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Enabling the mass adoption of autonomous driving

Lessons from the aviation industry

Contacts

Dubai

Camil Tahan
Partner
+971-4-436-3000
camil.tahan
@strategyand.ae.pwc.com

Gerasimos Skaltsas
Manager
+971-4-436-3000
gerasimos.skaltsas
@strategyand.ae.pwc.com

Nabil Katicha
Manager
+971-4-436-3000
nabil.katicha
@strategyand.ae.pwc.com

About the authors

Camil Tahan is a partner with Strategy& Middle East, part of the PwC network. Based in Dubai, he is a member of the industrial manufacturing and automotive practice in the Middle East. He has over 12 years of experience in strategy consulting focusing on transport, logistics, aviation, and aerospace. He has advised leading government organizations and large corporations through various transformation programs, growth strategy definitions, sector strategy, governance, and privatization.

Gerasimos Skaltsas is a manager with Strategy& Middle East. Based in Dubai, he is a member of the industrial manufacturing and automotive practice in the Middle East. He has worked with transportation authorities and leading airlines in the U.S., the GCC, and Europe mainly focusing on strategy formulation, policy setting, cost reduction, and operating model design.

Nabil Katicha is a manager with Strategy& Middle East. Based in Dubai, he is a member of the industrial manufacturing and automotive practice in the Middle East. He has worked with transport policymakers in the GCC mainly focusing on developing sector strategies to improve the sector's performance and safety.

EXECUTIVE SUMMARY

Autonomous vehicle (AV) technology promises tremendous gains in terms of transport efficiency, safety, and an improved urban environment. Yet, despite significant advances in recent years there has been no mass adoption. Considerable barriers remain because there are no established communication protocols and infrastructure standards. Even countries at the leading edge of the automotive industry lack national frameworks. Liability regimes are undefined, and safety and security concerns are widespread. Governments, manufacturers, and other AV stakeholders need a path through this mixture of technological promise and legal and regulatory uncertainty.

A promising avenue is for AV stakeholders to adopt the mind-set and approaches that civil aviation has used to resolve similar issues. Already, most commercial aircraft operate with significant autonomy in almost all phases of flight. The next generation of air-navigation technology, currently in development, will bring civil aviation closer to full autonomy.

In particular, there are three areas in which AV stakeholders can learn from civil aviation:

- *Infrastructure*: Civil aviation uses a range of physical and technological infrastructure to maintain extremely high safety standards, such as multiple redundant-communication and collision-avoidance systems.
- *Regulations*: International authorities set principles and regulations that airlines, original equipment manufacturers (OEMs), and air traffic control providers abide by. There are consistent, agreed standards for interoperability and safety, which encourage consumer demand.
- *A public–private ecosystem*: Aircraft fly autonomously because of a plethora of back-up systems — including pilots, airline operating control centers, air traffic control facilities, and other public- and private-sector bodies. There is also a network of public and private stakeholders responsible for operations, monitoring, and maintenance.

Governments, manufacturers, and other stakeholders can use the experience of civil aviation to develop the policies, regulations, infrastructure, and business environment that will enable the safe, effective, and widespread introduction of AV technology.

TABLE OF CONTENTS

THE FUTURE OF TRANSPORTATION IS COMING 03

STRONG MOVES BY INCUMBENTS AND NEW MARKET ENTRANTS 04

STEEP BARRIERS TO WIDESPREAD ADOPTION 05

LESSONS LEARNED FROM THE AVIATION INDUSTRY 07

THE FUTURE OF TRANSPORTATION IS COMING

Autonomous vehicle (AV) technology is advancing rapidly. Allied Market Research projects that the worldwide market will grow from an estimated US$54 billion in 2019 to $557 billion by 2026.[1] At the end of 2018, 74 cities around the world had autonomous vehicle pilot programs under way. The number has increased since then, and for good reason. AVs have the potential to transform the transportation industry, making it far safer and more efficient than the current system of driver-controlled vehicles. The technology could also have broad effects on society at large, radically changing the notion of car ownership, where people work and live, and how vehicles are designed and evaluated by consumers. The Covid-19 pandemic and the need for social distancing with contactless interactions has accelerated mass pilot programs of AV technologies, with a number of public and private organization around the world using AVs for the transportation of passengers, medical supplies, food, and parcels.

