Spaces on Wheels: Self-Driving Cars and the Future of Urban Mobility

SPACE10 REPORT

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Introduction

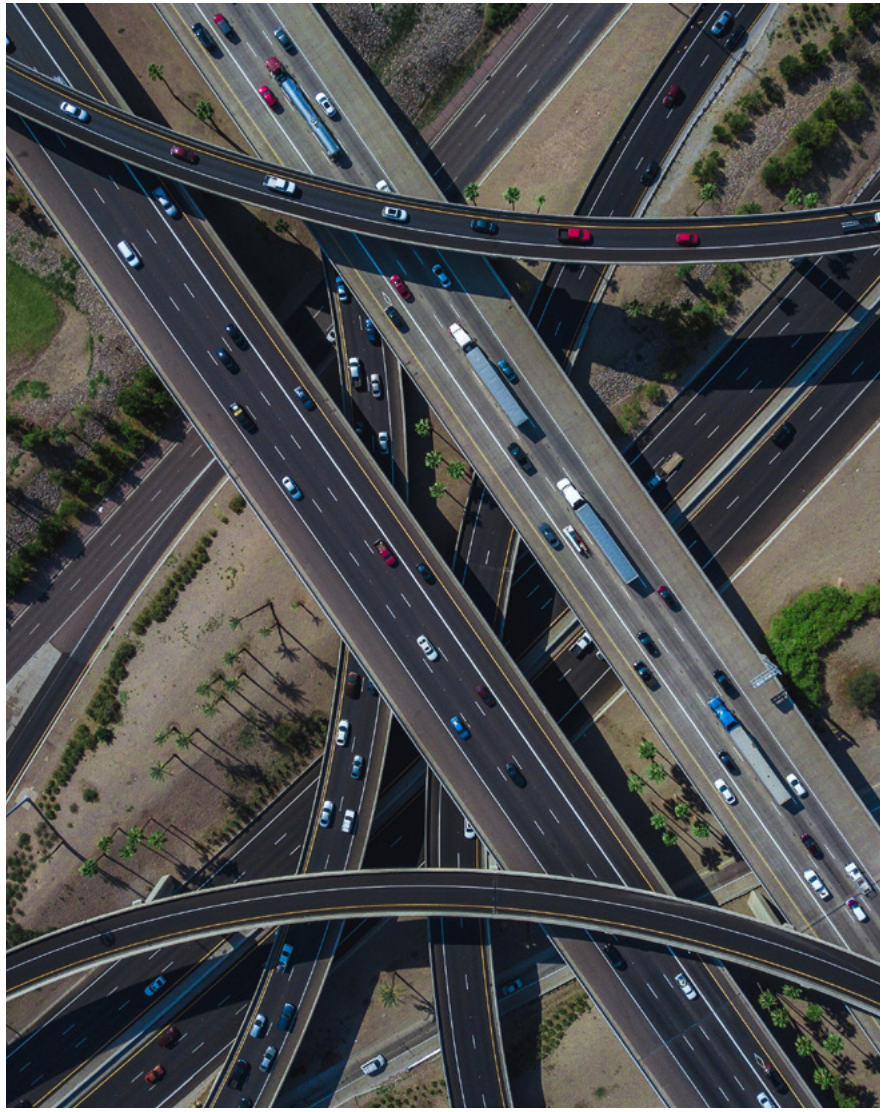
Self-driving cars have long been the preserve of science fiction. No longer. Fully autonomous vehicles (AVs) are on the verge of becoming commonplace in daily life—especially in cities. Most of the world's biggest automobile makers are developing AVs, often in partnership with innovative tech companies. Meanwhile, in many countries, including China and the United States, governments are drafting legislation to permit the use of self-driving cars in cities.

Some experts say we'll have AVs on roads by 2030, others by 2022. Either way, self-driving vehicles will transform not only how we get from A to B, but how we interact with each other and experience cities.

> Indeed, the real potential of self-driving cars isn't in our ability to drive without having our hands on the wheel. It's in what we will be able to do or experience within self-driving cars. Mobility is changing for ever—and life on wheels will never be the same again.

SPACE10 is a future-living lab on a mission to design a better and more sustainable way of life. As part of that mission we reimagine how emerging technology—such as self-driving vehicles—could be made as accessible and as democratic as possible.

To that end, we have created Spaces on Wheels—a playful research project that challenges the traditional idea of the car and explores how we can repurpose it to create a more fulfilling life on wheels. A key part of that project, this report is an A-Z guide to self-driving cars—including the history, opportunities, key questions and forces behind this technological shift.



A Brief History of Self-Driving Cars

1925

Inventor Francis Houdina drives a radio-controlled car through the streets of Manhattan

1939

The self-driving car cements itself in popular culture with the first appearance of the Batmobile

1969

Researcher John McCarthy writes "Computer Controlled Cars"—an influential essay that envisions a future of automatic chauffeurs behind the wheel

1982

The first appearance of the most iconic self-driving car in popular culture: KITT, the super-intelligent, fully autonomous Pontiac Trans Am, in the TV series Knight Rider

1986

German engineer named Ernst Dickmanns became the first person to enable a vehicle to drive autonomously. (A van he suped up with computers, cameras and sensors made its way independently on a university skidpan.)

1987

Pan-European organisation Eureka initiated the PROMETHEUS project, the largest R&D project ever in the field of driverless cars (it received €749 million in funding from member states). In 1995, for one of the project's final presentations, Dickmanns's team drove a semi-autonomous car over 1,700 kilometres, from Bavaria to Denmark, at speeds of over 175 kph.[1]

1995

Carnegie Mellon University robotics researcher Dean Pomerleau develops and road-tests a self-driving car system called Navlab. Though it can control only its speed and brakes, the autonomous minivan travels safely from Pennsylvania to California

2004

A branch of the US defense department launches the DARPA Grand Challenge—a competitive race to foster the development of self-driving vehicles

2007

In a follow-up race, the DARPA Urban Challenge, 11 "robot" cars successfully drive 60 miles alongside human-controlled vehicles

2009

Google starts working on its self-driving car project—which is later renamed Waymo

2011

Nevada is the first US state to pass legislation allowing the operation of AVs on its roads

2013

China announces Made in China 2025, a nationwide plan to position it as a leader in cutting-edge industries, with self-driving cars identified as a cornerstone of the plan

1 Janosch Delcker, "The Man Who Invented the Self-Driving Car (in 1986)", Politico, 24 July 2018.

What are Self-Driving Cars?

Self-driving cars are vehicles that operate with varying degrees of autonomy, using a combination of technologies. The level of autonomy is determined by the SAE Autonomy Scale—the automobile industry's international standard (see page 5). "Self-driving cars" refers to levels 1–4, while "autonomous vehicles" refers to level 5.[2] (We use the same terms throughout this report.)

Because self-driving cars rely largely on software, manufacturers can retrofit old or unused cars to accommodate hardware such as LIDAR, cameras and computers. Which is important: US manufacturers had more than four million unsold vehicles on their books in 2016—a record high—so this emerging technology could alleviate much of the environmental damage caused by the overproduction of vehicles.[3] Today, almost all self-driving vehicles are hybrids or purely electric, and 58 percent of AVs and retrofits are built over an electric powertrain.[4]

Waymo, Google's first build of their self-driving car

2 David Levinson, "On the Differences Between Autonomous, Automated, Self-Driving and Driverless Cars", Transportist, 29 June 2016.
3 Paul Ausick, "GM Has a Huge Supply of Unsold Cars", MSN.com, 14 March 2017.
4 Ryan McCauley, "Why Autonomous and Electric Vehicles Are Inextricably Linked", Government Technology: State & Local Government News Articles, Government Technology, 15 March 2017.

The SAE Autonomy Scale

Level 0
No automation

Vehicle may have cruise control, but the driver must change speed and control steering at all times.

Level 1
Limited driver assistance

Vehicle can control steering and acceleration/deceleration under specific circumstances, but not at the same time.

Level 2
Partial automation options available

Vehicle can match traffic speed and follow the road in ideal conditions, but the driver must pay attention at all times and take control immediately if the conditions exceed the system's limitations.

Level 3
Conditional Automation

Vehicle can drive itself in certain situations, such as in traffic on divided highways, but a driver must be prepared to take control if the vehicle encounters a situation that exceeds its limitations.

Level 4
High automation

Vehicle can drive itself most of the time, but may need a driver to take over in certain situations, such as poor weather conditions.

Level 5
Full automation

Vehicle can drive itself at all times and in all circumstances, with no need for manual control.

How Do Self-Driving Cars Work?

Self-driving cars combine sensors and software to control themselves, navigate their surroundings and drive. Most self-driving systems create and maintain an internal representation of their surroundings based on a wide array of sensors.

Generally, at the core of the software that powers a self-driving car is what's known as a stochastic system. Essentially, it means a self-driving car learns by being exposed to variations and inconsistencies—not only in terms of the inputs it receives but also in the moves it makes (much like a human would). A car using this system needs to practise extensively on real roads—to gain robust real-life experience and learn how to react as safely and as accurately as possible.

Alternative models of teaching AVs to drive also exist. Take MIT's iSee, which applies cognitive science to develop algorithms that try to match and understand how humans interact with the world.[5] The goal is to give AVs "common sense"—ultimately enabling them to learn with less data, more accurately predict the intentions of objects and cars around them, and react more quickly in new situations.[6]

5 See, for example, Nvidia, Perceptive Automata.
6 Will Knight, "Boston May Be Famous for Bad Drivers, but It's the Testing Ground for a Smarter Self-Driving Car", MIT Technology Review, 21 September 2017.

