FUTURE AGENDA
Open Foresight

AUTONOMOUS VEHICLES
THE EMERGING LANDSCAPE
An Initial Perspective

Glossary

Abbreviation	Definition
ACC	Adaptive Cruise Control - Adjusts vehicle speed to maintain safe distance from vehicle ahead
ADAS	Advanced Driver Assistance System - Safety technologies such as lane departure warning
AEB	Autonomous Emergency Braking – Detects traffic situations and ensures optimal braking
AUV	Autonomous Underwater Vehicle – Submarine or underwater robot not requiring operator input
AV	Autonomous Vehicle - vehicle capable of sensing and navigating without human input
CAAC	Cooperative Adaptive Cruise Control – ACC with information sharing with other vehicles and infrastructure
CAV	Connected and Autonomous Vehicles – Grouping of both wirelessly connected and autonomous vehicles
DARPA	US Defense Advanced Research Projects Agency - Responsible for the development of emerging technologies
EV	Electric Vehicle – Vehicle that used one or more electric motors for propulsion
GVA	Gross Value Added - The value of goods / services produced in an area or industry of an economy
HGV	Heavy Goods Vehicle – EU term for any truck with a gross combination mass over 3,500kg (same as US LGV)
HMI	Human Machine Interface – User interface between a vehicle and the driver / passenger
IATA	International Air Transport Association - Trade association of the world's airlines
LIDAR	Light Detection and Ranging - Laser-based 3D scanning and sensing
MaaS	Mobility as a Service - Mobility solutions that are consumed as a service rather than purchased as a product
ODD	Operational Design Domain - Definition of where and when a vehicle is designed to operate
OEM	Original Equipment Manufacturer - The original producer of a vehicle or its components
ROI	Return on Investment - Performance measure used to evaluate the efficiency of an investment
SAE	Society of Automotive Engineers – US based professional association and standards developing organization
UAV	Unmanned Aerial Vehicle - An aircraft piloted by remote control or onboard computers
V2V	Vehicle to Vehicle – Wireless exchange of data between nearby vehicles
V2X	Vehicle to External Environment - Wireless exchange between a vehicle and its surroundings

First published September 2018 by:
Future Agenda Limited
84 Brook Street
London
W1K 5EH
www.futureagenda.org

Autonomous Vehicles
The Emerging Landscape

An Initial Perspective

Tim Jones
Richard Bishop
Caroline Dewing
Mark Priest

Contents

Setting the Scene

Imagine a world where pretty much everything moves smoothly, efficiently and securely. People and goods arrive when and where they need to be while making efficient use of available resources. This is a future seen through the lens of the widespread adoption of autonomous vehicles.

We are on the cusp of the transformation of the automotive industry. So much so that Mary Barra, CEO of GM, suggests that we will see more change in the next 5 to 10 years than in the past 50. The sector, which currently has revenues of over $2tn per annum, is expected to reposition its focus from product sales to service delivery and in so doing revolutionise the way people, goods and services move about. This is such a significant shift that some see that autonomous vehicles (AV) will act as a 'catalysing technology' with far reaching social and economic consequences. Much focus is on land-based AV but there is also growing excitement for the sea and air.

Many analysts are working hard to quantify the opportunity:

- BCG sees that by 2030 the shift to 'shared, autonomous and electric vehicles' will account for 25% of all US journey miles.[1]
- McKinsey estimates that up to 15% of all new vehicles sold in 2030 could be fully autonomous.[2]
- Accenture suggests by 2035 as many as 23m AVs will be on the US highways – just under 10% of all registered cars and trucks.[3]
- Goldman Sachs has forecast the global AV market to be $96bn by 2025 and that by 2050 the total annual economic benefit of AV adoption could be over $3.5tn.[4]

Independent of technology availability, it is going to take some time to change the whole vehicle fleet – maybe up to 25 or 30 years.

What is a realistic view of market penetration for AV by 2030?

While there is growing enthusiasm and investment underway, many recognise that, independent of technology availability, it is going to take some time to change the whole vehicle fleet – maybe up to 25 or 30 years. There are just over 1.3bn vehicles in the world today and around 100m new ones are sold every year - so simple replacement with no market growth would take at least 13 years. Add in a projected addition of another 700m vehicles over the two decades and, from launch, some are talking more than 20 years as the minimum for significant change in the total fleet.[5] Others consider that it may be quicker as perhaps we have already reached peak car in the US and Europe. BCG suggests that by 2030 global sales will plateau at around 100m annually and that, by 2035, 30% of the vehicle fleet will be electric and 25% will be autonomous.[6] According to KPMG, by 2030, 75% of the UK motor-park (vehicles in use) will comprise connected vehicles and around 40% will be partially automated, but less that 10% will be fully autonomous. The UK Government has an objective to see fully driverless cars on public roads by 2021.

Recent assessment suggests that initial adoption rates will be *faster* in Europe and the US (20% by 2025) than in Asia (10% by 2025) but *deeper* in Asia later on (75% by 2035) than Europe and US (30% by 2035).[7] A mandate from the Chinese central government is that 50% of all new vehicles sold in China by 2020 must have partial or full autonomous functions.[8] Globally, there are clearly great expectations from AV, but how will this potential change actually occur? If you compare to other transport innovations, automatic transmission took 50yrs to scale, GPS took 35yrs while airbags took 25yrs.[9] Will AV be faster? Will it be slower?

Hype vs Reality

Across the claims and assumptions being made, what is hype and what is reality? Evangelists believe that a shift to AV will eliminate congestion, massively reduce road injuries and deaths, free up billions of dollars' worth of time, optimise transport systems, reduce energy consumption, improve air quality, drive social inclusion, create hundreds of thousands of new jobs and increase GDP. Others have more conservative views and argue, for example, that if the overall ambition is for a cleaner, low-carbon environment then, rather than supporting substantial but uncertain AV investment, a simple approach could be to make it easier for people to walk or cycle round cities. Some even suggest that at the end of the day, the autonomous shift in transportation is really only about increasing traffic density without increasing congestion. Whatever your view, it is certainly the case that AV is currently considered an investment opportunity and is enjoying its time in the media spotlight. Understandably, many want to know what the true picture is and how will this all play out.

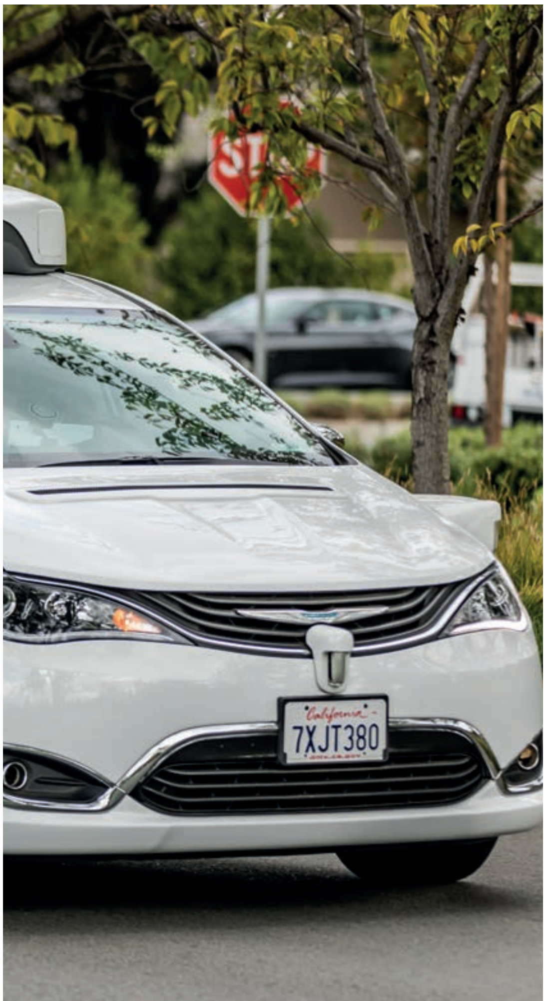
If the overall ambition is for a cleaner, low-carbon environment then, rather than supporting substantial but uncertain AV investment, a simple approach could be to make it easier for people to walk or cycle round cities.

Where We Have Come From

How important will international standards and commonly shared technologies be for AV adoption - or will it be more regional?

Two decades ago, in 1997 the US National Automated Highway System Consortium demonstrated eight cars operating a single platoon on a 12km test track in San Diego. This was a seminal moment in AV innovation. Since then technology has been developing apace. Spurred on by initiatives such as the 2005 DARPA Grand Challenge, there have been many new proof-of-concept developments from a range of organisations including big tech companies like Google as well as major truck manufacturers such as Scania and Volvo.

Everyone it seems now wants a bit of the action. Organisations like Waymo and Tesla have both captured media attention and, significantly, high profile but more secretive companies such as Apple and Amazon are also working in the AV space as are some less well-known but highly innovative firms such as Nvidia, Mobileye and NXP. Auto manufacturers are also keen not to be left out - back in 2008 GM announced it would start testing driverless cars in 2015 ahead of launching in 2018. Ford and Volvo quickly shared similar ambitions and today virtually every OEM has a self-driving division.



Controlled Environments

Away from the highways and cities, autonomous technologies have been in use in a number of off-road applications for a while. AV tech has been developed and tested in many controlled environments. The port of Rotterdam was, for example, the first port in the world with automated guided vehicles.[10] Likewise, in countries such as Australia, the benefits of robotic tractors have been in the headlines for some time with trials now underway.[11] In addition, having launched in 2015,[12] many of the large mining vehicles in Australia are also self-driving,[13] while Volvo has been testing self-driving trucks within a Swedish mine since 2016.[14] Also in Sweden, Einride has launched all electric autonomous logging trucks that are designed to navigate hilly, winding forest roads.[15] Self-driving pods have been in use at various airports including London's Heathrow, with other autonomous vehicles also planned for Gatwick, Paris' CDG and Tokyo's Haneda.

Looking ahead many see airports as the ideal test-bed for new AV technologies. The main airline industry body, IATA, proposes over 40 further use cases for AVs at airports including, for example, baggage handling.[16] However one key point made by experts here is that these automated systems are all operating in essentially fully controlled environments. They are separated from other traffic and so the navigation technology is comparatively basic. While controlled environments have demonstrated some early steps for AV, there are more complex challenges to be addressed on the open road.

Away from the highways and cities, autonomous technologies have been in use in a number of off-road applications for a while.

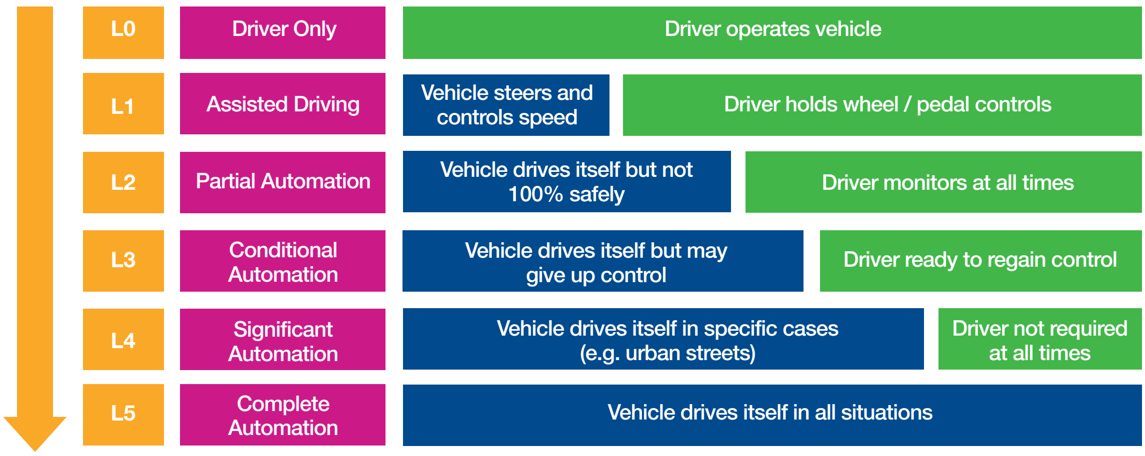
Will controlled environments such as mines, freight terminals and airports be valuable proving grounds for wider AV development?