However, technology is only one aspect of an autonomous transportation network — and likely not the greatest barrier to adoption. Governments need to sort through issues such as changes to infrastructure and regulations. OEMs and telecom companies will need to collaborate on communications standards. Insurers will need to rethink liability in a vehicle accident. Also, consumers will need to embrace the technology, primarily by believing that it is safe.

These are challenging issues, but they are not new. Indeed, the commercial airline industry may have the answers. Today, commercial aircraft operate mostly through automated systems. The next generation of avionics and air traffic control technology will bring the industry one step closer to full autonomy. In that way, the airline industry offers critical lessons for how AV technology may develop, and how government policymakers and other stakeholders across the AV ecosystem should properly prepare for the gradual introduction of the technology.

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STRONG MOVES BY INCUMBENTS AND NEW MARKET ENTRANTS

OEMs and new players such as technology companies are investing heavily because AV technology is developing so fast. Automakers have recognized the large-scale shifts needed to prepare for a future with pervasive autonomous technology on the roads. Toyota has invested $1 billion in the Toyota Research Institute, and Hyundai has pledged $1.7 billion to AV research and development.[2] Other companies have focused on technology acquisition: GM spent $0.6 billion to acquire a start-up called Cruise Automation that focuses exclusively on autonomous cars.

Some OEMs have forged partnerships with technology companies, such as Daimler's arrangement with Bosch, and Hyundai's partnership with Cisco. Others have joined forces with each other. BMW and Daimler created a €1 billion ($1.12 billion) partnership to develop a number of autonomous vehicle–related services.[3] Ford and Volkswagen have partnered to invest in autonomous driving technology, with VW investing $2.6 billion in Ford's Argo AI initiative.[4]

At the same time, technology companies are bringing their expertise to the automotive industry.[5] Alphabet's subsidiary, Waymo, is moving into a 200,000 square-foot manufacturing space to install its driverless system into partner cars.[6] Apple recently revived its AV research activities through its purchase of Drive.ai. The company is also testing Light Detection and Ranging (LIDAR) and sensor technologies on a fleet of Lexus SUVs.[7] Ride-sharing companies have reinforced their commitment to AVs. For example, Toyota, DENSO Corporation (DENSO), and the SoftBank Vision Fund (SVF) will invest $1 billion in Uber Technologies Inc.'s Advanced Technologies Group. The investment, in a newly formed corporate entity, aims to accelerate the development and commercialization of automated ridesharing services.[8]

Technology infrastructure companies have AV initiatives under way, as well. Qualcomm, Intel, and Nvidia are all developing chipsets that can handle the data-processing requirements of AV operation, and Cisco is leveraging its networking capabilities to enable the kind of high-capacity data streaming that emanates from vehicle sensors.[9]

STEEP BARRIERS TO WIDESPREAD ADOPTION

Despite the recent initiatives, there are significant barriers to drivers embracing AV transportation, and they go beyond the in-vehicle technology. Consider communications standards, which will need to provide a single, universal means by which autonomous vehicles can interact with each other, the road, pedestrians, and remote networks (*see "Dueling communications standards"*). Governments will also need to update and standardize physical infrastructure.[10]

- Lane markings will need to be redesigned with different materials and capabilities, allowing LIDAR systems to help AVs maneuver safely in different weather and light conditions.
- Road geometry could change, with narrower lanes that increase traffic volume, or with standardized turn radii to aid AVs in approaching at optimal speeds.
- Current road signs with text-based information will become far less relevant, used only by active drivers and pedestrians, and will instead need to be adapted so that AV sensors can detect them.

