: Federal Highway Administration.

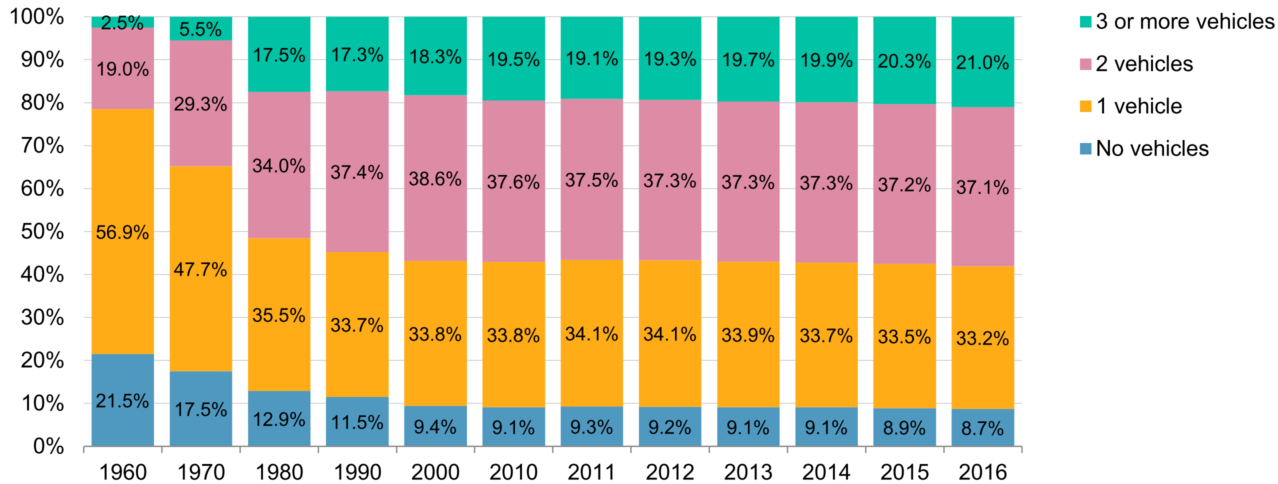
In the very long run, the high penetration of AVs is likely to reduce traffic congestion as utilization of roadways becomes more efficient and traffic flows equalize rather than peak. More immediately, however, the impact of automation is uncertain given the expected uptick in VMT and increase in ride-sharing services. More fundamentally, the key questions are: how will advances in artificial intelligence, and augmented and virtual reality change the workplace and workforce and thus the need for mobility and AVs on the scale being forecast?

Vehicle ownership patterns could change. With more AVs on the road, individual car ownership will face deflationary pressures as driverless cars serve multiple purposes and passengers. We see a wide range of predictions about the share of all U.S. passenger miles likely to be served by fleets of AVs owned and operated by TNCs--from 27% to 95% by 2030. But even some auto manufacturers see declines in car ownership as consumers make rational economic choices. The cost advantages offered by TNCs compared to the annual ownership costs of a vehicle will be attributable to the absence of labor, higher asset utilization, and lower operating costs. There is also the possibility of shared or fractional ownership. However, many people will still want to own a car. Due to these conflicting factors, we believe car ownership will remain stable, potentially with fewer vehicles per household but more households owning cars. U.S. households without a car have gradually declined to 8.7% from 9.1% since 2010. However, the average U.S. household currently owns fewer than 2 cars (with a very low utilization rate of about 4%), falling from 2.05 cars 10 years ago. We believe household ownership trends will remain the same in the near term but decline over time as TNC and the mobility-as-a-service model expands (see chart 10).

Chart 10

U.S. Household Vehicle Ownership

We believe household ownership trends will remain the same in near term but decline over time as TNC and the mobility-as-a-service model expands



U.S. Department of Transportation, Bureau of the Census.

Infrastructure funding model will need to evolve. Another broad impact of AVs will be how the public sector replaces an estimated $251 billion in annual gas taxes, transit fares, tolls, vehicle sales taxes, municipal parking, and registration and licensing fees linked directly to the current model of personal car ownership. At the state and local level, a search for replacement fees and taxes will be necessary to backfill these anticipated declines. In fact, the state legislatures, state regulators and local government officials are where the rubber meets the road with respect to developing and testing new approaches to raising revenue, providing oversight on the operation of TNCs and approving rates imposed on electricity customers.

At the federal level, the current motor fuel and related taxes as a funding source for the Highway Trust Fund--$41 billion in federal fiscal 2017--is being eroded by improving vehicle fuel economy standards. That erosion will continue with more electric vehicles, which purchase little or no fuel. Because of inflation, the 18.4 cent per gallon tax on gasoline enacted in 1993 is worth about 11.5 cents today, and at the current rate of outlays the fund will require another bailout by Congress by 2022.