The Forward View

Several have been mapping the future AV roadmap. The most commonly used definition of automation levels is that of the Society of Automotive Engineers (SAE) which identifies six separate levels (L0-L5) ranging from fully manual to fully automated systems. This classification system is based on the split of responsibility between the human and the computer system, from all human responsibility at L0 to all computer responsibility at L5.

For AV to get real traction it may be necessary to turn transport planning on its head.

Taxonomy for Driving Automation Systems for On-Road Motor Vehicles



Source: https://www.sae.org/standards/content/j3016_201806

Will we see automation equally across all levels or will we by-pass some?

While widely adopted and logical in order for discussing various approaches to automation, some suggest that the 6 levels should not however be interpreted as representing a sequential deployment path. In fact, some levels (such as level 3 in which a human is relied upon for a safety fall-back role) may not have a sufficient business case for deployment.

What sociopolitical forces may accelerate the adoption of full automation?

Having ideas, even building prototypes is comparatively easy; ensuring they become a reality in the wider community is much more challenging, particularly when it involves changing the status quo and dealing with human interactions. Some suggest that for AV to get real traction it may be necessary to turn transport planning on its head and, rather than follow the traditional approach of predicting transport needs and planning accordingly, it may be necessary for nations and cities to deliver a new vision which in turn will drive demand. To do this the key will be to understand what the varied ambitions of manufacturers, technologists and governments are, how they intersect and align and so what can be delivered. This is why a global rather than local conversation is important. Uncovering the bigger picture and recognising different perspectives from multiple regions and companies will provide a richer outlook that can then help guide some of the pivotal decisions that lie ahead.

Furthermore, while it is easy to get distracted by current trends and the short-term needs, if we look ahead, beyond the immediate transportation problems and consider the 20 to 30-year horizon we may see a significant alternative future in which the AV ambition has delivered change across many areas, not just on land, but also on and under the sea and as well as in the skies.

Purpose of this Document

Ahead of a multi-country open foresight programme to explore the emerging AV landscape, this document provides an initial perspective that brings together what is already being shared and discussed. It is based on largely public information plus several expert interviews and is designed to capture existing thinking so that we can challenge current assumptions, debate likely developments in pivotal regions around the world and build an informed, collaborative view of AV over the next 20 to 30 years. The resulting synthesis will be curated into a comprehensive report that will be shared widely to help guide policy development, identify innovation priorities, highlight potential industry partnerships and support investment decisions.

This document provides an initial perspective that brings together what is already being shared and discussed.

Common Misconceptions

Before exploring the ideas that are being proposed, there are two critical issues to highlight that are increasing sources of confusion for AV dialogue. These are the difference between connected and autonomous vehicles and where potential safety benefits may come from.

Connected Vehicles vs. Autonomous Vehicles

Firstly, distinction needs to be made between the increasingly wide range of connected vehicles across the world's transport systems and the less developed, but potentially more impactful, autonomous vehicles of the future. Connected vehicles are not necessarily autonomous, nor are AVs inevitably connected. An autonomous vehicle is one that can fully operate and guide itself without human interaction whereas a connected car is one that shares information with other systems via wireless networks. Most new vehicles are already connected to some degree and many significant innovations which do not require autonomy are already in the pipeline.

Will a change in the vehicle fleet from AV accelerate safer transportation?

There is clearly overlap - for example, improved AV traffic flows will depend on enhanced vehicle-to-vehicle (V2V) connectivity. Connectivity and autonomy are certainly complementary technologies and the end-point may well be that there are vehicles which are both connected and autonomous. Indeed, a number of organisations include the term CAVs (Connected and Autonomous Vehicles) in much of their strategy development. Several leaders in the field are however concerned about the unintended consequences of the focus on this CAV combination and argue that, as many of the benefits from connectivity will occur irrespective of advances made in AV, implicitly linking together the two areas can unnecessarily integrate decisions that may have greater impact if taken separately.

Connected vehicles are not necessarily autonomous, nor are AVs inevitably connected.

Impact on Safety

The second potential area of misunderstanding is the impact that can be delivered for safety. Many are understandably engaged on and by the benefits to be gained from new technology improving the safety of transportation – whether on land, sea or in the air. In 2015 there were 1.25m deaths on the roads worldwide and over 40,000 fatalities in the US alone.[17] Globally road traffic injury is the #1 cause of death among people aged 15 to 30.[18] In many of the world's transport systems the #1 priority is always safety, and this drives most policy decisions both at local and national levels. Safer vehicles and better infrastructure are clearly needed – and progress towards this ambition is variously underway across many regions and sectors.

In 2015 there were 1.25m deaths on the roads worldwide and over 40,000 fatalities in the US alone. Globally road traffic injury is the #1 cause of death among people aged 15 to 30.

In the automotive industry, a frequent assertion is that AV will reduce accidents by 90%. Not only does the OECD see that this claim is untested,[19] but others highlight that most of this may be gained from other sources. For instance, ADAS (advanced driver-assistance systems) have already made a huge impact. As one example, since 2002 autonomous emergency braking (AEB) has been fitted to Volvo XC90s which correspondingly have a zero-fatality safety record. As it becomes standard in more vehicles, Thatcham Research estimates across the UK alone AEB could save over 1,000 lives and prevent over 120,000 casualties over the next 10 years.[20] Other ADAS innovations include adaptive cruise-control, driver monitoring, forward collision warning and lane departure warnings.

Virtually everyone advocating AV claim huge safety benefits, but the majority of these benefits may well come from ADAS.

Proponents are attaching many of the safety benefits from ADAS and other similar developments to AV. For example, a UK industry view is that, by 2030, AV will save 2,500 lives and prevent 25,000 accidents.[21] Does this include the 1,000 lives to be saved by AEB? In the US, BCG suggests that over the same timescale, shared, autonomous, electric vehicles will mean 25,000 less deaths and 3m fewer accidents.[22] There are certainly some distinct advantages that fully autonomous cars can provide – especially overcoming human behaviours such as drunk and reckless driving but these are relatively small. Virtually everyone advocating AV claim huge safety benefits, but the majority of these benefits may well come from ADAS. Many highlight that some safety benefits are incorrectly 'mashed' into AV analysis: "If AV doesn't happen for some reason, ADAS will, and so crash rates will go down anyway." They see that AV is not, in itself, responsible for safer roads and less accidents. Rather it is part of the mix.

What are the distinct benefits from AV that are not already coming from current and future-connected ADAS?

The Benefits of AV

Irrespective of such confusion, momentum behind AV adoption in passenger and goods vehicles is building globally. For many there is growing agreement that AVs will at some point be sufficiently safe, convenient and affordable to displace most human-operated vehicles; will provide independent mobility to non-drivers; reduce the stress and tedium of driving; and maybe become a panacea for congestion, accident and pollution problems. All of this, some say, by 2030.[23] Others suggest it is more likely to be by 2050. However, while there is widespread alignment on some potential benefits, current opinions differ significantly on the socio-economics.

In terms of the big numbers, Goldman Sachs analysis suggests that the global economic benefits from autonomous vehicles could amount to $3.5tn a year by 2050.[24] Although much of this is accounted for by $1.2tn from the estimated 90% reduction in traffic accidents, the rest includes $1.3tn attributed to increases in mobility and $0.9tn for productivity. Geographically this is spilt as $820bn for North America; $900bn in Europe and $1.3tn in Asia.

Excluding safety, is the ROI on other benefits from AV compelling enough for the investment?

Others believe that by 2030 the gains from reclaimed driving hours alone will boost global GDP by $1 trillion.[25] Much of the non-safety savings come from a reduction in travel time due to assumed significant drops in congestion and the cost of travel. Based on the supposition that the typical AV car operating with a shared vehicle system will cover as many as 100,000 miles per year, BCG research predicts that by 2030 the cost of travel will have reduced by as much as 50% and that by 2050 AVs will generate 30bn hours of 'reclaimed time' currently wasted in driving.[2]

The global economic benefits from autonomous vehicles could amount to $3.5tn a year by 2050.

The typical AV car operating with a shared vehicle system will cover as many as 100,000 miles per year.

But, along with savings, AV also presents opportunities for growth. Indeed, EU analysis proposes that it will contribute $17 trillion to the European economy by 2050 and by as soon as 2020 AV will add 0.15% the annual GDP growth rate.[27] A UK industry view suggests that by 2030 AV cars will contribute over £50bn and create 320,000 new jobs.[28] By contrast the UK government veers on the side of caution, claiming that job creation will be net positive and $10bn new GVA will be added to UK economy by 2035.[29]

Some also suggest that AVs will have particular impact in economically deprived areas. SAFE (Securing America's Future Energy) estimates the cumulative benefits for the US alone will have reached $6.3bn by 2050, including a doubling of the typical 10 mile 'reasonable commute' from today while simultaneously enabling the 'driver' to lose less income from dead time.[30] Others see that many of the benefits from AV may come from second and third order impacts that the mainstream are not yet anticipating.

Global economic benefits from autonomous driving ($bn)

	Accident Reduction	Congestion Reduction	Increased Productivity	Additional Drivers	Total Benefits
United States	$249	$7	$195	$331	**$782**
North America	$261	$10	$199	$352	**$821**
South America	$81	$4	$67	$90	**$242**
Europe	$348	$13	$262	$282	**$904**
Asia Pacific	$439	$15	$321	$499	**$1,275**
Middle East/Africa	$74	$4	$72	$114	**$264**
Global	$1,202bn	$47bn	$921bn	$1,337bn	**$3,506bn**

Source: Goldman Sachs Global Investment Research

A key question here is who will be the winners in the race for AV adoption? The widely shared mantra is that mobility is no longer about product, but it is a service. Therefore, we can no longer assess the 'mobility' market by only looking at vehicle sales. With this in mind BCG is warning that value creation is shifting away from OEMS and towards the new tech suppliers.[31] In particular, profit pools are moving towards components, data services, mobility services and connectivity services. This is now driving OEM acquisitions and new corporate ventures, especially in the combination of AV and EV.

A UK industry view suggests that by 2030 AV cars will contribute over £50bn and create 320,000 new jobs.

These are just some of the multiple shifts being attributed to AV deployment. Taking a worldwide view, a central global scenario analysis undertaken by the Transport Systems Catapult in the UK envisages that AV will account for 25% of vehicle sales by 2035, with cars and vans contributing around 95% of this.[32] However, there is considerable uncertainty. The same analysis has a high growth case for AV accounting for 84% of global vehicle sales and a low case of only 8% - quite some spread. Within this, total global market value for the central case scenario quadruples from £5bn in 2020 to £20bn in 2025 and passes £60bn by 2035. Underlying Goldman Sachs research suggests that the share of overall average value will vary for L3 and L4/5 vehicles between £1250 and £2700 per vehicle.[33]

Will AV need to be aligned with EV for greatest impact?

How significant will public funding be to the success of AV deployment?

Are the implicit job losses from full AV acceptable to society?