Similarly, regulatory frameworks need to be revamped for AVs as they were originally designed for driver-based vehicles. This effort has only just begun. Current efforts are under way in markets around the world; however, many of them have focused on the scope of testing that companies can conduct on public roads. China, Germany, Japan, the Netherlands, Singapore, Sweden, the U.K., and the U.S. have led regulatory efforts to promote safe testing of AVs.

Some countries have taken a clear leadership position in terms of regulation. For example, Singapore has founded a dedicated center to simulate road conditions, develop testing requirements, and help establish international standards.[11] The government has also designated three districts for companies to pilot autonomous buses and shuttles. Similarly, the U.K. has passed a law requiring insurers to cover claims when cars are using automated technologies.[12] The U.K. is keen to be a leader in the AV space, with the government wanting fully self-driving vehicles on the road by 2021.[13]

These are a patchwork of efforts that represent the initial steps toward a solution. Other countries are much further behind. In the U.S., for example, laws regarding liability in the case of an accident vary from state to state, impeding a national adoption framework.

In the absence of clearer rules regarding the operation, regulation, and insurance of autonomous vehicles, consumers are going to be concerned about safety. This applies even though AVs are statistically likely to be far safer than driver-operated vehicles because they remove the inherently human component of operator error. As a result, consumers are looking to governments for strong oversight over the development of AV technology. Across geographic regions, at least half of all consumers surveyed wanted "significant oversight" in terms of government involvement.[14]

Dueling communications standards

To operate safely, AVs need to communicate with their environment, including other vehicles, pedestrians, infrastructure, and remote networks. Collectively, this entire set of communications is referred to as vehicle-to-everything (V2X). The data transfer must be high speed and high capacity, unfailingly reliable, and standardized across stakeholders. For example, a buffering lag in data transmission at 85 kilometers per hour could be fatal. Currently, there are three competing communications standards for AV systems.

Dedicated short-range communications (DSRC)
DSRC uses low-latency, short-range wireless networks, with the ultimate goal of creating a large-scale network that enables communications between vehicles and roadside access points or other vehicles. DSRC was built specifically for V2X communications and is championed by the U.S. Department of Transportation, making it the current emerging standard for V2X communications in that country.[15] However, the U.S. federal government has not mandated DSRC nationally, which is unlikely to change in the near future. Short of that requirement, OEMs are unlikely to include DSRC technology on their cars in the U.S. market.

Cooperative intelligent transport (C-ITS)
C-ITS is the effort parallel to DSRC under way in Europe, with parameters set by the European Telecommunications Standards Institute, an independent body.[16] The version officially adopted by the European Commission is called ITS-G5.[17] As with DSRC, the goal of C-ITS is to unify the efforts of member states in developing low-latency, short-range wireless communication networks on roadways, and make them interoperable through continent-wide standards. Proponents of C-ITS argue that the technology can be quickly put in place and then supplemented by future 5G technologies.[18] Opponents cite C-ITS' aging technology and argue that it will prevent the development of a seamless European market.[19]

Cellular vehicle to everything (C-V2X)
A late entrant into autonomous intelligent transport systems, C-V2X achieved standardization in mid-2017 and relies on existing mobile networks (4G/LTE and 5G in the near future).[20] This allows it to capitalize on existing telecommunications infrastructure. C-V2X offers nearly twice the range of DSRC or C-ITS, with lower latency because it uses mobile cellular service rather than short-range wireless spectrum. 5G technology is being rolled-out in some markets, however, current versions of 5G do not offer its fully anticipated benefits, notably the Ultra-Reliable Low Latency Communications connection that is critical for autonomous vehicles.