Glossary

A
B

Computer Vision

Originally defined as “the scientific discipline of giving machines the ability of sight”, computer vision is today less about “seeing” as it is about machines learning to identify objects on a large scale in order to understand and contextualise situations.

Control

The act of turning the steering wheel and hitting the throttle or brake.

D
E
F

GPS

(Global Positioning Software)
Self-driving cars use GPS to navigate and identify the beginning and end of a journey.

H
I
J
K

LIDAR

(Laser Illuminating Detection and Ranging)
A unit that enables driverless cars to accurately detect objects up to 100 metres away. (The iPhone X’s FaceID also uses LIDAR.)

Localisation

Sophisticated, mathematical algorithms that enable a car to localise itself within 1–2 cm.

M
N

Optics

High-powered cameras used to identify road markings and traffic signals.

Path Planning

How a self-driving car reaches its destination. Involves predicting the movement of other vehicles, manoeuvring in response and taking a route based on that information.

Processors

On-board computers that evaluate the car’s instruments and needs. They process all the data generated by the cameras and sensors, and learn from the behavior of other drivers, pedestrians and objects around the vehicle.

Q

Radar Sensors

Bumper-mounted units that help the vehicle detect road dynamics such as detours, traffic delays, vehicle collisions and other obstacles.

Sensor Fusion

How data from sensors—primarily radar, lasers and cameras—is integrated and combined to provide a vehicle with a comprehensive understanding of its surroundings.

T
U
V
W
X
Y
Z

Electric Vehicle (EV) Charger

The Electric-Car Question

We tend to think of self-driving and electric cars as two separate types of vehicle, each with its own functions. In fact, the relationship between autonomous and electric vehicles is tightly knit and will likely continue to remain so.

First, computers find it easier to drive electric vehicles than cars that run exclusively on fuel. Second, electric vehicles have inherent advantages in terms of saving fuel and reducing their environmental impact—something that's been touted as one of the potential benefits of self-driving vehicles.

Cost remains a barrier—both electric and autonomous technology are expensive—but researchers predict that the per mile cost of operating these vehicles will drop substantially within the next decade.[7] A 2017 report identified electric power as the likely cornerstone of self-driving technology a decade from now.[8]

7 McCauley, "Why Autonomous and Electric Vehicles Are Inextricably Linked."
8 Norton Rose Fulbright, "Future of Transport: Electric Vehicles and Autonomous Vehicles", November 2017.

When Will We Have Self-Driving Cars?

We know that self-driving cars are coming—but when? Many automobile manufacturers claim they will be able to put level 4 or even level 5 AVs on public roads by the early 2020s. Renault-Nissan Alliance, for example, claims that it will launch 10 types of self-driving car by 2020; Volvo's ambition is to have level 5 AVs on the road by 2021.

In 2017, the US government launched the Public-Private Intelligent Transport Systems (ITS) Initiative/Roadmaps—a programme explicitly aimed at realising level 3 or higher autonomous driving on main roads from 2020. In February 2018, the California Department of Motor Vehicles passed regulations to let AVs with remote human drivers to operate before the end of the year.

In the UK, autonomous shuttle buses, supermarket delivery vans and even some cars are already being tested on private roads. From 2019, France will have the legislative framework in place to allow level 5 AVs on the road.[9] China, meanwhile, expects to have 10,000 AVs in operation by 2020, 90 percent of which will be used for public transport.

9 Jean-Pierre Lagarde, "Voiture Autonome, Le Défi De La Sécurité", Le Monde, 12 April 2018.

However, some experts believe that most projections of when AVs will be on the street are rather ambitious, and intended more as drivers of investment and media attention than as realistic trajectories. Moreover, even if the technology were to develop fast enough to make it possible to roll out level 4 vehicles by 2021, some experts believe that legal and regulatory hurdles may present a significant barrier to AV production and deployment.[10]

In a recent panel discussion involving representatives of the UK's investment, finance, technology, infrastructure, academia and energy sectors, participants envisaged a predominantly EV-driven world, but 10 years from now, and predicted that level 4 autonomy wouldn't become very common until 2027.[11]

10 Hideaki Tomita, "Awaiting the realization of fully automated vehicles: Potential economic effects and the need for a new social and economic design", VOX, CEPR Policy Portal, 17 December 2017.

11 "Future of Transport: Electric Vehicles and Autonomous Vehicles."

Moreover, some experts believe that rebuilding infrastructure and allowing self-driving cars to train in certain areas is one thing—but teaching them the nuances of day-to-day social interactions on the road is another.[12] Consider the following scenario: an AV drives down a one-way road and encounters something blocking its path. How should it proceed? Should it ask the passenger for advice? If so, does it need to know if the passenger has a driver's licence (making the advice valid) or a medical impairment (making it questionable)?

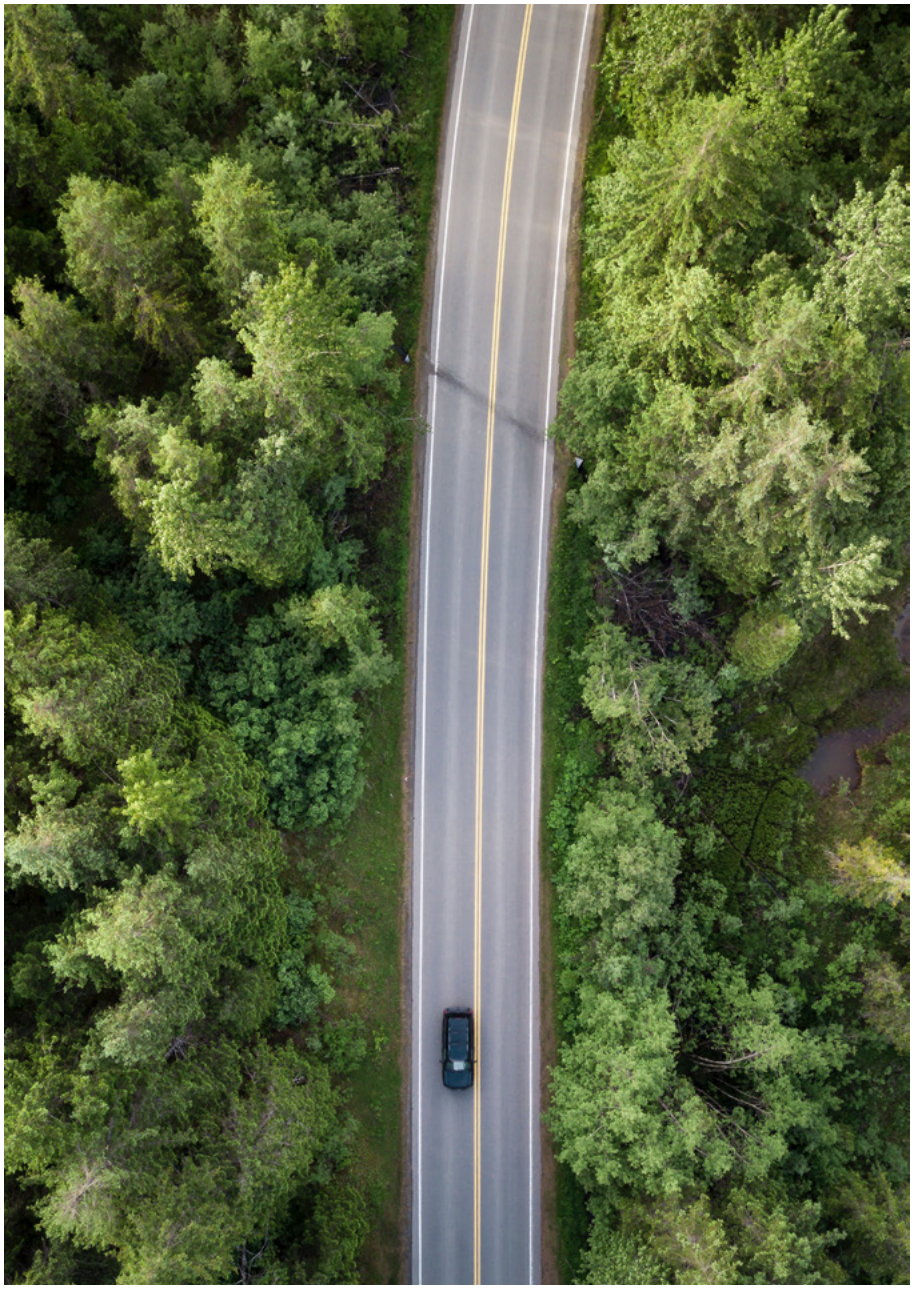
In any case, would the AV be able to determine whether reversing was the best choice, even if it were technically illegal? Or would it get stuck because it's programmed to follow the law at all times? If if reversed, would law enforcement be notified? What would reprimanding a driverless vehicle entail? And if the car chose to stay put, would it cause congestion if other cars followed suit, thinking they could drive through unimpeded, only to get stuck behind each other?

This is just one example of what roboticist Rodney Brooks calls the "edge cases" of self-driving cars—situations in which the vehicles would need to apply highly situational judgement.[13] Though not impossible to teach, this level of logic and common sense may take much longer than the five or 10-year "arrival date" that's typically associated with self-driving cars. In fact, Brooks has written that edge cases "will cause it to be a very long time before we have level 4 or level 5 self driving cars wandering our streets".[14]

12 Rodney Brooks, "Edge Cases for Self Driving Cars", Rodney Brooks's personal blog, 17 June 2017.
13 Ibid.
14 Ibid.

The Benefits of Self-Driving Cars

Environment



According to the US Environmental Protection Agency, more than a quarter of all greenhouse gas emissions come from the transportation sector.[15] Self-driving cars promise to be a lower-carbon method of transportation. Some experts estimate that AVs could produce 20–50 percent less carbon dioxide than fuel-based vehicles. AVs powered by electric energy could further reduce energy consumption.