Beneath this enthusiasm and future planning there are, however, voices of caution - particularly around the impact that full autonomy will bring in reducing congestion, where much may potentially again be achieved by earlier developments. For instance, a form of connected automation known as CACC (Cooperative Adaptive Cruise Control) illustrates the promise of the marriage of automated control with connectivity. UC Berkeley simulations have shown that, if all vehicles adopt CACC, US highway throughput capacity of cars will double from today's average of 2000 vehicles per lane per hour. Furthermore, the benefits start to show when only 30% of vehicles are fitted with CACC.[34] Given that hundreds of thousands of cars already have ACC, a transition to CACC can be expected pretty soon.

A move to AV will also present a peculiar set of challenges in itself. While several experts have more positive views, according to KMPG, three-quarters of automotive executives think that mixing autonomous and conventional vehicles will lead to severe safety issues.[35] Recognising that many people like to drive and enjoy their personal space, some also see public interest in a significant rise in sharing vehicles may not be as high as expected. In addition, there may be a push-back against significant job losses for taxi and truck drivers. Maybe "optimism and confirmation biases risk plaguing the protagonists of AV futures."

Value creation is shifting away from OEMS and towards the new tech suppliers.

Will AV increase or decrease total traffic flow and congestion?

People vs. Goods

Discussions over the past 20 years have provided notable debate around whether AV will be for people or for goods or both.

In considering where there may be greatest initial impact, discussions over the past 20 years have provided notable debate around whether AV will be for people or for goods or both. While developments such as driverless trains and other tracked vehicles helped set some initial expectations, for road-based transport the debate has focused on where scale will occur first. Will it be in moving goods long-distances on highways, will it be small urban delivery vehicles, or will it be in replacing traditional cars? The repeated view from expert dialogue in 2004, 2007 and 2010 was that, while cars will grab much of the spotlight, it could be that growth will first occur around platooned, articulated trucks on the highways and small electric delivery pods within cities. Once the technology is proven in this context, with minimal human interactions, it then can be applied to the more sensitive challenge of moving people.

Will AV have greater short-term impact in moving goods rather than people?

However, in the past few years, the mood music has changed. The advent of Uber, Lyft, Waymo, DiDi and others has shifted perspectives so that, when considering the transportation of people, the business case is no longer about AV replacing the existing cars ownership model, but rather that AV will become pivotal in the development of fleets of shared vehicles. The 'access not ownership' trend has major relevance to how many now view autonomous mobility. Given this, it may well be that the use of AV to move people could scale in parallel with the movement of goods and not follow in their wake.

Will industry collaborate to select a single system for AV globally?

The use of AV to move people could scale in parallel with the movement of goods and not follow in their wake.

Goods Vehicles

Which regions will lead the way in agreeing regulation and setting operating boundaries?

For trucks, high utilisation is a key part of existing business models – long-distances and / or near constant availability are both common characteristics for many operators. In addition, compared to cars, where there are numerous organisations in the mix and high levels of competition between established suppliers, within the world of HGV trucks there are fewer manufacturers, greater collaboration, more regular maintenance and a strong business orientation on ROI (return on investment). Moreover, if ROI is achieved, then there is less cost sensitivity. As such the industry is already seeing several levels of transformation moving forward simultaneously due to the strength of the business cases for level 1 truck platooning, level 4 driverless trucking driverless vehicles off-road and autonomous delivery on city streets.

Platooning

Given the conservative nature of the trucking industry, can it embrace automation as quickly as advocates foresee?

After 20 years of planning and technology maturation, 2018 saw the first commercial trials of platooning where a lead truck has a number of follower trucks in close proximity. Platooning can be done at any level of automation. Currently logistics companies are lining up to deploy level 1 platooning that provides significant fuel economy benefits while drivers remain engaged in the driving task. Pioneered by manufacturers such as Scania, Volvo, MAN and Freightliner as well as start-up companies such as Peloton Technology, wireless links between vehicles are providing constant communication and so near-immediate acceleration and braking when needed. A series of trucks can therefore follow each other in very close proximity thereby saving fuel. In order to ease the integration of this operational mode into public roads, initial platooning consists of just two trucks, but platoon lengths are likely to increase in certain (especially remote) areas and for the right types of freight.

2018 saw the first commercial trials of platooning where a lead truck has a number of follower trucks in close proximity.

There is no real opposition to level 1 automation at the political level and regulators are, in general, supportive of platooning since it offers societal as well as business benefits, without requiring high levels of automation and risk. In Europe, the UK, Finland, Sweden, Germany and the Netherlands, have taken steps to permit the testing and deployment of platooning – the same is the case in Australia. In the US, 17 states currently fully allow the commercial operation of platooning and more are expected to follow.

Regulators are, in general, supportive of platooning since it offers societal as well as business benefits, without requiring high levels of automation and risk.

Fully Autonomous Stand-Alone Trucks

Ultimately the significant automation (level 4) of highway trucks is of huge commercial interest to the freight community. The eventual aim is to enable trucks to move without a driver on board any vehicle for hundreds of miles. This will transform long-haul journeys. Coast-to-coast across the USA currently takes 5 days due to required driver breaks. Driverless trucks could achieve the same in 48 hours. The associated economic gains for haulage firms from removing drivers for long-distance trucking are massive.

Coast-to-coast across the USA currently takes 5 days due to required driver breaks. Driverless trucks could achieve the same in 48 hours.

In terms of interaction with existing systems, driverless trucks may interface with human-driven trucks at ‘transfer hubs.’ Drivers will bring loads from logistics centres to the hub, a driverless tractor attaches to the trailer and begins the long motorway run. At the exit point, the reverse occurs. This concept was pioneered by Otto Trucks - acquired by Uber in 2016. Since then, Waymo has announced its development of driverless trucking, along with start-ups Embark Trucking and TuSimple (founded in China and now with parallel operations in the US). Regulatory issues are however much thornier for level 4 than for lower level automation because of the complete absence of human supervision, even from afar. In the US new legislation may be required that could take years to agree, while other countries such as Australia are seeking to clear the way expeditiously, possibly by 2020.

When will harmonization across jurisdictions enable system-wide integration at international levels?

Urban Delivery

Will small delivery robots be pivotal in building public confidence in AV?

Away from the world of large vehicles, HGVs and long-distance haulage, another area where the logistics sector is anticipating notable change is that of urban delivery. There is significant focus on the health, energy and efficiency benefits of fleets of electric, autonomous vehicles operating within our towns and cities.[36]

Starship Technologies' six-wheeled robots for pavement delivery have been publicly testing in 20 countries since 2015.

Improving the inefficient 'first mile' and 'last mile' has long been seen as a major opportunity for innovation and today many companies are seeking to gain from addressing this challenge.[37] For example, DHL, the world's largest delivery company, is upgrading its fleet of 3,400 electric delivery vehicles with the latest autonomous technology. By changing its existing fleet, DHL says it can use its current networks to improve efficiency and so enable a 24/7 service for its consumers.[38] In the UK, the Gateway project in Greenwich is testing self-driving food delivery in residential areas.[39]

Elsewhere, Starship Technologies' six-wheeled robots for pavement delivery have been publicly testing in 20 countries since 2015 and are now in commercial use in Mountain View, California.[40] Similar products from the likes of Thyssenkrupp, Nuro, Marble, and Robby Technologies are also scaling – some in partnership with established manufacturers.[41] Additionally, robo-taxi players such as Uber and Waymo primarily focused on passenger transport also see a dual opportunity to also offer local parcel and food delivery services.

amazon

For many it is Amazon that may have the greatest impact on AV adoption for logistics. The company's robots are already widely used across its huge warehouses around the world.[42] Since its acquisition of Kiva, Amazon has scaled up its automation capability reaching over 100,000 warehouse robots in 2017.[43] The company has filed multiple patents for autonomous delivery from airships and drones as well as ground vehicle robots.[44] In 2018 Amazon announced 'postman' robots that can open doors and deliver parcels 24 hours a day.[45] As this giant company with substantial international reach and very deep pockets rolls out autonomous robots in cities, all integrated into its expanding footprint, many anticipate that it may set the global standard for fast, low-cost, automated delivery.[46]

Passenger Vehicles

In terms of moving people, two fundamental changes are underway that are leading us towards shared, autonomous vehicles becoming the new model for passenger vehicles. As new technology enables the shift from driver control to the self-driving ideal, we are simultaneously seeing the long-anticipated move from ownership to access. The rise in popularity of car leasing and the increase of short-term rental from the likes of Zipcar, Car2Go and DriveNow, suggest to many that the target future AV business model is that of providing access to vehicles not owned by drivers or their employers.

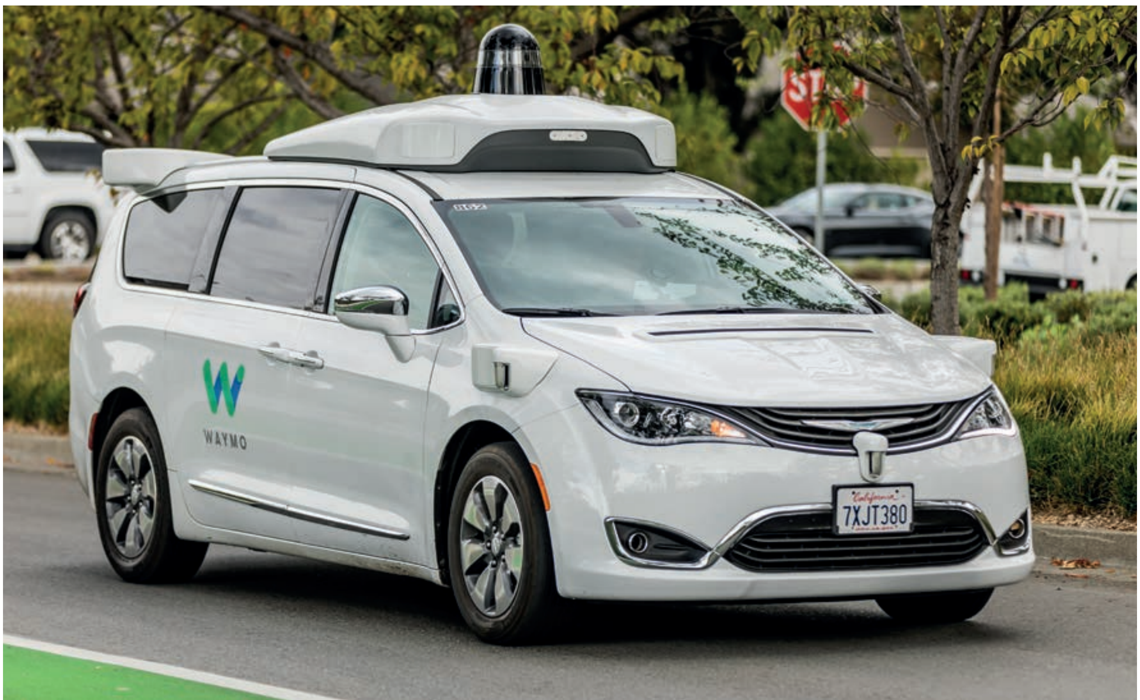
Mobility is set to be delivered as a service which will not only increase vehicle utilisation but correspondingly reduce the cost-per-mile. Whereas currently privately-owned passenger cars are parked for over 90% of the day and have low utilisation, fleets of automated vehicles, constantly available on demand, could be in operation nearly 24/7. In preparation for this scenario, GM recently announced a platform to allow their customers to share their private cars,[47] while in 2019 Volkswagen is launching WeShare – an EV fleet sharing sub-brand for cities.[48]

Mobility is set to be delivered as a service which will not only increase vehicle utilisation but correspondingly reduce the cost-per-mile.

Personal AVs will continue to cost more than human-operated vehicles, but access to a shared AV will be cheaper than human-operated, ride-hailing and taxi services.