Governments and taxing authorities will need to find new revenue, with fees based on VMT, or with dynamic tolling. We also have to consider that a portion of transportation-related revenue often supports the general fund of state and local governments, and the loss of transportation-related revenue could hurt state and local services. How changes to travel and commuting patterns will affect urban property values and ad valorem tax revenues is also a significant unknown.

Automated And Autonomous Vehicles: The SAE Scale

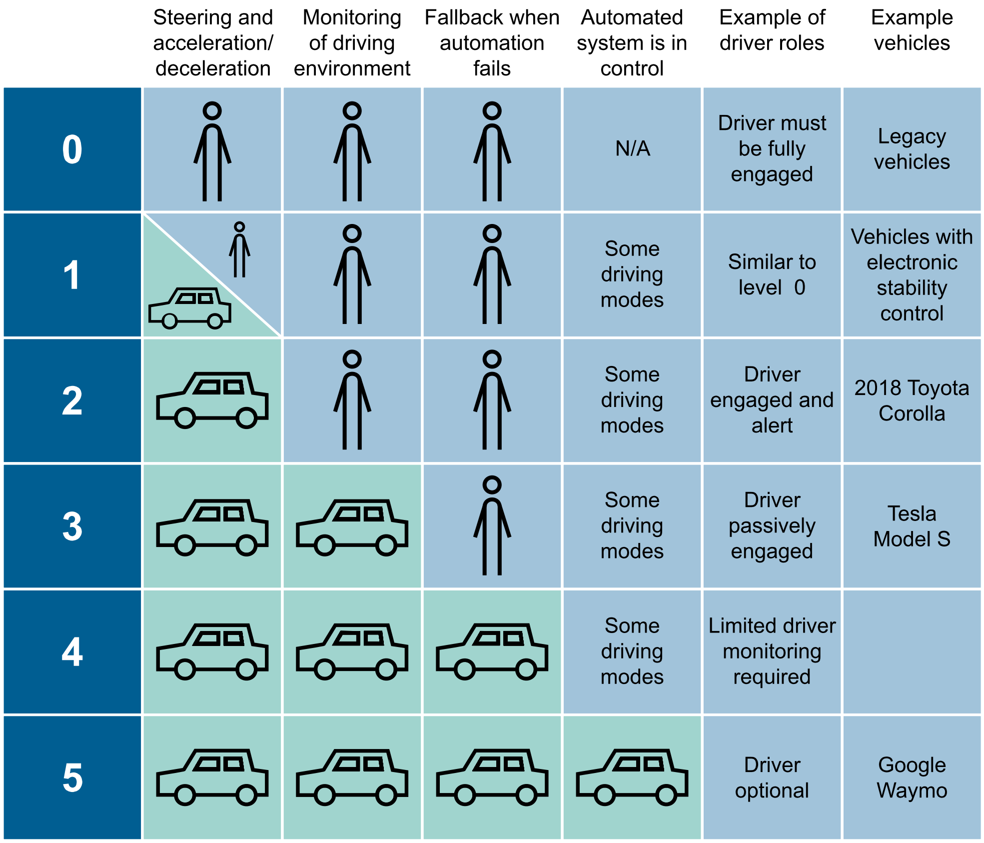
Defining automated or autonomous vehicles has been a moving target. But the industry has come to a consensus regarding the multiple definitions for various levels of automation as defined by the Society of Automotive Engineers (SAE) International, which was adopted by the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) in its Federal Automated Vehicles Policy.

According to the SAE, vehicle automation is defined by six levels (see chart 11). At the bottom, a SAE level 0 car would be a vehicle that has no advanced driver assistance system (ADAS) features and at the top, a SAE level 5 would be a vehicle that is fully autonomous with no expectation that a driver would need to control the vehicle at any time. SAE levels 1-3 are viewed to be semi-automated (requiring some driver input in situations) and SAE levels 4 and 5 are viewed to be fully automated (driverless). As of today, all cars manufactured in the United States after 2013 have been mandated by the NHTSA/DOT to include electronic stability control, which would classify these vehicles as SAE Level 1.

Going one step further, 100% of the 90 cars selected for the "Top Safety Picks for 2017" by the U.S. Insurance Institute for Highway Safety have a collision mitigation system, thus representing at least SAE level 2 automation because they have at least two primary control functions working in unison (collision mitigation and electronic stability control). The conclusion is that SAE level 2 autonomous vehicles are readily available to the market for purchase, with SAE level 3 automation (all safety-critical functions to be automated) right around the corner. Once SAE Level 3 automation becomes a household product, the concept of driving will be rethought.

Chart 11

Society Of Automotive Engineers' Five Levels Of Automation



Source: Society of Automative Engineers.

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