With ride-sharing expected to play a major role in AV adoption, personal ownership of vehicles could plummet. Some estimate that there will eventually be 80 percent fewer cars on the street, thanks to AVs and ride-sharing. AVs could also eliminate the need for environmentally damaging safety equipment such as anti-lock brakes, airbags and laminated glass.

AVs could produce
20–50%
less carbon dioxide

15 US Environmental Protection Agency, "Sources of Greenhouse Gas Emissions", 11 April 2018.

Society

Autonomous vehicles could increase opportunities and accessibility for people with mobility barriers—including the elderly, disabled people and marginalised groups. A 2015 study by Harvard University found that access to efficient and affordable transportation is associated with aspects of upward mobility such as employment, education and healthcare. It also showed that the longer someone's commute, the less likely he or she is to climb the economic ladder.

Moreover, many experts believe "robo-taxis" will be subsidised, which is significant given that lower-income households on average spend 16 percent of their income on transportation.[16] If autonomous technology were to lower the cost-per-mile and trigger a boom in ride-sharing and efficient public transport, it could increase economic and social opportunities for low-income populations. Autonomous vehicles could offer another benefit to elderly people or those who struggle with physical mobility. Assuming they wouldn't require a driver's licence or physical engagement with the vehicle, AVs could broaden access to transport.

AVs could change how we design cities, too. For example, there may be fewer car parks. Traffic lights and stop signs could disappear: AVs could instead navigate the streets by communicating with each other rather than obeying traffic signs. Malls and shopping centres could cease to exist, too. If an "IKEA on wheels" could come to you, why would you need a physical store?

With the number of car crashes likely to decrease, the demand for auto-repair services, associated medical care and traffic enforcement should fall, too. The US government estimates that medical and legal services as a result of traffic accidents cost about $240 billion a year.

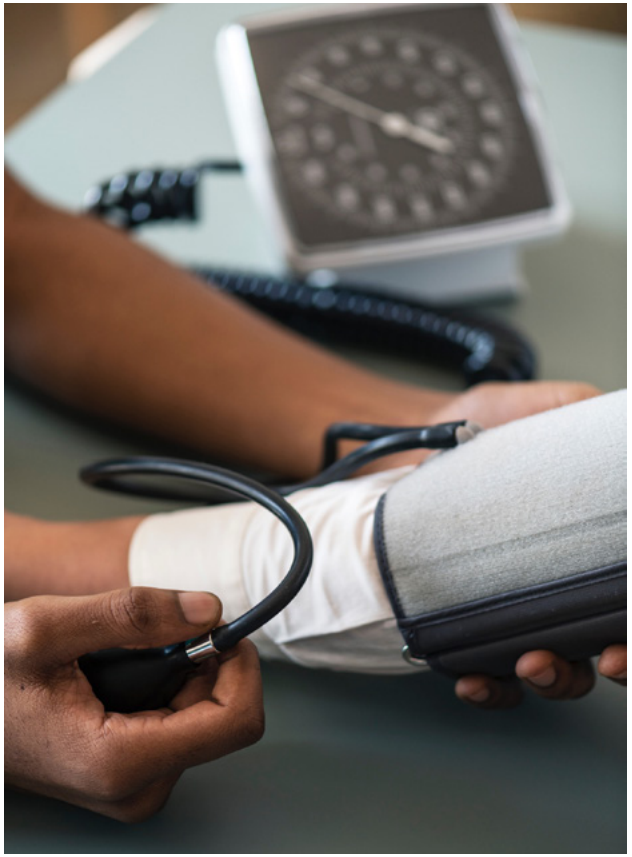
AVs could reduce the cost of traffic-related accidents by

$240 billion

a year

16 Doug Newcomb, "How Self-Driving Cars Could Help the Underprivileged", PCMag UK, 20 November 2017.

Health and Safety



Human error causes more than 90 percent of car crashes. In the US, a third of fatal crashes in 2015 involved alcohol. By eliminating the human factor, AVs could save an estimated 10 million lives per decade. They could also make health services more efficient. With fewer emergency room visits following traffic accidents, hospitals will be able to divert resources elsewhere.

> Better still, a mobile hospital—or walk-in "clinic on wheels"—could come to citizens wherever they are. On average, 25 percent of patients in the US miss medical appointments because they lack access to available or reliable transportation. Mobile hospitals could make a tangible difference to public health.[17] (Marginalised groups, which disproportionately struggle to access health services, would especially benefit.)[18]

AVs could encourage more physical activity, too. Since car ownership is correlated with time not spent walking, if people no longer own a vehicle, they may instead walk to work;[19] alternatively, cycling may become safer because cars will be more aware of their surroundings—something that could position cycling to work as a more appealing option for larger groups of people.[20]

Finally, air pollution killed nine million people in 2015.[21] Because AVs will emit significantly fewer greenhouse gases, they could contribute to lowering the mortality rate due to pollution.

17 Samina T. Syed, et al. "Traveling Towards Disease: Transportation Barriers to Health Care Access", Advances in Pediatrics, U.S. National Library of Medicine, October 2013.
18 Patrick O'Donnell, et al., "Exploring Levers and Barriers to Accessing Primary Care for Marginalised Groups and Identifying Their Priorities for Primary Care Provision: a Participatory Learning and Action Research Study", International Journal for Equity in Health, 3 December 2016.
19 "Future of Transport: Electric Vehicles and Autonomous Vehicles."
20 Jim Sallis, "Driverless Cars Could Be Better or Worse for Our Health – It's up to Us", The Conversation, 2 August 2018.
21 Philip J. Landrigan, et al. "The Lancet Commission on Pollution and Health", The Lancet, vol. 391, no. 10119, 3 February 2018.

Convenience and Efficiency

One of the most promising—and speculative—potential benefits of AVs is the space inside them, combined with the increased "free" time we'll have. AVs could help us travel around town faster. Self-driving cars could reduce traffic congestion thanks to their efficient use of road space. They're also likely to lead to an increase in shared ownership. We could have more "free" time inside self-driving cars, too. Some experts argue that self-driving cars will enable us to be more productive on our way to work.[22] This could lead to shorter hours at the office, and a productivity boost that would amount to $448 billion in annual revenue.[23]

Others see increased opportunities for media and retailers: with augmented reality windows integrated into self-driving cars, we could online grocery shop during our commute, for example. Thanks to a "farm on wheels", we might find it easier to buy fresh, local and healthy food. We could travel more efficiently by getting our shut-eye in a "hotel on wheels". The global hotel industry is worth about $495 billion. A shift towards mobile hotels could lead to a more flexible and personalised mode of transport for each traveler.[24]

"Spaces such as retirement communities, campuses, hotel properties, and amusement parks can all benefit from level 4 autonomy technologies. Autonomous vehicles can take many different forms, including golf carts, wheelchairs, scooters, luggage, shopping carts, garbage bins, and even boats. These technologies open the door to a vast array of new products and applications, from mobility on demand, to autonomous shopping and transportation of goods, and more efficient mobility in hospitals."

—Daniela Rus, Director of the Computer Science and Artificial Intelligence Laboratory (CSAIL) at MIT and leader of MIT's iSee project

Self-driving cars could generate

$448 billion

in annual revenue

22 Gwyn Topham, "Look Ma, No Hands: What Will It Mean When All Cars Can Drive Themselves?" The Guardian, 25 November 2017.
23 Tomita, "Potential Economic and Social Effects of Driverless Cars."
24 "Global Hotel Industry Retail Value 2014-2016", Statista, December 2017.

Concerns about Self-Driving Cars

Employment

According to official US labour statistics, in 2012, at least 1.7 million people worked as tractor-trailer truck drivers, more than 650,000 as bus drivers and about 250,000 as taxi and delivery drivers.

The adoption of self-driving cars by the trucking and freight industries, alongside the emergence of “robo-taxis” and ridesharing, could lead to 2.6 million job losses. If delivery vans and light trucks were automated, too, the number could rise to four million; if management positions related to those driving jobs were rendered obsolete by automation, the number could double again.[25] This would be especially detrimental to immigrant communities, who have long seen taxi driving and other transportation services as a gateway to integration.[26]

Self-driving cars could lead to

2.6 million

job losses in the trucking and freight industries

25 Ibid.
26 Cathy Engelbert, “Driverless cars and trucks don’t mean mass unemployment—they mean new kinds of jobs”, Quartz, 1 August 2017.

Privacy and Security

Most self-driving cars store all their data to enable engineers to reconstruct events and make critical changes. One concern is that AVs could further erode our privacy and function as a "panopticon on wheels"—constantly gathering data that could enable companies to target passengers as consumers. However, some experts believe there is a cap on how much data AVs need to generate,[27] and that laws will be introduced to regulate how they may use public data.

Another concern is that the more digital controls self-driving vehicles have, the more vulnerable they will be to cyber-criminals. If a vehicle were hacked, our personal data could be exposed. In the worst-case scenario, AVs could be used as tools in cyber-warfare. Some experts believe the solution lies in highly distributed computing. Others say law enforcement agencies will have to control, observe and restrict transportation to counterbalance the risk of digital hacking.[28]

"I think people have to recognise that when you get into a Lyft or an Uber, you're essentially in a public space, just like when you get on a bus or a train. There are also cameras there and your every move is being recorded. So when you get into a driverless car that you don't own and you're just paying a service fee, what should be your reasonable expectations of privacy? We certainly need regulations and laws. For this, we depend on the government to basically say what data the companies running AVs can collect."