As is often the case for many new high-tech features, change takes place first at the premium-end of the market. Here some expect existing car owners to simply switch to an AV – when attractive. Products are already available from Tesla and the Cadillac CT6 is the first vehicle to offer a true level 2 system which allows 'hands off, feet off' driving as long as the driver is paying attention. However, even as availability increases, some forecasts propose that personal AVs will continue to cost more than human-operated vehicles, but access to a shared AV will be cheaper than human-operated, ride-hailing and taxi services. Given this, leading OEMs such as GM, Toyota, Mercedes, BMW and VW have all now indicated that rather than selling or leasing AV to individuals, the first product they will offer will be 'robo-taxi' services.[49] In 2018, Waymo announced its plans to initiate the robo-taxi era with potential tie-ups with Wal-Mart and others, shedding further light on how the service platform may evolve.[50]

How may the slower paced introduction of AV on mass-market cars (go anywhere) interact with faster pace launch of robo-taxi services (limited geographic extent)?



How quickly will OEMs actually introduce highly automated mass-market vehicles?

How rapidly will localised robo-taxi services expand to serve larger regions and stimulate wider social change?

During this 'fleet' phase the absolute cost of development will not be as important as ROI. The aim is to give the system a chance to mature and help production costs to come down over successive vehicle generations. This in turn will open the way for the mass market introduction of highly automated vehicles. If successful, US automated mobility costs may decline from 85¢ per mile in 2018 to about 35¢ per mile by 2035.[51] Therefore many initial deployments focus on city streets where speed (and therefore risk) is lower. The next evolution of the service is expected to extend operations to high speed limited access motorways. In areas such as Silicon Valley where freeways are a vital part of the transport network, this will be pivotal to ensuring robo-taxi services really do serve the needs of the local populace.

What level of safety (crashes) is acceptable for the full launch of AV in the next decade?

However, not everything is quite going to plan, especially regarding the 100% safety ambition. Accidents have caused some to doubt the technology readiness - despite the fact that high-profile crashes involving Tesla and Uber vehicles were the result of human failures rather than those of the machine. They are not good bellwethers: These sorts of events raise concern that maybe the technology is not yet as advanced as some, particular early adopters, would like. It is difficult for outsiders to really understand the current development status. The real answers lie deep within the laboratories of the major technology developers that are understandably reluctant to share the strengths and weaknesses of their respective systems.

Will robo-taxis be an interim step or a key part of the future of mobility?

Many initial deployments focus on city streets where speed (and therefore risk) is lower.

Maybe the technology is not yet as advanced as some, particular early adopters, would like.

What we do know is that there are numerous assertions of near-term deployment plans in the robo-taxi space plus a host of cities that are enthusiastic about serving as initial deployment sites. Fleet is increasingly seen as the way forward for both trucks and passenger vehicles with the likes of Uber, Lyft and DiDi all moving ahead. Proponents also say that coming years will see the public directly experiencing automated mobility at a very low cost. This could possibly change travel patterns and car ownership decisions in the regions where it is available. Equally there are several within the AV tech community who doubt the technological readiness and expect the timelines to stretch.

Public Transport

For the automated mass-movement of people, driverless trains and trams have been commonplace for some time. Now the focus is on buses. Today pretty much every major urban body is putting autonomous public transport plans on the agenda and, assuming the early pilots are successful, many are anticipating a wider roll-out over the next decade. Trials are underway in multiple locations including Cambridge, Michigan,[52] Stockholm,[53] Perth,[54] Frankfurt and Munich,[55] while Mercedes-Benz's Future Bus is being used in The Netherlands on a 20km route between Schiphol airport and the town of Haarlem.[56] In China, Baidu is launching autonomous buses into Beijing, Guangdong, Shanghai and Shenzhen[57] while in Singapore residents in three new towns can expect to ride in an autonomous bus from 2022.[58]

Pretty much every major urban body is putting autonomous public transport plans on the agenda.

Which public bodies and systems can change fast enough to accelerate AV roll-out?

Quite how autonomous buses will work at scale is not yet clear as the operational cost at times of low use may, in some locations, be unacceptable – just as is the case with some conventional pubic transport today where a significant cost is in paying the human driver. Planners are therefore considering whether the operational design of autonomous buses will cover all or some of the current service areas and whether robo-taxis could be used to extend reach and fill transportation gaps. While tomorrow's driverless services may have the potential to enable 24/7 mobility and improve access to jobs for local communities, the constraints of the public purse will still have limitations.

Will automated mobility services replace, reduce or extend the reach of public transport?

A central question for many mayoral offices and governments is whether or not the wider infrastructure will be ready for AVs. Many cities and states are facing budgetary constraints which have led to crumbling infrastructure, overburdened and out of date public transit systems, and increasingly higher traffic congestion. While some consumers, politicians and industry leaders see autonomous vehicles as the salvation of commuting woes, poor coordination between transit systems, poor urban planning, and lack of attention to long-term transit solutions may delay or prevent the benefits of autonomous vehicles from ever being realised.[59]

Which dense cities will have integration challenges that slow AV adoption?

Given this, Uber has recognised that electric bikes may be an important part of the urban transport mix for short trips.[60] In the UK, a series of trials are now underway supported by the Centre for Connected and Autonomous Vehicles.[61] A core focus is how driverless vehicles will be integrated in a real-world environment and how, from a multi-modal transport systems perspective, they can align with buses, trams, subways and trains.

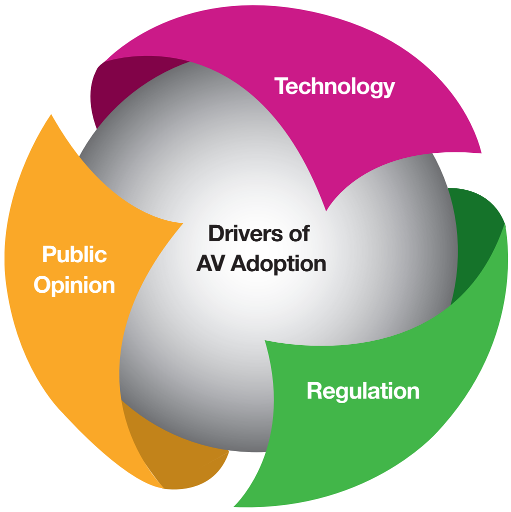
A central question for many mayoral offices and governments is whether or not the wider infrastructure will be ready for AVs.

Drivers of Adoption

Which will be the pivotal organisations, cities and governments that control adoption rates?

As with any major shift, AV will have greatest impact where there is an alignment of proven technology, real social need and viable business models for investment and return. Think of mobile payments in Africa, low-cost desalination or the escalating growth in take-up of solar energy. For AV in particular there is a significant role for regulation and policy that will both help accelerate the development and introduction of critical technologies and also set the parameters within which associated products and services can best operate. In addition, since in many regions the proposed shift is changing the status quo and so requires consumers to make a clear choice to move from one platform to another, the views of the users and their willingness to switch and adopt new solutions - and for what benefit - must also be considered. So, there are three essentially primary drivers of AV adoption to consider – public opinion, technology and regulation.

Drivers of AV adoption



There are three essentially primary drivers of AV adoption to consider – public opinion, technology and regulation.

Within these, we need to appreciate what developments may be global in nature - and so potentially become international industry standards - as well as those which may be more regional.

Public Opinion

Paramount for the public acceptance of AVs will be convincing consumers to use them – whether as owners, operators or customers. Initial omens are positive but inconsistent. Overall around 45% of people consider that they are likely to use fully autonomous vehicles in the future.[62] For customers across multiple markets, the core benefits from AV are seen to include reduced stress, the ability to rest on long journeys, more comfort and greater flexibility - just as achieved for a fee in some regions today via Uber, Didi and Lyft. Additional advantages should also include fewer accidents, cheaper mobility as well as lower insurance and fuel costs.

As yet, quite which organisations will be most trusted to deliver a safe, reliable and comfortable experience is still unclear, especially with changing sentiment following recent crashes. US analysis by Deloitte suggests that over half of us will prefer to trust traditional car brands, while a quarter are looking towards a specialist new company such as Tesla, and a fifth would have more faith in big-tech such as Google, Apple or Amazon.[63] Additional Deloitte research sees that half of UK consumers think that AV will be a positive experience.[64] In Germany a pragmatic approach may be needed as the majority of potential AV users there expect to see demonstrations under realistic conditions as opposed to manufacturer guarantees, economic data and technical explanations.[65] In China there are positive attitudes to AV with 45% of drivers expecting lower risk and hence lower insurance premiums for autonomous vehicles.[66]

Which organisations will be most trusted to deliver a safe, reliable and comfortable experience is still unclear.

Who will customers trust more to deliver a safe, reliable and comfortable AV experience?

The core benefits from AV are seen to include reduced stress, the ability to rest on long journeys, more comfort and greater flexibility.

Acceptance does not come without concerns however. These include the potential for system failure, vehicle hacking and liability in case of an accident.[67] In the UK, 73% are concerned about the safety of fully autonomous cars.[68] In addition some aspects of AV are more attractive than others. For example, although the principle of demand response ridesharing (vehicles with flexible routes to pick up and drop off passengers at or near their destinations) is appealing, sharing a confined space with complete strangers is not. Just 20% of Uber rides are currently shared via Uber Pool,[69] and in China DiDi recently suspended its Hitch carpool system.[70] Whether more consumers will be willing to share an AV without a driver present is uncertain.

If AV is focused on sharing rides with strangers, will this have a negative impact on personal safety?

Will a marketplace of the old, young and disabled justify initial AV investment?

Although there are many views, globally people-focused AV is seen to have greatest appeal for those who currently do not have access to affordable mobility or who are uncomfortable about driving - the young, the old and the disabled.

- For the **elderly** AVs offer the ability to maintain flexible, personal mobility for longer. As the number of those over 75 increases by 50% in most G8 countries, many see this as a significant sector for growth.

- For the **disabled** the opportunity to overcome mobility constraints is also highly attractive. Especially for those were have previously been unable to drive, and so had to rely on carers, the potential for independent transport on demand may open multiple doors, including access to work and education.