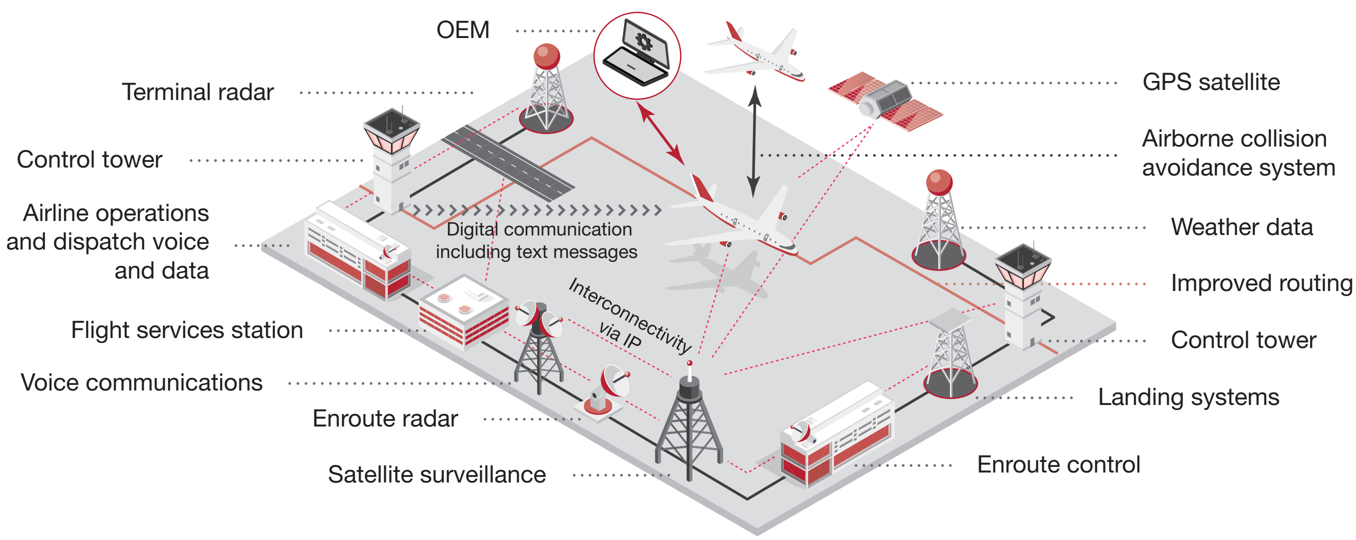
China has been the front-runner in C-V2X development, with China Mobile, Huawei, and Chinese automakers involved in testing. Other OEMs that have committed to C-V2X include Audi, BMW, Daimler, Ford, PSA, SAIC, Tesla, and Toyota. Ford, in partnership with Qualcomm, has already released C-V2X commercial solutions that are undergoing testing. Lobbying efforts are under way in Europe and the U.S. to make space for C-V2X, but in China, the government appears ready to mandate C-V2X for C-ITS and safety-related services. It has set aside spectrum and announced C-V2X trials in six major cities.

LESSONS LEARNED FROM THE AVIATION INDUSTRY

The growing automation in the aviation sector can provide useful lessons for the automotive industry as it seeks to overcome barriers to adoption. The commercial aviation industry has operated with significant autonomy among planes for several decades, via technological standards that are set on an international basis (*see Exhibit 1*). The underlying rationale for automation is the same for both industries: safety is paramount, with efficiency, reliability, congestion management, and other factors secondary though important. What works for aviation, can work for automotives (*see Exhibit 2*).