— Marshall Brown, Director of the Princeton University Center for Architecture, Urbanism, Infrastructure and Founder of the Driverless City Project

27 Benedict Evans, "Cars and Second Order Consequences", Benedict Evans's website, 29 March 2017.
28 Geoff Nesnow, "73 Mind-Blowing Implications of a Driverless Future", Medium, 9 February 2018.

Health and Safety

One of the biggest hopes of self-driving cars is that they will reduce road injuries and fatalities. However, some experts cast doubt on these promises because they assume perfect implementation.[29] If a glitch or software failure were to happen, would a driver be able to take control of the wheel? Or would our driverless future deem that possibility unnecessary?

According to a 2017 report, bicycles are the most “difficult detection problem” that AVs face. However, solutions are being developed. For example, in early 2018, Ford, Tome Software and Trek Bicycles teamed up to produce a bike that can communicate its position and intentions to an AV and vice versa. Waymo has also been working on cyclist detection technology.

There’s a question mark, too, over how self-driving cars will affect our health. Besides deadly crashes and pollution, cars kill people because they sit in them for too long, instead of using healthier forms of transport such as walking or cycling. Too much sitting and not enough physical activity contributes to chronic diseases such as diabetes. In fact, more than 90 percent of the negative health impacts of cars derives from their role reducing our physical activity and exacerbating chronic disease.[30]

29 “The Ultimate Guide to Autonomous Self-Driving Cars”, Automotive Technologies, 2016.
30 Sallis, “Driverless Cars Could Be Better or Worse for Our Health – It’s up to Us.”

Culture and Lifestyle

Some fear that AVs will change our social habits, much as the smartphone did. For example, will we still look out of the vehicle when we're passengers? Or will we browse websites on our augmented reality windows? Will we spend more time socialising with our friends and family? Or will we spend more time inside our AVs, tempted by all the entertainment options at hand?

What impact will self-driving cars have on city traffic? Services such as Uber and Lyft have purportedly made street traffic and congestion in cities like Boston considerably worse.[31] If ride-sharing only increases with the advent of self-driving cars, how will that affect traffic? Then there's the question of walkability. Some experts fear that the further and faster AVs enable us to travel, the less walkable our cities will become and the more urban sprawl we'll see.

31 Steven R. Gehrke, et al., *Fare Choices: A Survey of Ride-Hailing Passengers in Metro Boston. Metropolitan Area Planning Council*, 2018, pp. 1–17.

Public Sentiment

Public sentiment is hard to ascertain, and varies according to demographics. However, in a 2017 survey by MIT AgeLab and the New England Motor Press Association, a smaller percentage of respondents expressed interest in full automation compared to the previous year. And some 48 percent of respondents said they'd never purchase a car that completely drives itself—largely because they don't trust the technology, think it is unsafe and worry about losing control.

Still, in a global survey conducted by Ipsos, 58 percent of respondents said they were curious about AVs, with 30 percent implied they couldn't wait to use them.[32] Indian, Malaysian and Chinese respondents seemed most excited about the prospects of AVs (in that order, too). German, French, American, English and Canadian respondents were most likely to say they'd never use an AV.[33] The least enthusiastic respondents reside in countries with traditionally high levels of concern about privacy and security issues.

In fact, in general, the majority of people seem to take privacy seriously when it comes to AVs.[34] A study conducted by USENIX found the majority of people are uncomfortable with the idea of AVs using recognition, identification and individual tracking, and 54 percent of people would spend over five minutes using an online system to opt out of identifiable data collection.[35] However, according to the AAA Automotive Engineering and Industry, 20 million more Americans would trust a self-driving vehicle to take them on a ride compared to a year ago.

According to the AAA

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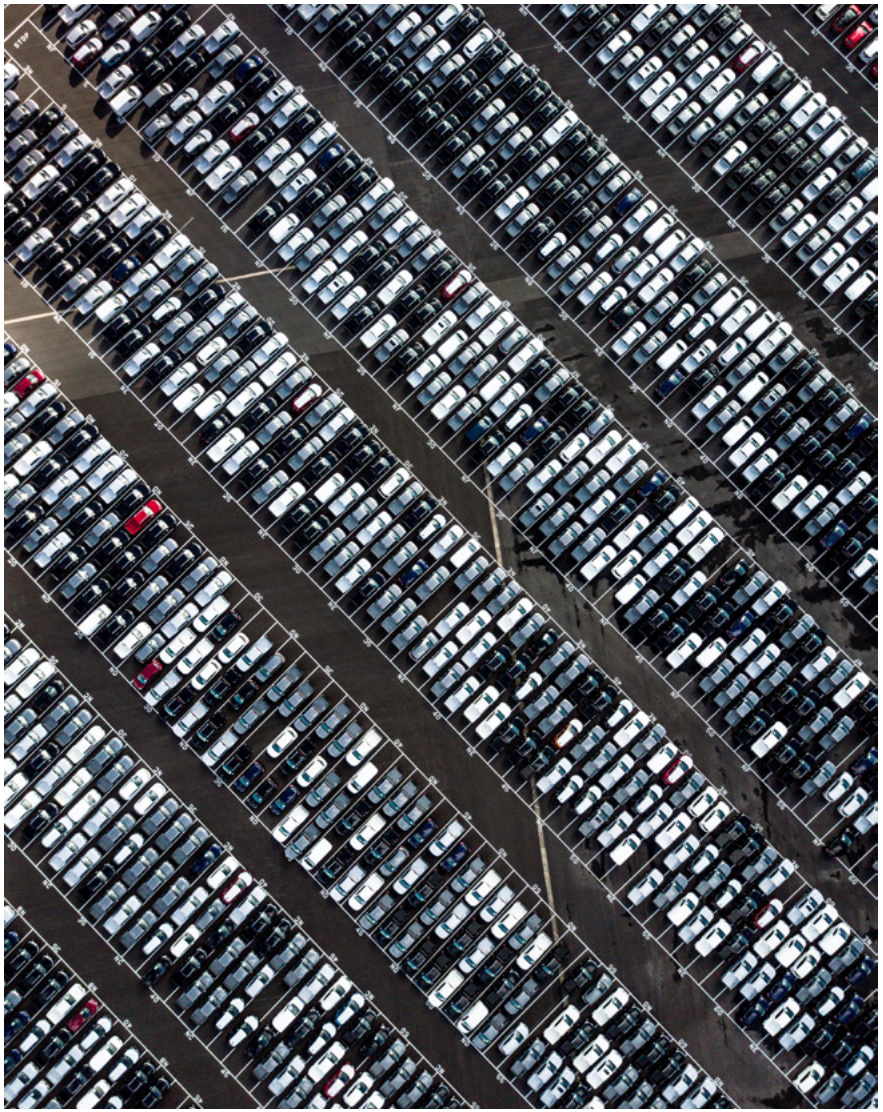
would trust a self-driving vehicle compared to a year ago

32 Chris Jackson and Mallory Newall, "Most Global Consumers are Intrigued by the Idea of Self-Driving Cars", Ipsos Public Affairs, US, 29 March 2018.
33 Ibid.
34 Ibid.
35 Cara Bloom, et al., "Self-Driving Cars and Data Collection: Privacy Perceptions of Networked Autonomous Vehicles", paper included in the Proceedings of the Thirteenth Symposium on Usable Privacy and Security, Santa Clara, CA, 12–14 July 2017.



Commercial Opportunities

Some people say AVs are “the next great media channel”.[36] Take drivers who spend an average of 48–60 minutes behind the wheel per trip;[37] integrate technology such as augmented reality windows,[38] and suddenly you have a car that acts as a hotspot for interaction, entertainment and information. This would position entertainment and gaming companies as the most likely winners, along with online retailers, local businesses and the travel industry.[39]

> For example, what if you were commuting to work on a cold, rainy day in April, and your AV suggested travel deals for a holiday in southern Europe in June? What if an AV were driving you to your next destination while you’re on that holiday and, knowing that you often visit wine websites, suggested stopping at a nearby vineyard?

36 Thomas Bloch, “The Next Great Media Channel Is the Self-Driving Car. Will Brands Be Ready?” Adweek, 30 October 2017.
37 Tanza Loudenback, “Study: Adding 20 Minutes to Your Commute Makes You as Miserable as Getting a 19 Percent Pay Cut”, Inc., 23 October 2017.
38 Eric Adams, “Think Self-Driving Cars Are Around the Bend? Time for a (Virtual) Reality Check”, The Drive, 22 December 2017.
39 Topham, “Look Ma, No Hands: What Will It Mean When All Cars Can Drive Themselves?”

As these scenarios are not far-fetched, they may enable businesses of varying sizes to have an easier time reaching and converting consumers. And AVs will most likely be a “treasure trove” of data.[40] They’ll process destinations, speed, demographics, weather, traffic conditions and perhaps even passenger biometrics. All of this could enable more efficient precision-marketing for each passenger, and see brands play a more intimate role in the lives of consumers.

In the long term, though, the most exciting opportunity for brands isn’t to offer more targeted ads but to *physically* reach people wherever they are. If you’re craving Domino’s Pizza, for example, imagine booking a Toyota e-Palette to deliver your favourite pie. (California-based Zume, a start-up which gets robots to prepare your pizza for you, even has a patent on a system that allows autonomous vehicles to prepare your order *en route*.)

Similarly, if you move into a new apartment and decide it’s time for a new bookshelf, perhaps you could book an “IKEA on wheels” to visit your apartment and deliver several bookshelves to choose from on the spot. Indeed, companies may one day be able to store their products or services in AVs and deliver them on-demand. This would give them access to a wider consumer base, including people who are unfamiliar with their brand or who live far from their stores. In fact, AVs could be able to connect brands to customers on *their* terms, wherever they may be.