- For the **young** the potential of lower cost and more flexible travel options is also appealing, especially if it improves access to tertiary education and better jobs. Currently those living in urban areas are most willing to consider using driverless vehicles in the future.[71]

Technology

To affect the desired change, it is evident that new technology has to be developed, tested and integrated across a wide range of systems. These include control systems, sensing and diagnostic systems, cameras, LIDAR (Light Detection and Ranging), location and mapping, connectivity systems, local and cloud-based data processing, AI and machine learning, security systems, safety systems, and human-machine interfaces.[72] Associated Goldman Sachs assessment of technology demands by 2035 (prioritised by total global value) are LIDAR $80bn; radar $40bn; V2X $32bn; cameras $31bn; mapping $23bn; HMI $20bn; controls $17bn; security $15bn and actuators $10bn.[73]

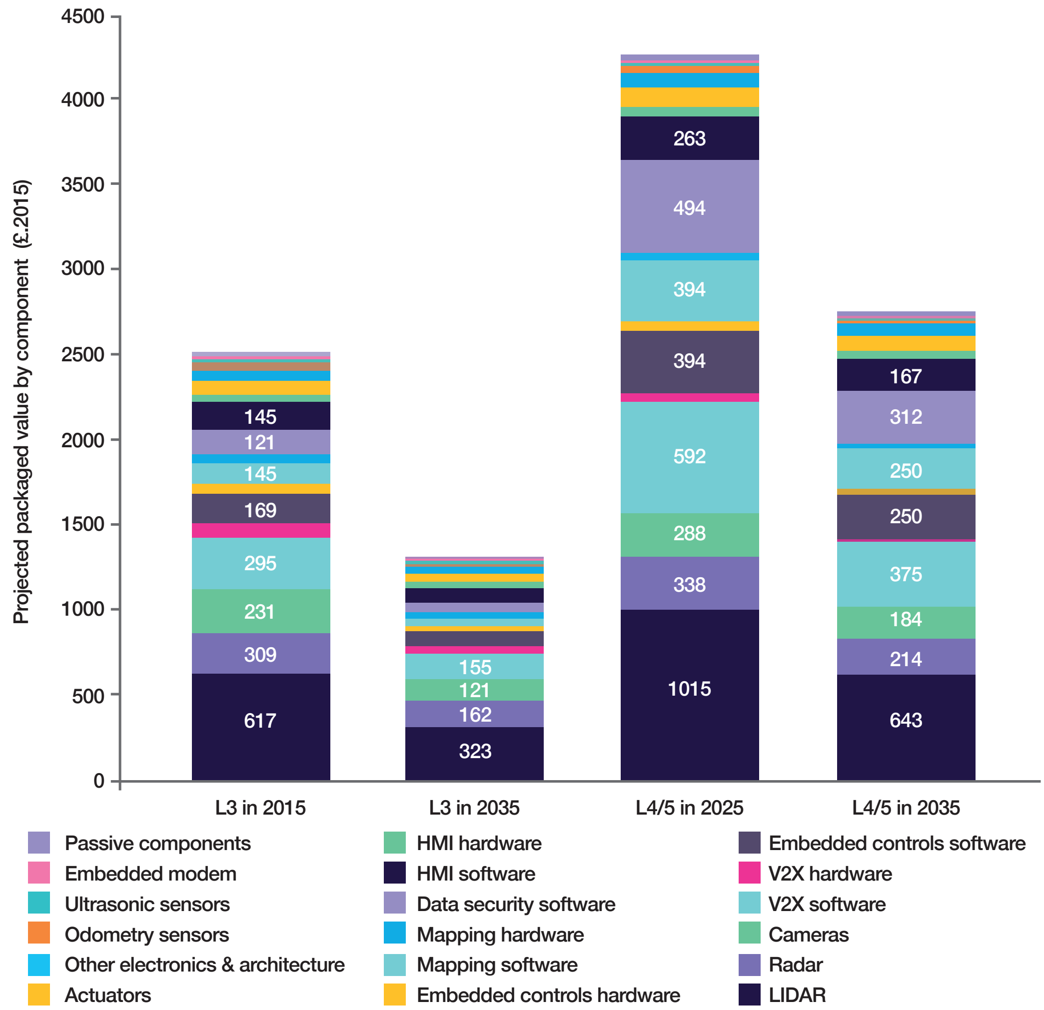
In addition, with increasingly smart technologies being applied to the infrastructure, further areas of R&D focus include:[74]

- Sophisticated environment monitoring,
- Traffic control, including advanced predictive modelling,
- Remote support to guide vehicle in tricky situations,
- Verification and validation protocols,
- External signalling to other car drivers and pedestrians of the intentions of the AV and
- The potential need for real-time ‘road certification.’

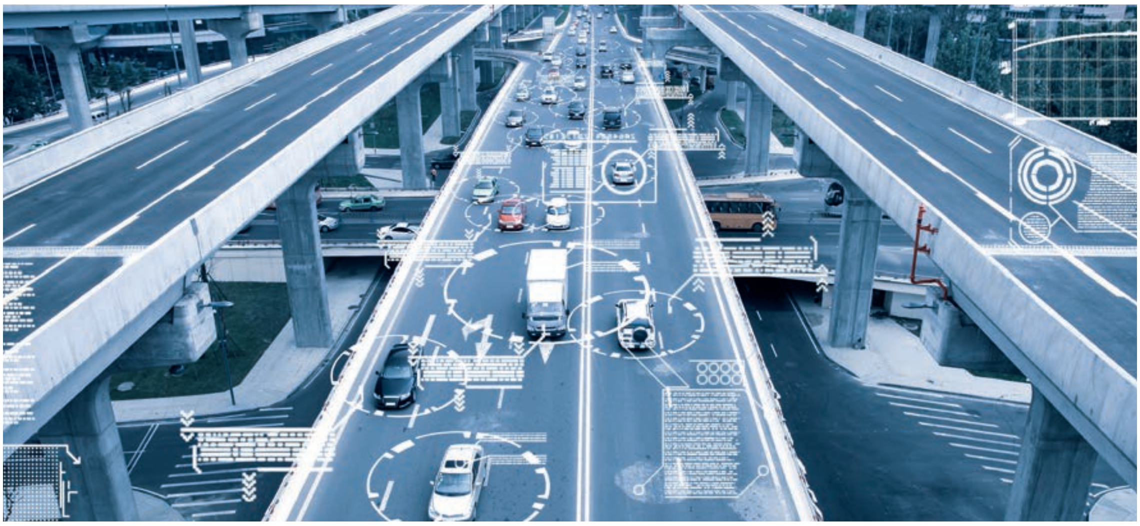
Of all the technologies in the mix, which ones are in greatest need of further development before the benefits of AV can be realised?

Costs of autonomy packages by technology 2035

To what extent will second generation deep-learning and self-learning AI impact AV?



Source: Transport Systems Catapult - Market Forecast for Connected and Autonomous Vehicles 2017



Will OEMs develop their own technologies or rely more on partnerships and acquisitions of tech venture and start-ups?

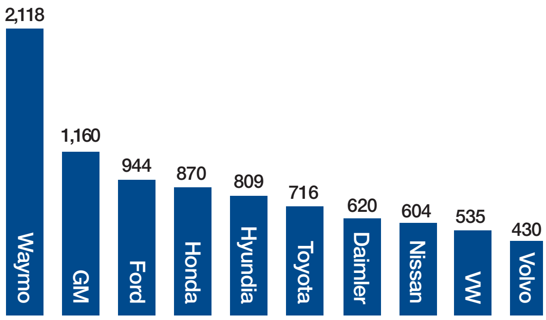
The full list of potential tech providers is substantial and rapidly evolving. There are numerous AV start-ups being funded around the world. [75] To date, alongside moves by Tesla, Uber and Waymo, we have seen most activity in spin-offs of AV-specific subsidiaries from Ford, Delphi, Volvo/Autoliv and others. There have also been a few notable M&A activities:

- In 2016, GM purchased San Francisco based start-up Cruise Automation for $1bn in 2016.[76]
- In 2017, Intel acquired Israeli computer vision leader Mobileye for $15.3bn.
- The same year Ford announced a $1bn multi-year venture with Argo AI to combine both companies' robotics and artificial intelligence expertise.

In terms of patent activity, the common indicator of technological innovation output, Waymo is by far the most active company in the AV space filing more applications than second and third places GM and Ford combined.

In terms of patent activity, the common indicator of technological innovation output, Waymo is by far the most active company in the AV space filing more applications than second and third places GM and Ford combined.[77]

Self-driving vehicles patents filed 2007-16



Source: LEK Consulting, US Patent Office 2017

Technology Readiness

With so many potential technologies in the mix, there are multiple competing views of which ones are closest to market, which will have greatest impact early on, which will become the agreed standards for scaling and which will win out in the longer term. Within this, many are looking not just at the AV market but also at the wider integrated transport system landscape and how all the future options can operate within a flexible, multi-modal model in a safe and affordable manner.

As well as the testing and certification of core technologies, here companies are also dealing with the challenges of reliability, redundancy, cybersecurity, integration of AI, verification/validation, as well as other fundamental tenants of automated vehicle design such as monitoring and self-awareness. Few innovations have been a similar catalyst for such widespread industry change.

In terms of specific timeframes for scale-up, some believe the date for mass introduction of AVs is when we are certain that they won't kill anyone. Others take the view that is it when they can start to save lives. RAND looked at this in detail in 2017 and concluded that putting AVs on the road before they're perfect improves the technology more quickly—and could save hundreds of thousands of lives over time.[78] "Waiting for the cars to perform flawlessly is a clear example of the perfect being the enemy of the good."

Waiting for the cars to perform flawlessly is a clear example of the perfect being the enemy of the good.

How can AV technologies be adopted faster than the 25 to 30-year industry norms?

How quickly will technology development move from assistive to partial and then full autonomy for the mass market?

Will regulators take a heavy-handed approach to new technologies or will they be light touch and maybe rely on self-certification?

NISSAN Human Remote Support

As in aviation, vehicles must have the ability to sense failures and switch to a fail-safe or fail-operational mode. When a problem is detected, the system then seeks a 'minimal risk condition' which may be as simple as pulling the vehicle off to the side of the road and signalling to a fleet management centre that help is needed. This may be fine in testing but not for delivering mass-mobility services. Therefore, some are adopting a 'remote support' paradigm, in which the AV is tethered to a cloud-based operation centre that is staffed by humans who can remotely intervene in unusual situations. For instance, roadworks may have a lane blocked with a flag-person waving traffic into the opposing lane to go around it. Some developers seek to have systems with sufficient intelligence to understand all human flag-wavers and to know that in some cases it is acceptable to drive in traffic designated for opposing traffic. Conversely, Nissan has pioneered 'Seamless Autonomous Mobility' concept in which a human mobility operator is able to view the situation through the vehicle's sensors, understand the situation, and plot a new path.[79] The vehicle then uses its autonomous capability to move change direction and then resume normal independent operations. Since Nissan announced this in 2017, many other self-driving car developers have adopted similar approaches. This is another means of managing the transition – rather than waiting for 'total capability' to be developed, companies aim to go to launch with practical and scalable methods that may involve intermittent human support.

Regulation

In which countries will the legal system be able to support AV?

The third core driver of AV adoption is regulation, and by implication the availability of insurance. Without these, no matter how compelling the consumer demand and how clever the tech, products will not get onto the streets. Policy makers will have a major impact on how, where and when AV is rolled out and it is a responsibility they are taking very seriously. In a 2018 EU survey, 87% indicated that action in AV was the top regulatory priority; more than for medical robots, drones, human enhancement, or human care robots.[80]

How will regulators prioritize enabling deployment of various types of automation for people and goods?

Although several companies have focused in the early stages of development on private test-tracks, without government sanction the use of AV at scale on public roads in many countries is currently illegal. The 1968 Vienna Convention on Road Traffic, which has been ratified by 74 countries, stipulates that “a human driver must always remain fully in control of, and responsible for the behaviour of their vehicle in traffic.” Some modifications to this for AV are now underway but are yet to be finalised. However, not all nations, and specifically neither the UK nor the US, are signatories.

Today, a range of countries have or are introducing regulation for self-driving cars and trucks on public roads.[81] Globally, as of March 2018, Canada, parts of the US, several European countries, the UAE, Russia, China, South Korea, Japan, Australia and New Zealand have all opened some doors to AV on their roads. Generally, the focus is more on testing than deployment and, given the variety of business and end user factors involved, deployment locations may or may not align with testing locations.

Globally, as of March 2018, Canada, parts of the US, several European countries, the UAE, Russia, China, South Korea, Japan, Australia and New Zealand have all opened some doors to AV on their roads.

Where is advanced regulation most likely to act as a catalyst for AV deployment?

Insurance

Integrated to the regulatory shifts is the question of how vehicles and people are insured. Globally the emerging view is that auto insurance, one of the most profitable areas of the insurance sector is facing a major disruption.[82] As was pointed out in one of our 2007 discussions "if cars don't crash, who needs insurance?" Certainly by 2040 many users of vehicles that have ADAS, or are indeed autonomous, will see no need to have personal accident insurance and equally society may just mandate minimum coverage. Traditionally there has been a 'three-pillar' system for vehicle insurance in many markets ensuring that there is cover for the driver, the owner and the manufacturer. This view is now in flux: Different countries are taking alternative views and again, in the US the approach changes from state to state.