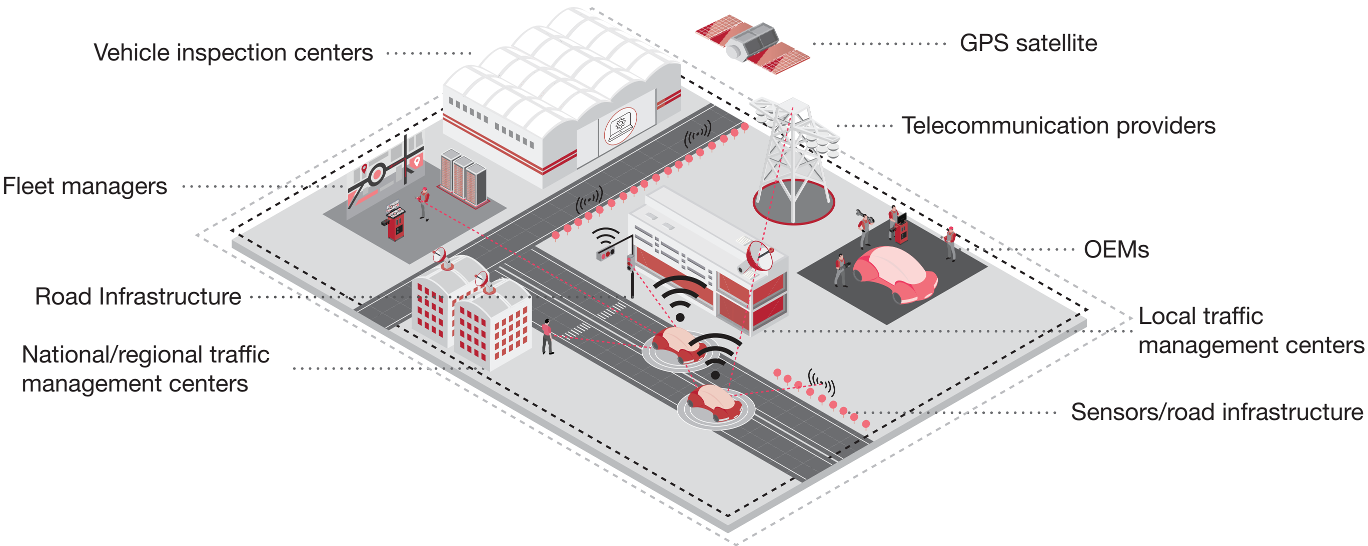
EXHIBIT 1

Components of the largely automated aviation system



Note: GPS = Global Positioning System; IP = Internet Protocol; OEM = Original Equipment Manufacturer.
Source: Strategy&

EXHIBIT 2
Components of an autonomous vehicle network



Note: GPS = Global Positioning System; OEM = Original Equipment Manufacturer.
Source: Strategy&

Just as airplanes do not fly automated without any backup or guidance, AVs will require an entire value chain of providers, infrastructure, and traffic control. Perhaps most important, AVs will require standardized communication systems and regulations that allow for the seamless movement across borders and jurisdictions. This will mean coordinating traffic management across district, national, and international levels. Operators and regulators will also have their own overlapping traffic management systems, akin to government air traffic control centers. Specifically, commercial aviation offers lessons in three key areas (*see Exhibit 3*).

EXHIBIT 3

Summarized lessons from the aviation industry for autonomous vehicles

	Lessons from aviation	Implications for autonomous vehicles
Infrastructure	- Multiple redundant-communication and collision-avoidance systems maintain extremely high safety records - Established communication between aircraft and OEMs (e.g., for engines) allows for early detection of faulty systems - Standardization of tangible and technical assets (e.g., communication protocols) creates market scale and operational efficiencies	- Standardized communication protocols between autonomous vehicles need to be introduced to increase safety standards - Real-time tracking of the vehicles' road worthiness by OEMs and authorities and ability to intervene as will be necessary - Standardization of tangible assets (e.g., lanes, curvatures, road sensors) and communication protocols (vehicle-to-vehicle, vehicle-to-infrastructure, etc.) needed to enable mass proliferation of autonomous vehicles
Regulations	- Commonly accepted principles and regulations set by international bodies (e.g., the International Civil Aviation Organization) support the standardization of the sector and encourage public acceptance - Broad industry collaboration in terms of technology testing and development promotes interoperability and adoption	- Consumers will be more encouraged to adopt AV technology if it is safe and seamless across borders and jurisdictions - Agreement and convergence of regulations and standards across geographic markets are required - Governments and OEMs will need to coalesce around clear standards in areas such as vehicle testing, insurance liability, and cybersecurity
Ecosystem	- Aircraft can fly autonomously because there is a network of public and private stakeholders responsible for operations, monitoring, and maintenance - Stakeholders have clear roles and responsibilities, collaborating seamlessly to provide a plethora of back-up systems	- Implementation of AV technology will require an ecosystem of existing and new public and private stakeholders, including but not limited to OEMs, traffic authorities, telecommunication and data providers, fleet managers, vehicle inspection centers, insurers, emergency services, and cybersecurity firms - New business models will emerge, and current stakeholders will have to adapt to remain relevant (e.g., car subscription model vs. car ownership)