Domino’s Pizza’s autonomous delivery robot called DRU

40 Bloch, “The Next Great Media Channel Is the Self-Driving Car. Will Brands Be Ready?”

Who Has a Stake in Self-Driving Cars?

Automobile makers. Tech firms. Investors. Governments. To date, more than 250 companies are involved in self-driving car development. In fact, the race to roll out an AV has been dubbed “the 21st century gold rush”. According to Intel, AVs and the “passenger economy” will add an annual revenue stream of $7 trillion to the global economy by 2030[41]—and global sales of self-driving vehicles could reach 10 million that year.[42]

41 Aarian Marshall, “Robocars Could Add $7 Trillion to the Global Economy”, Wired, 1 February 2018.
42 Jennifer Bradley, “Will You Need a Driving Licence in the Age of Self-Driving Cars?”, BBC News, 31 July 2017.

Automobile Makers

Alibaba

In early 2018, the Chinese tech giant invested in Xiaopeng Motors, an electric vehicle start-up. A few months later, Alibaba announced that it is in the process of testing self-driving technology that it has developed. The company began its efforts to make urban mobility more efficient in 2016, when it launched an AI-powered “city brain”, in Hangzhou, to reduce traffic congestion and collect data from mapping apps.

Baidu

China’s largest search engine has developed Apollo, a software system for AVs. Unusually, Baidu made Apollo open source, arguing that collaboration will result in more data, better testing and ultimately the faster development of safe AVs. Earlier this year, the Chinese government gave Baidu permission to test cars on 33 public roads in Beijing. The company also aims to to produce level 4 AVs by 2021, in partnership with Chinese automaker BAIC Group.

BMW

BMW says its goal is to get highly and fully automated driving into series production by 2021, even deploying level 4 or 5 cars. The company has a fleet of about 40 cars which can drive using level 4 technology around Munich and California. BMW has employed about a thousand people on its AV research and development team.

Daimler

The manufacturer of Mercedes-Benz cars is considered the European leader in AVs. Its new Drive Pilot system allows the driver to stay in the same lane, maintain a safe trailing distance, and follow the car in front and stop when necessary while in congestion. Daimler is working with Silicon Valley intelligent computing company Nvidia Corporation, which it hopes will result in safe AVs by the early 2020s. Daimler also sees the sale of individual cars being limited to level 3 technology, but is ramping up production for level 5 ride-sharing.

Ford

In 2017, the automobile manufacturer paid $1 billion to acquire a stake in Argo AI, a leading artificial intelligence company that is developing self-driving technology. Since then, Ford has been testing its third-generation Fusion sedan, and plans to deploy self-driving cars with level 4 capability by 2021.

General Motors

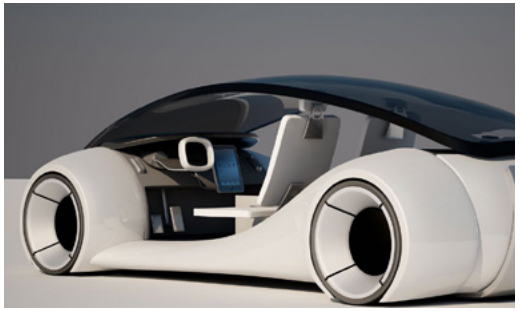
GM has spent $1 billion on developing AVs, has tested its fleet of Chevy Bolts on roads in San Francisco, Arizona and Michigan, and says it plans to launch an autonomous ride-hailing service in late 2019, using a pedalless electric car.

Hyundai

The Korean manufacturer intends to test its autonomous system—dubbed “Future Mobility”—in 2021, and expects to bring a self-driving car to market in 2025. Hyundai is also investing $1.7 billion in AV development, and expects to employ over 3,000 people to work on its self-driving car programme.

Tesla

Elon Musk’s company has rolled out Autopilot for its Model S and X, which are both able to pass other cars and change lanes without requiring the driver’s hands on the wheel. Instead of LIDAR—something most other carmakers and tech companies rely on—Tesla is developing its own imaging system, which it hopes will give its cars a stronger ability to “see”, as well as access to better data. Tesla hopes to deploy level 4 cars in 2020.



Project Titan

Following rumours that it had pulled back its autonomous car initiative, in spring 2018 Apple hired engineers from both Waymo and Tesla. A few months later, it filed a patent for a system that lets cars inform passengers about route decisions. Despite these developments, however, Apple has yet to announce either a release date or concrete plans for Project Titan.

Renault-Nissan Alliance

In early 2018, the Chinese tech giant The France-Japanese strategic partnership claims to have sold more cars equipped with adaptive safety than its rivals, and recently unveiled Symbioz—a concept car that can go 80 mph (129 kph) in full self-driving mode. The alliance intends to release 10 different self-driving cars by 2020.

Tencent

The Chinese tech giant has started to test its self-driving car on public roads. It is also backing ride-hailing conglomerate Didi Chuxing, which has invested in self-driving technology that could result in a service being deployed by 2022.

Tata Motors

In 2017, India’s largest automobile manufacturer sought permission to test its driverless vehicles in the city of Bengaluru. It also announced a long-term partnership with Waymo, which will see Tata integrate Waymo’s self-driving technology into a model of Jaguar. Tata has also launched an electric bus, and employs over 4,500 engineers, designers, scientists and technicians, who work on creating vehicles with self-driving or electric technology.

Toyota

The Japanese car manufacturer was one of the first companies to develop self-driving technology (it installed a self-parking system in the Prius, in Japan, in 2003). The company has invested $1 billion in the Toyota Research Institute, which is dedicated to developing AVs. In January 2018, it unveiled the e-Palette shuttle, which it hopes will be used as a delivery vehicle by service providers such as Netflix and Pizza Hut. In August 2018, it announced a $500 million investment in Uber.

Uber

In 2015, Uber recruited researchers from Carnegie Mellon University to help build its Advanced Technologies Group, which has spearheaded the ride-sharing firm's AV programme. In 2016, it acquired Otto Trucking, whose team included former employees of Alphabet's self-driving car project. The move led to a lawsuit over trade secrets. Following a fatal collision between a self-driving Uber vehicle and a pedestrian in Arizona, Uber suspended AV testing. However, in August 2018, it announced a $500 million investment from Toyota.

Volkswagen

The company's Audi A8 has the most advanced AV on the market today. Using LIDAR, its Traffic Jam Pilot sees the road and allows the driver to go fully hands-free at speeds of up to 37 mph (60 kph). Working with Silicon Valley tech company Nvidia, Volkswagen is aiming to produce a fully autonomous car by 2020.

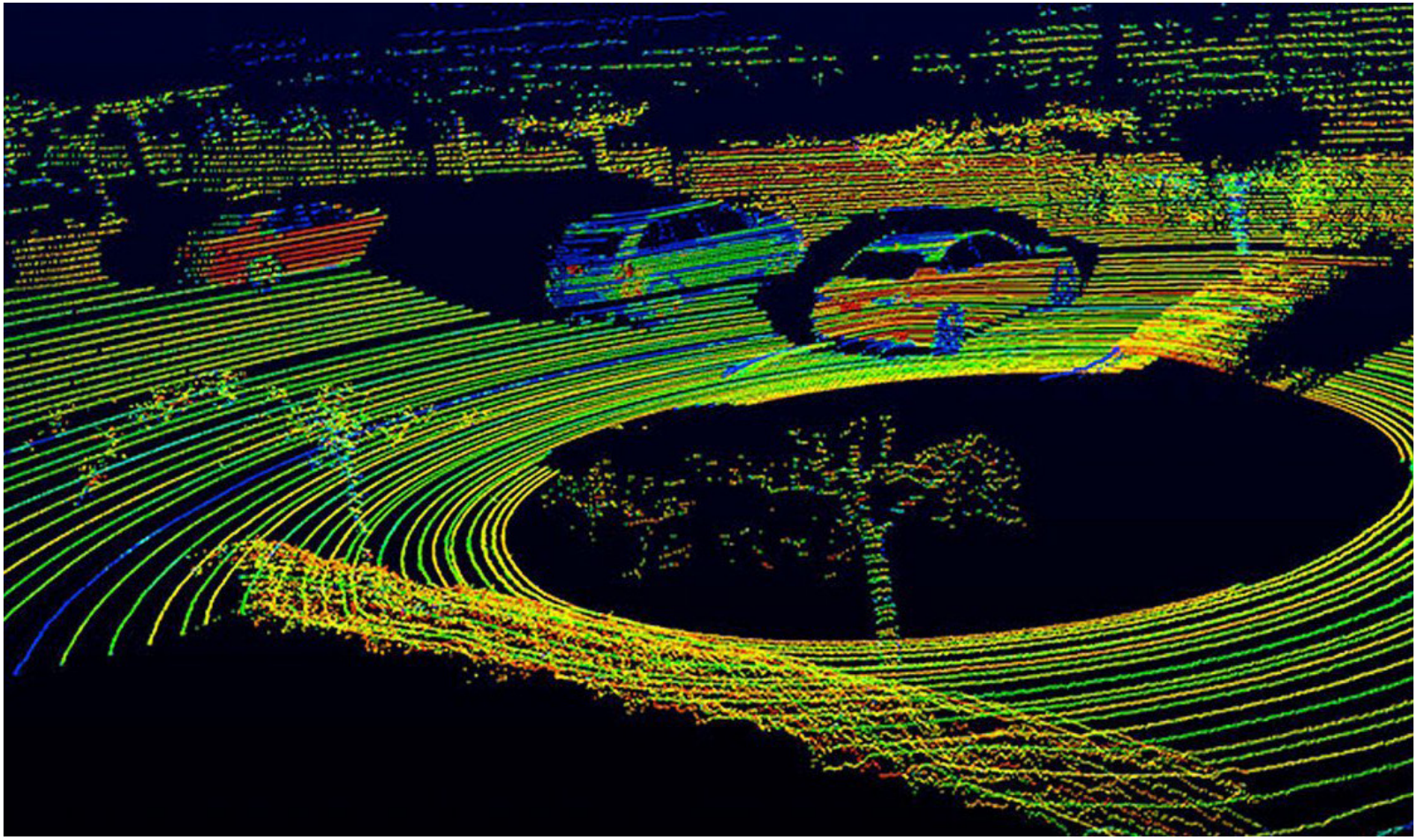
Waymo

A subsidiary of Alphabet Inc. and formerly Google's self-driving car project. It began a public test pilot phase of its latest fleet of self-driving cars in March 2018, and is hoping to deploy a ride-hailing service in late 2018.