An OECD study claimed that the burden of liability will remain the most important barrier for the manufacturers and designers of autonomous vehicles:[83] Many have been expecting that in the early days automakers will assume liability and Google, Volvo and Mercedes Benz are already doing this. Tesla is taking a step further by extending insurance to purchasers of its vehicles. However, when fleets are providing services the personal insurance questions change significantly - with the advance of the robo-taxi model things may evolve. In some countries it may be that initial deployment is self-insured by government.

In terms of profitability, a recent HBR article[84] highlighted that if up to 94% of US accidents are caused by human error then "as AV rolls out the number and severity of accidents and insurance claims will drop, leading to lower premiums as insurers price in accordance with real risk." In addition, with more fleet owners there will be more competition and hence lower prices. The net impact is estimated at a $25bn loss of income for US insurers by 2035 out of a $200bn market.

To mitigate this 'loss' some see that new insurance products may be developed for risks such as cyber security, hacking and ransomware; product failure liability for manufacturers and software developers; and insuring the smarter infrastructure.

Recent EU analysis highlights that there are six key categories of risk relating to the liabilities of AVs:

1. Risks relating to the failure of the operating software that enables the AVs to function,
2. Hardware failure,
3. Network failures,
4. Hacking and cybercrime
5. Programmed decision making, and
6. Risks relating to programming choice.[85]

In the US, Ford, GM and Waymo have submitted Safety Assessment Letters to the Department of Transport seeking to address these.

Applying current US rules to AVs will likely shift the balance in liability distribution between consumers and producers, further accentuate existing gaps, and could potentially contribute to legal and administrative costs in connection with uncertainties. In the EU the application of the Product Liability Directive to autonomous vehicles will provide a degree of protection, but there are a number of issues that could potentially lead to decreased cover and increased costs for consumers; these include limited reach and meaning of product liability as well as restricted lists of liable persons and evidentiary burden. Some suggest that, overall, much of the premiums that consumers currently pay for auto insurance will move from the personal auto market to the commercial liability market, specifically into the product liability category.[86]

Much of the premiums that consumers currently pay for auto insurance will move from the personal auto market to the commercial liability market, specifically into the product liability category.

How much of a threat is AV to the insurance industry?

Who can best drive alignment of legislation around common multinational standards?

Where may appropriate insurance lag technology availability and so hinder adoption?

Will regions take different approaches to liability and insurance or will we see global norms?

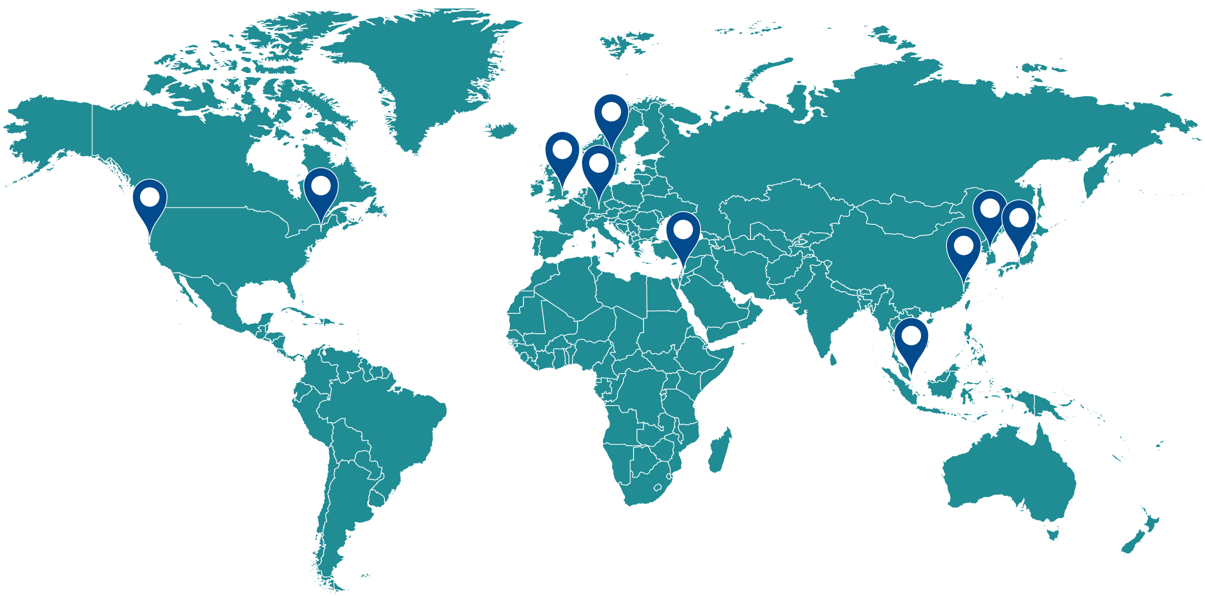
Centres for Innovation

Given the above, and especially in order to focus investment attention, many analysts are seeking to define the global hot-spots for both development and deployment. There are many different views. Bain sees that Shanghai, London, Stockholm and Singapore are the cities leading in readying themselves and driving AV adoption.[87] Others highlight South Korea, The Netherlands and Israel. MIT in Boston is, as ever, significant and while California is a major centre for development, the state has created a cumbersome regulatory environment, so early deployments are more likely in Arizona, Florida and other more permissive US states. Tokyo is trialling self-driving taxis ahead of the Olympics.[88] The Chinese government has begun to show strong support for autonomous driving vehicle technology as it begins to fast-track the sector.[89] The aim is for China to showcase to the world that it is a leading player in self-driving vehicles.

The aim is for China to showcase to the world that it is a leading player in self-driving vehicles.

Where will be the key hot-spots for AV development and deployment?

Major AV Innovation Hot-Spots



Managing the Transition

Many assume that AV is ultimately inevitable, so the big question is how long will the transition take? The short answer is that it will probably take longer than the current expectations suggest. Michigan Mobility Transformation Center director, Huei Peng, reckons that "it may be decades before a vehicle can drive itself safely at any speed on any road in any weather."[90] Several experts propose important areas where AV strategy should be focused for best managing the transition. These include operational design domain, edge cases and dedicated lanes.

Operational Design Domain

Use instances with promising business cases in specific scenarios are already within reach - hence the massive funds which are being invested to develop and launch new services. It is here that the concept of Operational Design Domain (ODD) becomes crucial to understanding current technology and business model development. For all AVs, tech developers define a set of conditions under which the vehicle will or will not operate in automated mode. This relates to factors such as road type, speed, weather conditions, road signage/markings and high definition maps. As one example, a typical robo-taxi has an ODD which allows operations only on city streets where the road environment has been pre-mapped, with speed restrictions of 40 mph, and in the absence of severe weather.

For all AVs, tech developers define a set of conditions under which the vehicle will or will not operate in automated mode.

The cause of the very high-profile AV accidents reported in the media relates to human failure.

Edge Cases

The development of AV systems includes a rigorous process intended to address all potential safety-relevant events. But highways and roads can be unpredictable, and any unexpected or undetected obstacle could be potentially a threat to life. There will inevitably be non-standard cases in which the AV system misinterprets a situation and makes an unsafe decision, possibly resulting in human harm. Because of this, the stakes for addressing 'edge cases' are enormous. To date, the cause of the very high-profile AV accidents reported in the media relates to human failure as drivers failed to respond properly to a safety-critical situation. Many studies rightly discuss the difficulties in addressing the myriad edge cases on public roads and, as a result, estimate the widespread adoption of AV services to be decades away. Others herald AI as the answer to the unpredictability of the roadways. However, early deployment sites are being selected on the basis of a road grid and other ODD-relevant factors which can be safely and effectively handled by existing automated driving software. This will enable the launch of an initial revenue-producing service while developers further evolve the software to operate over a wider range of conditions.

At what pace will ODD limitations broaden to cover most roads and most driving conditions?

Who will lead on integrating all the varied systems needed to enable AV to operate?

Dedicated Lanes

Another key issue is whether traffic will increase or decrease in an automated world - some studies say yes, some no: Many see that AV's are as vulnerable to being stuck in traffic as we humans are today. This is where the connected car technology can make a difference. The AV community is in the early stages of considering how cooperation between vehicles and the surrounding infrastructure can significantly improve traffic efficiency, both at the street level and on highways. Implicit within this is that AVs will not, as some had originally proposed, have dedicated lanes. Although partitioned highways are possible in some regions, such as parts of Australia and the US, in most places they are impractical, costly and, even if funds could be raised, would take many years to build. Instead AVs need to share infrastructure with other vehicles and users. Managing this will be a key challenge.

The potential for land-based AV is clearly considerable, and the target benefits substantial. It is clear that with the rapid technology development underway multiple solutions will become available. The challenge for many will be in ensuring that the transition towards the AV visions increasingly being shared will be as smooth and sustained as possible.

AV's are as vulnerable to being stuck in traffic as we humans are today.

WAYMO

In July 2018 Waymo announced that it had reached 8m miles of on-road testing with its self-driving fleet of 600 vehicles.[91] This is impressive but far from sufficient - and Waymo knows it. The company therefore extracts the unusual real-world edge-case situations that their cars encounter and abstract them into a highly detailed simulation of a road environment, applying permutations of all possible variances on the situation. Waymo's software is then tested against these situations virtually. To date, Waymo's 8m road test miles have been augmented by 5bn simulated miles.

In March 2018, Waymo announced that they would purchase 20,000 Jaguar Land Rover SUVs over several years. In addition, the company is adding some additional 62,000 Fiat Chrysler minivans to the 600 it already has in use. Having tested AVs in over 25 US cities, the company also launches its first commercial hailing service in Arizona this year.[92]

Seaborne AV

Although land-based AV has retained the spotlight, there are considerable developments around sea-going autonomous vehicles. The merchant maritime industry is currently growing at over 3% p.a. and will top 11bn tonnes of trade in 2018.[93] Over 80% of global trade by volume and more than 70% of its value is carried on board ships and handled by seaports worldwide. As it explores AV, the maritime industry's goal is not yet to remove humans from the decision-making process completely but rather to eliminate the need for crew to be on board vessels at all times. There are significant advantages to this not least in terms of cost, efficiency and safety. Without crew, piracy becomes very difficult and, since there is no need for crew quarters, ventilation, heating and sewage systems, ships can become lighter and more aerodynamic – thereby enabling the carrying of more cargo.[94] Moreover, as was highlighted in our 2010 research, autonomous ships are also a key ingredient in the move to cleaner shipping – better managing ocean transit routes and timing and so using less fuel.[95]

How can autonomous ships be made at least as safe as existing vessels?

Rolls-Royce

The President of Rolls-Royce's Marine division believes that "autonomous shipping is the future of the maritime industry…. the smart ship will revolutionize the landscape of ship design and operations." Rolls-Royce is indeed one of several companies leading the development of fully autonomous ocean-going cargo ships which it expects to launch in the 2035.[96] These will be preceded by less complex harbour tugs and short distance car ferries that will be trialled within the next few years. Initial focus is on the Baltic where the aim is for fully remote ships to operate in coastal waters by 2020.[97] In addition, the Norwegians are undertaking trials looking at un-manned electric vessels to transport freight along the country's coast.[98] In Denmark, Rolls-Royce and Svitzer have already demonstrated remote control tugs in Copenhagen harbour.[99]

Timeline for Autonomous Ship Deployment

Reduced crewe with remote support and operation of certain functions	Reduced controlled unmanned coastal vessel	Reduced controlled unmanned ocean-going ship	Autonomous unmanned ocean-going ship
2020	2025	2030	2035

Source: Rolls Royce

What will be the business incentive for owners and operators to invest?