Note: AV = autonomous vehicle; OEM = Original equipment manufacturer.
Source: Strategy& analysis

Infrastructure

Civil aviation uses a range of physical and technological infrastructure to maintain extremely high safety standards, including components on the ground, aboard aircraft, and on satellites. Communication and collision-avoidance systems are all multiply redundant. Communication for the purposes of traffic management happens in zones called Flight Information Regions (FIRs), segments of airspace that are managed by a controlling authority on the ground. As planes travel along their flight path, they move through FIRs and are actively handed from one control center to another, until they ultimately get transferred to an airport's control center. Throughout the trip, an airplane's systems communicate with airline operations, air traffic control, and information management services and satellites. Pilots also communicate verbally.

Similarly, AVs will require an entire suite of redundant tracking and communication systems to allow vehicles to reliably move from point A to point B. Some technologies will be built into vehicles, such as LIDAR systems and transponders. Infrastructure will need to include sensors for AV detection, systems for lane guidance, and various levels of control from traffic monitoring systems.

Another key feature of aviation infrastructure is how planes with different levels of autonomy, different sizes, and different degrees of pilot expertise are able to fly in the same airspace. This is managed through standardized communications, separate allocations of flight space, and other factors. Similarly, AVs will need to operate alongside driver-controlled vehicles, particularly during a transition phase. The change from roads on which there is mainly human driving to fully autonomous will happen gradually. This shift has already begun with the steady increase in automated safety features on cars, such as blind-spot monitoring and lane-departure warnings, and will conclude with having cars that can operate with full autonomy in all conditions and with no driver input.

As AVs are introduced on roads alongside human-driven vehicles, the need for communication standards, protocols, and connected car technology will increase significantly. Short-range communication will be essential to safety due to the unpredictable nature of human driving. Self-driving technology will need to learn as it undergoes assimilation into traffic. A complicating factor is skills erosion. Experience from the aviation industry has shown that the more you take humans out of engagement with the process, the less you make them able to quickly and effectively intervene.[21] Similarly, as people drive less, they will become worse at it, meaning human errors could rise in driver-controlled vehicles during the transition despite the mitigation of improved safety technology. This is another challenge for regulators, who will need to clearly define the degree of drivers' required intervention at each level of autonomy. OEMs should adopt a "human-centric" automation approach ensuring that vehicles have the right sensors and systems in place to validate drivers' level of attention and ability to intervene at any given time. Regulators also should revise their licensing processes, which should be adapted to different levels of autonomy, ensuring that licensed drivers maintain the required skills over time.

Regulations

Public acceptance of technology is critical to its adoption. In aviation, international authorities such as the International Civil Aviation Organization and Eurocontrol in Europe set principles and regulations that airlines, OEMs, and air traffic control abide by. There are consistent, agreed-upon standards for interoperability and safety, and the safety aspect encourages consumer demand.

For example, accident investigations are centralized at a national level, with established industry standards for record-keeping and data analysis. Similarly, the industry broadly collaborates in terms of testing and technology development, which has led to the aviation industry's extremely strong safety record. This kind of collaboration would be challenging in the automotive industry as it is more fragmented, and manufacturers use safety as a means of differentiation. In addition, the communication and physical infrastructure standards discussed above are all determined by regulation, along with requirements for testing, communication, and aircraft management.