Volvo

The company is developing its own-self driving technology—which something it hopes will eliminate all passenger injuries in Volvo cars by 2020. Volvo has also struck a deal with Uber, said to be worth around $1.4 billion, which will see Uber's self-driving technology installed in 24,000 Volvos between 2019 and 2021. Volvo is hoping to deploy a car that can drive fully autonomously on main public roads by 2021.

Tech Companies



Argo AI

An American company that develops robotics and AI solutions to create safe and efficient AVs. In 2017, Ford invested $1 billion in the company. It's led by alumni of Carnegie Mellon University who formerly worked for Google and Uber.

Cerebri AI

A start-up that uses AI to find ways to monetise the driving experience and interactions inside the vehicle. Specifically, it quantifies an individual's commitment to a brand or product and predicts the "next best actions" for a company to take to further convert or strengthen a relationship with a customer.

Cortica

Founded in 2007 as a research project emerging from the Technion–Israel Institute of Technology, the company takes a biological approach to developing AI. Cortica applies an unsupervised learning approach, which enables machines to learn and train without being managed by humans.

EV Safe Charge

A US-based electric-vehicle-charging installation and services company. In early 2018, it launched EV Charge Mobile—the first charging station for level 2 AVs, capable of bringing most cars to 80 percent capacity in under 30 minutes.

Ghostwave

Ohio-based start-up that makes radar sensors that are less prone to interference and so help self-driving cars avoid collisions.

Innovitz Technologies

An Israeli company that's developing solid-state LIDAR with no moving parts. Laser sensors are essential to AVs, but the majority of those being built today have spinning mirrors, which are expensive and fragile. LIDAR with no moving parts such as Innovitz's would solve this problem.

Mighty AI

A Seattle-based start-up that gamifies AI training and crowdsources it. It provides training data as a service, which enables businesses such as automobile companies to acquire the data sets they need to build effective AI software.

Mobileye

An Israeli company that develops vision technology for advanced driver-assistance systems (ADAS) and autonomous driving. It counts 27 automobile manufacturers as partners and has tested its technology in over millions of driving miles.

Neteera Technologies

An American start-up working on a Terahertz sensor that combines micro-radar, LIDAR, software and algorithms, and which enables AVs to scan their environment.

nuTonomy

A spin-off from the Singapore-MIT Alliance for Research and Technology, nuTonomy is a software company working on a full set of technology for powering a driverless vehicle. Bought by automotive supplier Delphi in October 2017 for $450 million, it recently received approval to test a fleet of "robotaxis" in Boston.

Nvidia Corporation

The US company develops hardware for personal computer graphics and AI, mainly for the gaming, professional visualisation, data centre and automotive markets. However, Nvidia has increasingly focused on self-driving cars via a long-term partnership with Daimler. One of their products is NVIDIA DRIVE—which they have dubbed "a scalable AI car platform that spans the entire range of autonomous driving".

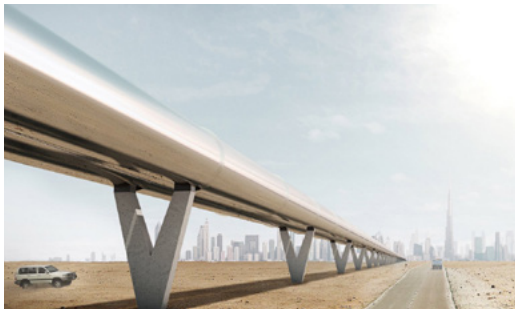
WayRay

A start-up that makes holographic augmented reality technology for connected cars. In 2017, it was named the top automotive startup at Automotive LA. Alibaba has invested $18 million in WayRay to integrate its technology into its self-driving cars.

Brands

Artefact

The Seattle-based studio has developed a self-driving medical clinic that uses a diagnostic ecosystem called Aim. Powered by AI, it tracks your health, using automatic monitoring, self-reporting and active testing. Over time, the system gathers enough data about a patient to enable an AV to offer in-depth tests as well as an on-board pharmacy.



BIG for Dubai Hyperloop

The Danish architectural firm BIG has designed a high-speed transportation system for Hyperloop One—an LA-based company aiming to realise Elon Musk's idea of the hyperloop (a sealed system of tubes that enables people to travel through pods at high speed without air resistance or friction). Hyperloop One has inked a deal with Dubai to realise the transportation system; the concept was exhibited in the city in February 2018.

Cabin

A mobile hotel that guests can book in advance and use to take overnight trips between San Francisco and Los Angeles. Marketed as an "'overnight travel experience"', each private cabin comes with all the trappings of a regular hotel room—including on-board attendants around the clock.

Dispatch

A local food-delivery service powered by a fleet of miniature autonomous vehicles specially designed for pavements and pedestrian spaces. The premise is simple: you order online, track your robot in real time as it makes its way to you, and pick up your order on your doorstep.

Dru

Domino's Pizza has created an autonomous delivery robot called DRU, replete with separate compartments that keep food hot and drinks cold. DRU navigates on footpaths while perceiving obstacles along the way thanks to its on-board sensors. Its roll-out date remains undetermined.

Geneva

The Swiss city is testing a system of self-driving public buses, with the goal of gathering data around the economic, logistical and social implications of using self-driving cars in the city. An initiative between local authorities and Geneva's public transport services, the buses are meant to provide information about issues such as user experience.

IDEO

The global design firm has launched “The Future of Automobility” project to conceptualise how we may use autonomous vehicles one day. Ride-sharing underpins the core of its explorations, with an emphasis on offsetting the cost of using a vehicle by splitting the fare between passengers.

Kasita

A start-up developing “mobile real estate” in the form of a portable living capsule. Kasita promises that each capsule takes only weeks to assemble and arrives decked out with the latest smart technology (and necessities such as appliances and a bed, of course). It’s not self-driving, but moving from city to city requires opening your app, scheduling a move and waiting for Kasita’s crane and flatbed truck to move your home.

Moby Mart

Launched by Chinese start-up Wheelys, Moby Mart is a 24-hour grocery store on wheels, run entirely by AI. Moby hopes its mobile food-delivery model will increase access to fresh food for rural communities. As of March 2018, Moby has been beta-testing in Shanghai.

Nuro

The start-up has created a self-driving car meant for urban logistics such as same-day grocery delivery. It has partnered with grocery giant Kroger to deliver food in city centres, but it hopes to expand into dry cleaning and other services that typically exist within city limits.

Robomart

The “world’s first self-driving grocery store” is an app-based service that lets you order goods online and track where they’re going, as an autonomous vehicle brings them to you. Robomart is expected to be deployed in the San Francisco Bay Area in autumn 2018.

7-Eleven

The Japanese arm of the global convenience store chain has partnered with Toyota’s e-Palette to develop a mobile store leveraging the self-driving platform. The e-Palette and its partners, including 7-Eleven, will make its public debut at the Tokyo Olympics in 2020.

Sion

A solar-powered electric car created by Sono Motors. With photovoltaic cells on its roof, sides and rear, Sion can both generate and provide energy: it acts as a “mobile power station” that can power all common electronic devices with up to 2.7 kW—using a household plug.

Starbucks Train Cabin

In 2013, in partnership with Swiss Federal Railways, the US coffee giant kitted out the exterior of a double-decker train carriage with its branding and converted the interior into a Starbucks store, with baristas and wooden tables for passengers. The on-board store could seat up to 50 passengers en route from Geneva Airport to St. Gallen.

Starship

A Silicon Valley start-up building mobile, miniature autonomous vehicles for local delivery services. Starship has already partnered with on-demand delivery service DoorDash to pilot its robots in San Francisco.

Uber Health

Launched in March 2018, the ride-sharing firm's dashboard enables doctors to schedule transport for patients going to and from care facilities. In particular, it lets them book multiple rides and days in advance, and can integrate text messages or phone calls—meaning patients don't need a smartphone to be able to access the service.

UISEE

A Chinese self-driving car start-up that counts the Beijing government as a client. It has collaborated with Guangzhou Baiyun International Airport to test driverless shuttles that can transport passengers between the terminal and parking lot.

About Spaces on Wheels

Spaces on Wheels is a playful research project that challenges the traditional idea of the car and explores how we can repurpose it to create a more fulfilling life on wheels.

It was produced in collaboration with FOAM Studio and Norgram.

Together we have conceptualised and designed seven spaces which we believe could support activities we spend most of our time doing when moving from A to B.

Office on Wheels

Flexible Workspace

In congested cities, an average person driving to work spends 75 minutes commuting. About 30 of those minutes are lost to congestion. This means that over 32 years, the driver will have spent two years stuck in traffic. Office on Wheels, on the other hand, helps people reclaim some of that lost time—whether they want to get a head start on the day's work to free up time for later or get an early meeting in with colleagues.