With all the investment now underway from governments and commercial companies alike, the current industry view is that we will see remote controlled unmanned coasted vessels by 2025, remote controlled ocean-going ships by 2030 and fully autonomous ocean-going ships by 2035.[100]

To help enable this, several initiatives are underway around the world:

- An EU project, led by the Fraunhofer Centre for Maritime Logistics, is assessing the economic, legal, insurance and technical feasibility of operating unmanned merchant vessels in the open seas.[101]
- A Swedish-led multi-country partnership is looking at safety implications[102] and similar research is also underway in the UK.[103]

What technologies can best be used to allow autonomous operation mid-ocean?

- In China an alliance including Rolls-Royce, ABS and Wartsila plans to deliver an unmanned cargo ship in 2021, while Wuhan University is one of several looking at how best autonomous ships can operate within both commercial and military maritime sectors.[104]
- The Maritime and Port Authority in Singapore has kicked off research with Nanyang Technological University; and
- In Japan NYK is planning to test autonomous operation of a containership in 2019,[105] while the government is supporting an R&D project with Mitsui aiming to have autonomous ships operational by 2025.[106]

Without crew, piracy becomes very difficult and, since there is no need for crew quarters, ventilation, heating and sewage systems, ships can become lighter and more aerodynamic.

To what extent can land, sea and air-based AV share technology?

Meanwhile, below the surface, the autonomous underwater vehicle (AUV) market is also developing. Lead users today are the military, scientists and contractors checking underwater cables. Boeing is one company partnering with the US Navy to create drone submarines, the latest of which, Echo Voyager, is over 50 feet long and designed to operate at sea for months at a time with no need for any surface ship stand-by support.[107] In 2017 Israel's Ben-Gurion University launched the country's first autonomous submarine, the 8-foot long HydroCamel II. It is fully autonomous, has high level manoeuvring and is able to dive almost vertically.[108] Kongsberg Maritime also has a growing range of small AUVs and has recently announced its intent to acquire Rolls-Royce Commercial Marine business.

Although less public than land-based AV, it is clear that the benefits of safety and efficiency are just as important at sea. With rapidly advancing technologies and compelling investment cases, assuming the myriad international legal issues can be addressed, many see that the trajectory for seaborne AVs is perhaps more predictable than others.

The autonomous underwater vehicle (AUV) market is also developing.

Will autonomous ships be legal and who is liable in the event of an accident?

Air-based AV

Lastly, there is also significant activity underway in the sky. While NASA has demonstrated remotely controlled planes for several decades and most space exploration has used more complex systems, the shift to autonomous UAVs (unmanned aerial vehicles) has, in recent years, also been gathering pace. Most significantly military drones have come under public scrutiny as partially automated UAVs have begun to appear alongside the more traditional remotely piloted models such as the USAF Reaper and Predator used for reconnaissance, combat and weapon delivery. However, other than for activities like automated in-flight refuelling, fully autonomous UAVs are still an emerging field, largely driven by military ambition.

Military drones have come under public scrutiny as partially automated UAVs have begun to appear alongside the more traditional remotely piloted models.

Although the likes of Elon Musk, Stephen Hawking, the UN and thousands of AI developers have all urged a ban on warfare using autonomous weapons, there is no industry consensus on the main legal and ethical issues and so development continues. “The limiting factor is not the technology but more the political will to produce, or admit to having, such capabilities.” Currently there is a shift from one crew remotely piloting a single drone to the same crew controlling a vast squadron via a single mother craft. Military law currently requires human presence in the decision cycle and the potential absence of this is pushing multiple boundaries – not least the ethical ones. Moving forward key questions include; the relative importance of military advantage vs. collateral damage and the principle of proportionality; as well as how much human interaction is required. Some believe that that allowing a machine to ‘decide’ to kill a human is a step too far. On the other hand, it could be argued that utilising autonomous drones is both acceptable and preferable to using human pilots and soldiers in areas of high risk. The current NATO view is that “the responsibility for war cannot be outsourced, least of all to machines.” However, the advent of fully autonomous military combat drones is not far away.[109]

Amazon's ambitions to deliver up to 90% of parcels weighing less than 2kg via drones have captured the imagination.

How realistic is Amazon's ambition for drone parcel delivery?

Beyond military applications there is growing commercial interest in drones for people and goods. UPS and FedEx are both experimenting with drones, but most significantly Amazon's ambitions to deliver up to 90% of parcels weighing less than 2kg via drones have captured the imagination. In anticipation of major growth, the company has already patented many innovations including autonomous air traffic control.[110]

Drones do not have the same level of collision avoidance systems as planes – largely because of weight and cost, so the aim is for a new type of flight management system which use sensors, digital certification and wireless communications to create a mesh network able to self-manage UAV air routing. As the US regulatory environment prohibits this, initial trials have taken place in the UK, Israel, Austria and France. Nokia is also working in this area and in 2016 ran pilots - first in The Netherlands and then Dubai.[111]

Are air-taxis going to be affordable beyond the very wealthy?

Alongside moving packages there is growing interest in the development of autonomous air taxis for people, notably in China, the US, Dubai and New Zealand. Although probably initially only for the wealthy, as they evolve, and cities become more populated, some, such as Google X founder Sebastian Thrun, see that air taxis could eventually compete with ground transport as a more flexible option for personal mobility.[112]

Air taxis could eventually compete with ground transport as a more flexible option for personal mobility.

Prominent Flying Taxi Developments

- Airbus completed its first test flight of its single person Vahana flying taxi in January 2018 and plans to launch a fleet of these multi-rotor aircraft to fly from rooftop to rooftop in dense cities where there are high levels of traffic congestion;[113]
- In China, drone manufacturer Ehang is more advanced and already flying test flights of up to 15km in Guangzhou and reaching speeds of up to 80mph. Passengers simply mark their destination and the drone creates and executes the flight plan; Air Taxi backed by Daimler and Intel is being tested as part of a government ambition for autonomous transport to account for 25% of all trips by 2030;[114]
- In the US, Uber is developing its 200mph Elevate air taxi ready for testing in 2020; and
- In New Zealand, Google co-founder, Larry Page, has developed a two-person plane / drone hybrid, the Kitty Hawk Cora, that can reach 110mph and fly for 50 miles at up to 3000ft. This is currently undergoing regulatory approval and may well propel New Zealand to the fore in certification and development.[115]

Who will manage the airspace?

Moving up in scale, several organisations are exploring the possibility of pilotless passenger flights. It seems a natural progression as many planes already fly on autopilot and many airports are already equipped for accommodating fully automated take-off and landing. In addition there is a growing need both practically, (Boeing estimates that another 637,000 pilots are required in the next 20 years) and economically (according to UBS, being pilotless could save the airline industry about $35bn a year).[116] As yet there is no regulation in place for full automation and there are obvious concerns about the lack of a human presence on the flight-deck, however the idea of remote pilots on the ground as back up is gaining traction.[117] In the interim, Airbus has set up a research facility in Shenzhen with the intention of using more automation to reduce the number of pilots in a plane from 2 to 1.[118] This could deliver over 40% of the $35bn saving calculated by UBS.

Again, alongside seaborne AVs, with international agreements already part of the system and a shorter list of companies involved than with land-based AVs, several expect that we will see rapid growth in UAV over the next decade or so. Regulation and consumer confidence are evidently important factors that will dictate the speed of adoption.

There are obvious concerns about the lack of a human presence on the flight-deck.

Summary and Key Questions

As we move forward to engage in a series of expert discussions in key locations around the world, exploring the key uncertainties will be a priority. As workshops are held in the development centres of innovation and early deployment hot spots, the full range of AV related topics will be interrogated. However, in order to gain a rich, informed and credible view, from the assessment to date there seems to be twelve key questions that should be addressed up front. These are pivotal to how the future AV landscape will emerge:

1. Where will be the key hot-spots for AV development and deployment?
2. Which sociopolitical forces may accelerate the adoption of full Level 4/5 automation?
3. Where is advanced regulation most likely to act as a catalyst for AV deployment?
4. What level of safety (crashes) is acceptable for the full launch of AV in the next decade?
5. Will AV increase or decrease total traffic flow and congestion?
6. Will automated mobility services replace, reduce or extend the reach of public transport?
7. Of all the technologies in the mix, which ones are in greatest need of further development before the benefits of AV can be realised?
8. What are the distinct benefits from AV that are not already coming from current and future-connected ADAS?
9. How important will international standards and commonly shared technologies be for AV adoption - or will it be more regional?
10. Which will be the pivotal organisations, cities and governments that control adoption rates?
11. Who will lead on integrating all the varied systems needed to enable AV to operate?
12. Who will customers trust more to deliver a safe, reliable and comfortable AV experience?

Over the next six months, expert workshops in over 15 leading centres globally will seek to answer these and other questions. From this initial review it is evident that AV is on the verge of having major global impact. As we explore the growing potential for more automation across land, sea and air-based AV, we will better understand the varied ambitions of manufacturers, technologists and governments as well as how they intersect and align. The informed, global view will provide a richer outlook that can then help guide some of the pivotal decisions ahead.

References

[1] https://www.bcg.com/en-gb/publications/2017/reimagined-car-shared-autonomous-electric.aspx

[2] https://www.mckinsey.com/~/media/mckinsey/industries/high%20tech/our%20insights/disruptive%20trends%20 that%20will%20transform%20the%20auto%20industry/auto%202030%20report%20jan%202016.ashx

[3] https://hbr.org/2017/12/driverless-cars-will-change-auto-insurance-heres-how-insurers-can-adapt

[4] http://pg.jrj.com.cn/acc/Res/CN_RES/INVEST/2015/9/17/f70472c6-f4ad-4942-8eab-3c01f3c717a7.pdf

[5] https://www.weforum.org/agenda/2016/04/the-number-of-cars-worldwide-is-set-to-double-by-2040

[6] https://www.bcg.com/d/news/11january2018-the-great-mobility-tech-race-183665

[7] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642813/15780_ TSC_Market_Forecast_for_CAV_Report_FINAL.pdf

[8] https://ihsmarkit.com/research-analysis/Chinese-government-drafts-policies-autonomous-vehicles.html

[9] https://www.vtpi.org/avip.pdf

[10] https://www.portofrotterdam.com/en/business-opportunities/smartest-port/cases/new-standard-in-container-terminals-and-services

[11] https://www.futurefarming.com/Machinery/Articles/2017/6/Farmer-shares-his-experiences-using-a-robotic-tractor-1614WP/

[12] https://www.telegraph.co.uk/technology/news/11940333/Driverless-trucks-transport-iron-ore-at-Rio-Tinto-mines-in-Australia.html

[13] https://www.technologyreview.com/s/603170/mining-24-hours-a-day-with-robots/

[14] https://www.volvogroup.com/en-en/news/2016/sep/news-2297091.html

[15] https://electrek.co/2018/07/12/einride-t-log-all-electric-autonomous-logging-truck/

[16] https://www.futuretravelexperience.com/2018/04/autonomous-vehicles-future-proofing-the-airport-environment/

[17] http://www.who.int/violence_injury_prevention/road_safety_status/2015/Executive_summary_GSRRS2015.pdf?ua=1

[18] http://www.who.int/gho/road_safety/mortality/en/

[19] https://www.itf-oecd.org/sites/default/files/docs/safer-roads-automated-vehicles.pdf

[20] https://www.thatcham.org/car-safety/automatic-braking/

[21] https://www.smmt.co.uk/industry-topics/technology-innovation/connected-autonomous-vehicles/