Similarly, the AV industry will ultimately require agreement and convergence of standards across geographic markets. Consumers will adopt AV technology only if it is safe and seamless across borders and jurisdictions. In particular, governments will need to coalesce around clear standards in areas such as vehicle testing, insurance liability, and cybersecurity.

A public–private ecosystem

Aircraft fly autonomously because of a plethora of back-up systems — including pilots, airline operating control centers, air traffic control facilities, and other public- and private-sector bodies. There is also a network of public and private stakeholders responsible for operations, monitoring, and maintenance. Similarly, it is highly likely that the implementation of AV technology will require input from an ecosystem of public and private stakeholders. These include:

- *OEMs and self-driving technology providers*: OEMs will develop their own infrastructure to track movement and performance data on vehicles to improve self-driving hardware and software and optimize vehicle operational performance. OEMs will also need to differentiate less on the driving experience of a vehicle, the way that cars are marketed today, and more on the passenger experience, such as seat arrangement and comfort, entertainment options, and other amenities. The U.S. Department of Transportation is already working on regulations for vehicles without designated seating positions.[22]
- *Traffic authorities*: Traffic control rooms will develop from being monitoring centers to active traffic management and control centers, communicating with vehicles and infrastructure through the cloud, and exercising control on movements of AVs for traffic optimization, road safety, and other purposes. For example, traffic control centers can be in charge of routing and monitoring AVs with zoned responsibility, and hand off AVs from one zone to another.
- *Telecommunication providers*: Telecommunication providers will play an instrumental role in the shift toward autonomous transportation. They will have to provide telecommunication networks that enable high-speed and high-capacity, unfailingly reliable data transfer between vehicles and their environment. Moreover, telecommunication providers will need to work closely with OEMs and regulators to standardize the communication protocols at the international level.

- *Data providers*: Map, weather, traffic, and other data providers will have active communication links through cloud-based infrastructure communicating with V2X technology in AVs, while AVs will use the information in real time to take routing and other decisions.
- *Fleet managers*: As autonomous technology reduces the need for privately owned cars, fleet owners and managers — particularly vehicle-sharing companies — will likely play a bigger role. A similar shift has occurred in the airline industry, where half of the world's commercial airline fleet is leased rather than owned by commercial airlines.[23] For this reason, fleet owners should prepare to operate larger fleets and plan for higher acquisition and management costs. They should also set their pricing and leasing strategies in line with increased demand. Technology such as cloud-based infrastructure can help vehicle-sharing companies, ground freight companies, car rental companies, emergency services providers, and similar players to track and control the movement of autonomous fleet vehicles.
- *Vehicle inspection centers*: As the level of automation increases, the AVs' health will have increasing importance on road safety. Vehicle inspection centers will be required to monitor and check periodically, or in real time, a vehicle's state and certify that it is fully functioning in line with all safety requirements.
- Insurers: The insurance industry was able to create aviation insurance that catered to the risks inherent in the business. Insurance companies will need to work closely with regulators on establishment of terminology, clauses, and limits.
- *Emergency services*: Emergency services will have cloud-based monitoring and action mechanisms to manage fleets of autonomous emergency response vehicles and further improve response times.
- *Cybersecurity firms*: In an increasingly sophisticated world, these companies have a unique role to play in the development of the AV ecosystem. Protection of data and secure control of AVs is vital for public adoption. Cybersecurity firms should strive to be at the center point among major stakeholders, including automakers, technology firms, and government officials.

> Governments will need to coalesce around clear standards in areas such as vehicle testing, insurance liability, and cybersecurity.

CONCLUSION

The technology to deliver roads filled with AVs has almost arrived. Visionary governments should facilitate their introduction by learning from aviation and crafting rules and regulations that will deliver the benefits of safer and more efficient transport. Moreover, private stakeholders should rethink their business models to become more relevant and monetize their offering in a very different automotive future.

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