OFFICE ON WHEELS
OFFICE ON WHEELS

Cafe on Wheels

Coffee On The Go

Studies show that the quality of people's relationships directly influences how happy they are. But in hectic, urban lives, people often have limited time to socialise; it's also been found that the older people get, the less time they spend with friends. Enter Cafe on Wheels—a mobile space which enables people to catch up with a friend over a coffee when they need to keep moving on a busy day.


CAFE ON WHEELS

Healthcare on Wheels

Mobile Treatment

Transportation difficulties are one of the three major barriers curbing access to healthcare, especially for low-income communities. It's known as 'the last mile' problem: health solutions tend to make it as far as medical outposts—but won't reach end users. Healthcare on Wheels solves 'the last mile' problem by getting medical professionals to visit people in need, not the other way around.


HEALTHCARE ON WHEELS

Farm on Wheels

Fresh Delivery

Especially for people in low-income communities, difficulty getting to a store or market that sells fresh, healthy food is a significant barrier to local food access. In contrast, Farm on Wheels brings local food to people wherever they are, while enabling local farmers to expand their businesses.


FARM ON WHE

Play on Wheels

AR Joyride

Augmented reality is set to revolutionise the gaming industry and become the next big educational platform. As the technology advances, it'll increasingly play a role in autonomous vehicles by providing real-time content for the passenger that's intimately tied to the vehicle's surroundings. In Play on Wheels, augmented reality windows enable people to try a new game in AR as they travel, or experience educational content that responds to and reflects their surroundings.


PLAY ON WHEELS

Hotel on Wheels

Urban Sleepover

More people are traveling than ever before. But air travel raises individual carbon footprints faster and higher than any other activity; in fact, the aviation sector is responsible for an estimated 4.9 percent of all human-made global warming. In contrast, Hotel on Wheels is an electric vehicle powered by clean energy which contains all the perks of a traditional hotel room. It takes people to their destinations while they're getting their shut-eye and enables them to reduce their carbon footprint.


HOTEL ON WHEELS
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Shop on Wheels

Pop-up Store

While bricks-and-mortar stores enable retailers to connect with many people, some don't live close enough to retail locations to go there that often. And although online shopping typically lets people buy, it doesn't really let them shop—which is where Shop on Wheels comes in. Shop on Wheels will come to people wherever they are—letting them try, buy and explore on their own terms.


IKEA

The project is brought to life thanks to an app that leverages augmented reality to let users experience what it could one day be like to book a “space on wheels” that could come to them. It will also be an exhibition where visitors can explore each of the spaces via augmented reality.

Learn more about Spaces on Wheels here

Expert Interviews

Marshall Brown

Director of the Princeton University Center for
Architecture, Urbanism, Infrastructure

SPACE10:
What's the biggest flaw with how self-driving cars are being positioned and what's the biggest opportunity?

Marshall Brown:
I think the biggest flaw is that the whole discussion about this new world has been (more or less) led entirely by technologists in the automotive and software industries. The public sector is really far behind, and the rest of society is not involved much at all. I see the issues and opportunities being more cultural than, let's say, technological. I have no doubt that the technical problems will be solved sooner than everyone realises; after all, there's so much money, talent and intelligence going towards solving those problems. With that being said, as an architect and urbanist, I think it's important for us all to recognise that cities are not problems to be solved. The urban environment is not a problem to be solved. So, the issue right now is that most of the people working with the topic of driverless vehicles are trying to problem solve *people*.

The opportunities are that evolution in transportation and technology changes the relationship between space and time. It brings places that are far apart closer together. This we know from history; it's not speculation. So, the opportunities there are myriad. There are lots of potential unintended consequences, but if we focus on the positives, I think there are huge opportunities in terms of equity issues, especially with how people get to work in decentralised urban environments like the one I live in, Chicago. One of the biggest problems in terms of economic justice is just getting people to where the work is located. And public transport, at least in the US, has not been effective at doing that. For example, I see big opportunities in the redefinition of public transportation like we see with companies like Lyft and Uber.

I think there are also opportunities in terms of environmental and ecological issues. If we can leverage this technology to reduce the amount of paved surfaces in metropolitan areas, that could have potentially huge positive benefits. Those are just a couple of concrete examples.

What do you think is the most effective method of getting citizens involved and engaged in the conversation?

That's an interesting question. I think in many ways, citizens have already been engaged in the conversation. What's interesting is that because of the widespread use of mobile devices, we've seen cases where people have been able to vote with their apps. Take Uber: over the past couple of years during which they've been having a lot of problems here in the US—labour and safety issues, for example—we've seen a couple hundred thousands of people at a time start a movement to leave Uber and go to other similar applications. So I think that in many ways, people have already started leveraging their power to vote with their apps.

Of course, that kind of happens after the fact. The more complicated question is how we can get ahead of the curve. The problem in the case of digital technology is that it moves so fast, it's very hard for the average citizen to keep up. And because of that, I think this will be an ongoing challenge that we don't really have the solutions for. I think that all of us are in a position to be really reactive to what's happening.

We've had some incidents recently in the US with these small, electric scooters in cities like San Francisco and Washington, DC. You can rent these scooters using a mobile app. They immediately became a public nuisance, in a sense, because people were leaving these scooters all over the city and in people's front yards. In some cases, broken. And no one saw this new service coming, so there was no way for citizens or even politicians to manage it beforehand. Therefore, they had to react after the fact. Unfortunately, this seems to be a pattern and I'm not sure how to get away from this pattern. At least, not until the public sector gets much more proactive in terms of engaging the tech industries that are pushing these things out into the world.

On that note, what do you think is stopping public bodies from being more involved? Is it the classic issue of getting things done at a snail's pace?

It depends on context. I don't want to generalise because governmental structures are different around the world. But in Chicago and in many places in the US—with some exceptions—risk aversion is actually baked into the system by law. Many metropolitan planning agencies cannot make any recommendations about what to do about driverless technology because they don't have any data on it. That's because they're prohibited by law from making any recommendations about anything for which they have no data. So there's this nasty catch-22: they know they should be doing something but they're hamstrung.

But then I think there are more problematic examples. A year ago here in Chicago, a few city council members got together to try to pass legislation basically banning driverless vehicles from the city. I think this is really problematic: it's counterproductive and frankly a fruitless way of thinking. There's no way to keep driverless vehicles away! So, I think that there's a communication gap between the industries and the public sector. With some exceptions. But the problem is—and we saw it in Pittsburgh, and Arizona recently with the infamous Uber collision—that the municipalities which try to get on the cutting edge and allow these technologies to be tested obviously experience accidents. And then those accidents get on front-page news, unfortunately. It's a kind of "damned if you do, damned if you don't" situation. It's not easy for governments. But around the world, we see different governments getting involved, some less aggressively, some more aggressively. I know in Singapore, for example, they've been on the cutting edge of trying to implement these technologies. I don't think anyone will ever be able to keep these vehicles out.

Recently, on a panel, I asked a gentleman from the Illinois Department of Transportation a question. I simply said to him, "How can you keep driverless cars out of Illinois?" And he confessed that we can't. I mean, we can't even keep people off of their cell phones when they're driving. How would you even spot these cars? That's the challenge.

What do you think of the argument that AVs won't be able to be rolled out unless infrastructure and legislation changes to accommodate them?

I'm not so sure about this argument. There are some tech companies who recognise that as a problem, so they're trying to develop the technology in such a way that driverless vehicles don't rely on massive changes to transportation infrastructure. So you'd embed all the sensory technology in the car as opposed to trying to make the city smart. The point is to make a car that's sentient and can see and think, and I think those tech companies are well on their way to doing that.

But I don't think it's either or: it'll likely be a combination, depending on context. So if you're out in the countryside, there's not going to be a dense, digital infrastructure. But if you're in the city where there's a dense infrastructure of cellular networks etc., then you can manage self-driving vehicles much more carefully. I don't buy the argument that the tech industry will wait for roads to be rebuilt everywhere. I don't believe that based on what I've seen in my travels and in my reading and research.

Can you think of any company that's making a valid effort to envision a future of AVs that's human and culturally beneficial?

I can't say that I've seen that, but maybe because I've focused on the urban environment. But when I was on that panel in Chicago, there was a representative from the tech industry there. And in many ways, our arguments were aligning. He was lamenting that there's a kind of gap between his industry and the public sector which needs to be closed. And I think this attitude has to do with a lot of the discussion that's going on in the tech industry in general right now. They're recognising they've made mistakes and now they realise they need to have more than just coders or engineers at the table. I think that's starting to filter through, but I cannot say that I know of any companies in particular that are on the leading edge of this issue.

It's a space race right now. All efforts are going into making the tech work and making it safe, which are important things. It's kind of like once we get into space, we'll worry about how we'll live there. Once we figure out how to make the tool work and the device, then we'll figure out how he want to use it.

All the energy is going into the area of problem solving. That's fine, but those of us who are interested in problems of values and culture and urban environment and how people live have to get connected into the conversation.

What do you think our urban environments will look and feel like in the driverless future, compared to what you wish they would look and feel like in your ideal scenario?

Again, it's hard to generalise because within our research we've found it's impossible to avoid the fact that the answers to these questions have to be situated. They must be site-specific. The so-called driverless city will not look like one thing. Driverless cities will look different all around the world, just as urban environments do now. Because a city is a cultural superorganism. And so, history, customs, beliefs, politics, laws, civics… all those things play a part. So depending on whether you're in the centre, wilderness, suburbs, etc., how you'll use these devices or robots will vary. And what kinds of spaces we build around them will vary. And what kinds of problems we have with them will vary. What kinds of opportunities, too. So, the ideas we have for them in Chicago or here in America will be different compared to other places.

I think parking is a huge question. It's certainly not true that we won't need parking anymore, although this is an idea that's been thrown around all over the place. In fact, we may need more parking than ever. However, parking may also take up less space. We may be able to park more cars in the same or less space, in a different manner, in different configurations. But again, this is very context-specific.