[22] https://www.bcg.com/en-gb/publications/2017/reimagined-car-shared-autonomous-electric.aspx

[23] https://www.vtpi.org/avip.pdf

[24] http://pg.jrj.com.cn/acc/Res/CN_RES/INVEST/2015/9/17/f70472c6-f4ad-4942-8eab-3c01f3c717a7.pdf

[25] https://static1.squarespace.com/static/585c3439be65942f022bbf9b/t/591a2e4be6f2e1c13df930c5/1494888038959/ RethinkX+Report_051517.pdf

[26] https://www.bcg.com/en-gb/publications/2017/reimagined-car-shared-autonomous-electric.aspx

[27] http://www.europarl.europa.eu/RegData/etudes/STUD/2018/615635/EPRS_STU(2018)615635_EN.pdf

[28] https://www.smmt.co.uk/industry-topics/technology-innovation/connected-autonomous-vehicles/

[29] ttps://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642813/15780_TSC_ Market_Forecast_for_CAV_Report_FINAL.pdf

[30] https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/Americas-Workforce-and-the-Self-Driving-Future_ Realizing-Productivity-Gains-and-Spurring-Economic-Growth.pdf

[31] https://www.bcg.com/d/news/11january2018-the-great-mobility-tech-race-183665

[32] https://www.gov.uk/government/publications/connected-and-autonomous-vehicles-market-forcecast

[33] http://pg.jrj.com.cn/acc/Res/CN_RES/INVEST/2015/9/17/f70472c6-f4ad-4942-8eab-3c01f3c717a7.pdf

[34] https://path.berkeley.edu/research/connected-and-automated-vehicles/cooperative-adaptive-cruise-control

[35] https://assets.kpmg.com/content/dam/kpmg/tr/pdf/2018/03/global-automotive-executive-survey-2018.pdf

[36] https://www.technologyreview.com/s/602896/fedex-bets-on-automation-as-it-prepares-to-fend-off-uber-and-amazon/

[37] http://archive.futureagenda.org/pg/cx/view/411?view=acs

[38] http://www.alphr.com/cars/1007293/dhl-aims-for-an-autonomous-future-with-a-fleet-of-self-driving-delivery-vehicles

[39] https://gateway-project.org.uk/uk-first-autonomous-grocery-delivery-trials-in-greenwich/

[40] https://www.theguardian.com/cities/2018/apr/30/robot-delivery-drivers-coming-to-a-campus-near-you-starship-technologies

[41] https://www.zdnet.com/article/this-pint-sized-autonomous-delivery-vehicle-is-coming-to-city-streets-this-year/

[42] https://www.ft.com/content/916b93fc-8716-11e7-8bb1-5ba57d47eff7

[43] https://www.nytimes.com/2017/09/10/technology/amazon-robots-workers.html

[44] http://uk.businessinsider.com/amazons-robot-army-has-grown-by-50-2017-1

[45] https://www.standard.co.uk/news/techandgadgets/amazons-postman-robots-that-could-unlock-doors-to-deliver-parcels-a3758376.html

[46] https://www.forbes.com/sites/parmyolson/2018/01/31/amazon-just-sparked-a-race-to-bring-robots-to-our-doors/#6c1af99c2b3a

[47] https://www.forbes.com/sites/joannmuller/2018/07/24/would-you-rent-your-car-to-a-stranger-gms-maven-hopes-so/#11cf3e85648f

[48] https://www.volkswagenag.com/en/news/2018/08/VW_Brand_We_Share.html

[49] https://www.vtpi.org/avip.pdf

[50] https://medium.com/waymo/growing-waymos-partnerships-in-metro-phoenix-965941451902

[51] https://www.vtpi.org/avip.pdf

[52] https://mcity.umich.edu/shuttle/

[53] https://www.forbes.com/sites/heatherfarmbrough/2018/01/31/ugly-but-useful-stockholm-introduces-driverless-busses/#3372e60560f4

[54] https://www.perthnow.com.au/news/wa/passengers-give-thumbs-up-for-driverless-bus-ng-23861a4c2156a46452f1674d036c853d

[55] https://www.dezeen.com/2017/10/27/germany-unveils-first-driverless-bus-bavaria-technology-transport/

[56] https://www.daimler.com/innovation/autonomous-driving/future-bus.html

[57] https://techcrunch.com/2018/07/03/baidu-just-made-its-100th-autonomous-bus-ahead-of-commercial-launch-in-china/

[58] https://www.straitstimes.com/singapore/transport/centre-for-self-driving-vehicles-opens-in-jurong-west

[59] https://www.autoindustrylawblog.com/2017/10/16/autonomous-cars-are-here-to-stay-but-are-cities-ready-for-them/

[60] https://www.ft.com/content/986d878a-a7c4-11e8-8ecf-a7ae1beff35b

[61] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/725522/ccav-research-and-development-projects.pdf

[62] https://www.smmt.co.uk/wp-content/uploads/sites/2/Connected-and-Autonomous-Vehicles-Revolutionising-Mobility-in-Society.pdf

[63] https://www2.deloitte.com/content/dam/insights/us/articles/3565_Race-to-autonomous-driving/DR20_The%20race%20to%20autonomous%20driving_reprint.pdf

[64] https://www2.deloitte.com/content/dam/insights/us/articles/3913_Driverless-cars-in-the-UK/DUP_Development-of-self-driving-vehicles-UK.pdf

[65] https://www2.deloitte.com/content/dam/Deloitte/de/Documents/consumer-industrial-products/Autonomous-driving-in-Germany_PoV.pdf

[66] https://www.sciencedirect.com/science/article/pii/S0965856417310595

[67] http://www.bain.de/Images/BAIN_BRIEF_An_Autonomous_Car_Roadmap_for_Suppliers.pdf

[68] https://www2.deloitte.com/content/dam/insights/us/articles/3913_Driverless-cars-in-the-UK/DUP_Development-of-self-driving-vehicles-UK.pdf

[69] https://techcrunch.com/2016/05/10/uber-says-that-20-of-its-rides-globally-are-now-on-uber-pool/

[70] https://www.bbc.co.uk/news/world-asia-china-45313074

[71] http://tsctechstrategy.co.uk/wp-content/uploads/2016/04/Tech_Strategy_Brochure.pdf

[72] https://www.technologyreview.com/s/609674/whats-driving-autonomous-vehicles/

[73] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642813/15780_TSC_Market_Forecast_for_CAV_Report_FINAL.pdf

[74] http://pg.jrj.com.cn/acc/Res/CN_RES/INVEST/2015/9/17/f70472c6-f4ad-4942-8eab-3c01f3c717a7.pdf

[75] https://techcrunch.com/2018/05/27/the-well-funded-startups-driven-to-own-the-autonomous-vehicle-stack/

[76] https://www.ft.com/content/16b55fe8-e79f-11e5-bc31-138df2ae9ee6

[77] http://uk.businessinsider.com/us-uk-self-driving-car-regulations-2018-3

[78] https://www.rand.org/blog/articles/2017/11/why-waiting-for-perfect-autonomous-vehicles-may-cost-lives.html

[79] https://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/sam.html

[80] http://www.europarl.europa.eu/RegData/etudes/STUD/2018/615635/EPRS_STU(2018)615635_EN.pdf

[81] https://medium.com/syncedreview/global-survey-of-autonomous-vehicle-regulations-6b8608f205f9

[82] http://pg.jrj.com.cn/acc/Res/CN_RES/INVEST/2015/9/17/f70472c6-f4ad-4942-8eab-3c01f3c717a7.pdf

[83] https://www.itf-oecd.org/sites/default/files/docs/safer-roads-automated-vehicles.pdf

[84] https://hbr.org/2017/12/driverless-cars-will-change-auto-insurance-heres-how-insurers-can-adapt

[85] http://pg.jrj.com.cn/acc/Res/CN_RES/INVEST/2015/9/17/f70472c6-f4ad-4942-8eab-3c01f3c717a7.pdf

[86] http://www.europarl.europa.eu/RegData/etudes/STUD/2018/615635/EPRS_STU(2018)615635_EN.pdf

[87] http://www.bain.de/Images/BAIN_BRIEF_An_Autonomous_Car_Roadmap_for_Suppliers.pdf

[88] https://www.theguardian.com/technology/2018/aug/28/driverless-taxi-debuts-in-tokyo-in-world-first-trial-ahead-of-olympics

[89] https://ihsmarkit.com/research-analysis/Chinese-government-drafts-policies-autonomous-vehicles.html

[90] https://www.vtpi.org/avip.pdf

[91] https://www.theverge.com/2018/7/20/17595968/waymo-self-driving-cars-8-million-miles-testing

[92] https://www.theguardian.com/technology/2017/nov/07/google-waymo-announces-fully-autonomous-ride-hailing-service-uber-alphabet

[93] http://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=1890

[94] https://www.techemergence.com/autonomous-ships-timeline/

[95] http://archive.futureagenda.org/pg/cx/view/374?view=acs

[96] https://spectrum.ieee.org/transportation/marine/forget-autonomous-cars-autonomous-ships-are-almost-here

[97] https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf

[98] https://www.dnvgl.com/

[99] https://www.rolls-royce.com/media/press-releases/yr-2017/20-06-2017-rr-demonstrates-worlds-first-remotely-operated-commercial-vessel.aspx

[100] https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/rr-ship-intel-aawa-8pg.pdf

[101] http://www.unmanned-ship.org/munin/about/

[102] https://www.eda.europa.eu/docs/documents/SARUMS-Flyer-2012.pdf?sfvrsn=0

[103] http://www.ukmarinealliance.co.uk/MAS

[104] http://english.whut.edu.cn/

[105] https://www.globalpsa.com/autonomous-ships/

[106] http://www.mol.co.jp/en/pr/2017/17031.html

[107] https://www.popularmechanics.com/military/navy-ships/a26836/boeing-teaming-up-to-build-autonomous-submarine/

[108] https://eandt.theiet.org/content/articles/2017/10/researchers-reveal-israel-s-first-autonomous-submarine/

[109] https://www.nato.int/docu/review/2017/also-in-2017/autonomous-military-drones-no-longer-science-fiction/EN/index.htm

[110] https://www.cbinsights.com/research/amazon-drone-air-traffic-control-patent/

[111] https://www.mobileeurope.co.uk/press-wire/nokia-s-drones-take-off-at-twente-airport-in-traffic-management-test

[112] https://www.theguardian.com/technology/2018/aug/26/sebastian-thrun-interview-costs-of-air-taxi-system-less-than-uber-google-glass-flyer-cora-kitty-hawk

[113] https://www.theverge.com/2018/2/1/16961688/airbus-vahana-evtol-first-test-flight

[114] https://www.theverge.com/2017/9/26/16365614/dubai-testing-uncrewed-two-person-flying-taxis-volocopter

[115] https://www.theguardian.com/technology/2018/mar/13/kitty-hawk-autonomous-drone-flying-taxi-service-regulatory-approval-google-larry-page

[116] http://uk.businessinsider.com/pilotless-planes-could-be-a-35-billion-opportunity-wall-street-is-missing-2018-7

[117] https://www.theguardian.com/business/2017/aug/07/pilotless-planes-what-you-need-to-know

[118] https://www.independent.co.uk/news/business/news/airbus-pilotless-planes-self-flying-aircraft-passenger-flights-cto-paul-eremenko-a8068956.html

Contact details

To discuss this project further please get in touch

Dr Tim Jones
Programme Director
Future Agenda

tim.jones@futureagenda.org
www.futureagenda.org
+44 780 1755 054
@futureagenda

FUTURE AGENDA

Open Foresight