It's never "either… or". It's always "both… and". Here's an example: in dense, central business districts or urban cores where land is expensive and scarce, a car that can park itself is a great thing. Because then you can send the car anywhere: it'll drop you off and then it'll just go somewhere else to sleep during the day or at night. That's great, especially for European town centres, many of which don't allow cars inside of them. However, the flip and dark side is, where do all these vehicles go? They're gonna going to go to places where the land is less expensive and more abundant. Either the countryside, or poor neighborhoods, or the suburbs. Parking could become some sort of new negative externality, similar to a trash dump. That could be very, very bad. There are always these kinds of situations where you see both positive and negative effects.

One wish I have is for less asphalt. Here in the US, we have asphalt everywhere. Surface parking lots, streets, etc. It's bad for the environment, it's aesthetically unappealing, it doesn't absorb rainwater, it's too hot in summer. If we can leverage this technology to reduce the amount of paved surface by twenty percent, that's a huge positive impact. It really depends.

What do you think we aren't talking about enough or are ignoring when we discuss self-driving cars and their social implications?

There's a lot of worry that this technology could lead to increasing social isolation. I don't believe that. This has always been the worry

every time we've had some new technology emerge, like the telegraph or the internet. The concern is always that people won't leave their house anymore, or won't talk to each other… yet they still do, and in greater numbers than ever. I don't think the technology forces us to do anything. We have to decide what we want our social values to be, and then figure out how to use the tech to get there. We can't take the pressure off ourselves and blame the technology for what's happening in our world.

Historically, greater access to mobility has decreased social isolation, for better and worse. In many European issues cities right now, one of the big problems is tourism. Tourism is mobility. With these technologies, we can only expect tourism to have a boost in the end, because it'll be easier for people to move around. But maybe they'll start going to places they're not going to now and stop crowding places like Barcelona. So it could lead to a revival in certain places that have been harder to access or passed over, like all these little abandoned Spanish and Italian medieval villages I hear about on the news.

But I don't expect self-driving cars to lead to greater social isolation. I don't think that's inherent. I think that depends on us.

What about privacy and surveillance concerns? Do you think they're justified?

We certainly need regulations and laws. For this, we depend on government to basically say what data the companies running AVs can collect. Europe, thankfully, is helping a lot with this issue with GDPR. That's great and we need more of that. When I get into a Lyft or Uber, there's often a camera pointing at me. I don't know what they're recording or using that data for. So the ongoing question is, what are our reasonable expectations for privacy? That's for governments to really work on and to help us with. Tech's business is collecting information and developing an increasingly detailed picture of the world, including us. We have to vote for people who are willing to put limits on that.

I think what people have to recognise is that when you get into a Lyft or an Uber, you're essentially in a public space. Just like when you get on a bus or a train. There are also cameras there and your every move is being recorded. There's a cultural lag that occurs with the introduction of any new technology that we have to get used to. So, when you get into a driverless car that you don't own and you're just paying a service fee, is that a public or private space or some kind of hybrid? And what are your reasonable expectations of privacy?

There's always cultural lag with any new technology. There's been a big cultural lag with smartphones. There's a cultural lag with social networking we're going through right now, both socially and politically. The problem is that the technology is moving exponentially faster so the lag keeps growing.

I think putting values more at the front of the discussion will help. We should say, "These are our values, so how does any new technology match up with our values and goals and dreams?" Any technology that gets introduced that doesn't promote those values or works against them should be judged accordingly. Right now, we judge tech based on what's newer and faster and more convenient. I don't think that's a valid criteria.

Daniela Rus

Andrew (1956) and Erna Viterbi Professor of Electrical Engineering and Computer Science and Director of the Computer Science and Artificial Intelligence Laboratory (CSAIL) at MIT. Associate Director of MIT's Quest for Intelligence Core. Director of the Toyota-CSAIL Joint Research Center.

SPACE10:
You and your team have been workin on a self-driving car project called MapLite. What is it, and how does the method you employ in the project differ from other ways of training AVs?

Daniela Rus:
MapLite enables self-driving cars to navigate on roads they've never been on before using only GPS and sensors. The system combines GPS data (of the kind that you'd find on Google Maps) with information from sensors that are constantly monitoring the road conditions. Together, these two elements allowed us to autonomously drive a car on multiple unpaved country roads in Devens, Massachusetts, and to reliably detect the road more than 100 feet in advance.

Specifically, how do you ensure that navigation that only uses GPS and sensors is safe enough?

We currently use a test site that is closed to other road users for safety reasons. However, as we build up our systems capabilities that may change. For the MapLite research we focused solely on the localisation and navigation aspects of autonomous driving since we believe this system could be smoothly integrated into the many existing approaches for detecting and avoiding other road users.

In the project 'Bringing human-like decision making to autonomous driving', your teams states that "our goal is to create algorithms for autonomous vehicles that incorporate variations in human driver personalities". Why is that important, and how would one go about achieving that from a technical or technological standpoint?

If we want self-driving cars to be a viable global technology, reliance on detailed prior maps is a problem. Today's autonomous vehicles are not able to drive in rural environments where we do not have maps—in other words, on the millions of miles of roads that are unpaved, unlit or unreliably marked.

We're developing new technologies as a first step for enabling self-driving cars to navigate on roads that they've never been on before using only GPS and sensors. Our system combines GPS data—like the kind you'd find on Google Maps—with data taken from LIDAR sensors. Together, these two elements allow us to autonomously drive a car on multiple unpaved country roads and reliably detect the road more than 100 feet in advance.

From what you've seen, what do you think is the most promising technological method of developing self-driving cars that are sentient as well as safe?

Existing systems still rely heavily on 3D maps, only using sensors and vision algorithms for specific aspects of navigation, like avoiding moving objects (i.e. pedestrians and other cars).

In contrast, MapLite uses sensors for *all* parts of navigation, using GPS data only to obtain a rough estimate of the car's location in space. The system first sets both a final destination and what we refer to as a "local navigation goal", which has to be within the view of the car.

The car's perception sensors then generate a path to get to that point, using LIDAR to estimate the location of the road's edges. Our system can do this without physical road markings by making general assumptions about the road and how it will be relatively more flat than the surrounding areas.

What do you see as the biggest obstacle to developing and rolling out safe self driving cars, and how do you think we could overcome it?

In terms of "level 5 autonomy"—that is, autonomy anywhere, any time—we are still some years away, and this is because of both a technical and regulatory perspective.

Some aspects of self-driving are solved, such as driving at low speeds and in low complexity environments. Other parts are more difficult, such as driving in congestion or in rain and snow. The more complex the road situation, the harder it is for an autonomous car. There are also challenges when the road changes since the map was created, like in situation with construction or temporary lane closings.

These are complex issues regarding the use of autonomous vehicles on public roads. At the same time, a form of autonomy that is already deployable now is "level 4 autonomy", defined as autonomy in some environments some of the time. The technology is here for autonomous vehicles that can drive in fair weather, on private ways, and at lower speeds.

Spaces such as retirement communities, campuses, hotel properties, and amusement parks can all benefit from the level 4 autonomy technologies. Autonomous vehicles can take many different forms, including golf carts, wheelchairs, scooters, luggage, shopping carts, garbage bins, and even boats. At CSAIL we are developing prototypes for all these types of autonomous vehicles. These technologies open the door to a vast array of new products and applications, from mobility on demand, to autonomous shopping and transportation of goods, and more efficient mobility in hospitals.

From a conceptual standpoint, the biggest sacrifice in giving up detailed maps is giving up the opportunity to perform through testing like you can with a map-based system, where you can drive over the entire course of the map and verify that the system is working well. For a MapLite system, driving on roads it has never seen before, it becomes more difficult to provide these guarantees. How we might get verification on such systems is still an open question under active research. From an implementation standpoint, we look forward to adding the capability to drive on a larger variety of roads and recognise a range of lane markings and road signs in order to follow complex traffic patterns.

There's a lot of talk about the potential outcomes of self-driving vehicles—increased urban mobility, less congestion, environmental benefits, etc. Of the potential outcomes, which do you think are the most realistic and most positive—and which do you think could have negative consequences?

Imagine if cars could learn how we drive and how to never be responsible for a collision. What if they could become our trusted partners to help us navigate tricky roads, watch our backs when we're tired, and even make our time in the car fun?

In the future, autonomous cars won't just be able to sense the state of the road; they'll be able to recognise the state of the driver. Imagine if your car could tell you were having a bad day and turn on your favorite album. Or imagine if it could talk to your fridge, figure out that you're out of milk, and suggest where to stop on your way home. Imagine if your car knew that you forgot to call your parents yesterday and could issue a gentle reminder and suggest a safe stretch of highway where you could make the call. These are just a few of the possibilities when we bring together cars, computer science and artificial intelligence.

What's next for your lab's exploration in self-driving technology?

Our goal is to further expand the diversity of different road types that it can handle, and ultimately have MapLite be as reliable as mapped systems, but with a much wider range.

What do you feel is the biggest misconception about self-driving cars?

While progress has been significant on the technical side, getting policy to catch up has been an understandably complex and incremental process. Policymakers are still debating the level at which autonomous vehicles should be regulated. What kinds of vehicles should be allowed on the road, and who is allowed to operate them? How should safety be tested, and by whom? How might different liability regimes shape the timely and safe adoption of AVs, and what are the tradeoffs? What are the implications of a patchwork of state-by-state laws and regulations, and what are the trade-offs in harmonising these policies? To what extent should policymakers encourage the adoption of AVs; e.g. through smart road infrastructure, dedicated highway lanes, manufacturer or consumer incentives?