FUTURE AGENDA

Open Foresight

THE FUTURE OF AUTONOMOUS VEHICLES

Global Insights gained from Multiple Expert Discussions

Glossary

Abbreviation	Definition
ACC	Adaptive Cruise Control - Adjusts vehicle speed to maintain safe distance from vehicle ahead
ADS	Driving System - Integrated performance of decision-making and operation of vehicle by machine
ADAS	Advanced Driver Assistance System - Safety technologies such as lane departure warning
ADSE	Automated Driving System Entity – Legal entity responsible for the ADS
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
DDT	Dynamic Driving Task – Operation functions that form part of driving the vehicle
DSRC	Dedicated Short-Range Communications - Wireless communication channels specifically designed for automotive use
EV	Electric Vehicle – Vehicle that used one or more electric motors for propulsion
GSR	General Safety Regulation – European type-approval for the safety of vehicles
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
INS	Inertial Navigation Systems - Device that uses sensors to calculate the position, orientation and velocity of a moving object
ISO	International Organization for Standardization - An international standard-setting body
ITS	Intelligent Transportation System - More informed, coordinated and safer transport network.
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
MSP	Mobility Service Providers - Entities that provide consumers with enhanced travel
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
TNC	Transportation Network Company – also known as a mobility service provider (MSP) matches passengers with vehicles
UAV	Unmanned Aerial Vehicle - An aircraft piloted by remote control or onboard computers
VMT	Vehicle Miles Traveled – Measure of distance of travel over a given period of time
V2I	Vehicle to Infrastructure - Wireless exchange of data between vehicle and the highway system
V2V	Vehicle to Vehicle – Wireless exchange of data between nearby vehicles
V2X	Vehicle to External Environment - Wireless exchange between a vehicle and its surroundings

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Foreword

The dream of self-driving vehicles has been a long time coming. It is however now within reach and the pressure is on the deliver on the vision. With sustained technology development, increased investment and raising public awareness, there is enormous interest in the imminent mainstream use of autonomous vehicles on the streets.

Although approaches vary from around the world, policy makers and urban planners in leading locations are now seeking to collaborate more with manufacturers, mobility providers, tech suppliers, logistics operators in order to align regulation for testing and mass deployment. And it goes both ways.

The investments being made in autonomy have rapidly shifted from millions to billions, so unsurprisingly those public and private organisations that are providing the funds are keen to ensure that the ROI is credible. There is much to play for and, although there has been substantial progress over recent years, significant questions on safety, social impact, business models and performance are still unanswered.

The Future of Autonomous Vehicles project was undertaken to canvas the views of a wide range of experts from around the world in order to create a clearer, informed global perspective of how autonomy will evolve over the next decade. Beginning with a discussion with government officials just outside Shanghai in July 2018 and ending with leaders from across the US autonomous vehicle community in the hills above Silicon Valley in February of 2020, our project has covered a lot of ground. In all, eight workshops and six additional discussions have engaged with hundreds of different opinions, shared perspectives and built considered future pathways.

We thank everyone involved for their time, input and insight. We would also like to specifically acknowledge the support of the individuals who have helped make this project happen: Alicia White, Alvin McBorrough, Andrea Kollmorgen, Andrew Cooper, Andy Gill, Bryan Sastokas, Caroline Dewing, Cheryl Chung, Christian Haas, Ed Forrester, Glenn Lyons, Gwen Van Vugt, Jan Hellaker, Jeremy Nassau, Lee McKenzie, Linda Beatty, Mark Priest, Martijn Tideman, Rita Excell and Sofie Vennersten.

This report is a synthesis of many voices and opinions on the likely future of autonomous vehicles and, as authors, we have done our best to accurately reflect the views we heard and the context in which they were expressed. Separately we have also sought to include our own reflections but have kept these distinct in the text. We hope that is useful.

During the course of this project two notable shifts occurred. One was expected by some, the other has been a surprise for many:

Just over half-way through there was the late 2019 reset in expectations on what autonomous vehicles can achieve within the next decade or so, where and how: a number of key influencers of opinion changed stance on the speed of autonomous deployment. This was recognised and debated within the discussions as we saw noticeable change in sentiment. This is integrated within the report.

The final workshop of this project in Silicon Valley took place just as the Covid19 was moving from being a regional epidemic towards a global pandemic. As such the expert views expressed in the varied discussions did not anticipate the imminent impact of such a major event. We have therefore refrained from comment on the implications and some lasting shifts in society that may variously accelerate or decelerate new innovation. We recognise that there may well be additional future changes but believe that the insight from this global project provides a sound perspective on how the next decade or so of development and deployment of Automated Transportation Systems will occur in a pre-Covid19 as much as a post-Covid19 world.

All output from this project is available on the Future Agenda platform but all stimulus and reports can be found on the dedicated mini site www.futureautonomous.org

If you have any questions don't hesitate to ask.

1.0 Introduction

Why this topic?

There are great expectations around the future of autonomous vehicles (AVs) and equally, much uncertainty. For example, some believe that AV's will transform safety and efficiency, and are making significant investments in new technologies in this area. At the same time, others are concerned that the technological developments are outpacing society's ability to adapt, and there is an urgent requirement to develop better regulation before there is widespread deployment. Moreover, there are questions in some cities of how far first-deployment trials starting now will evolve to scale by 2030 or beyond. It is clear that there are multiple views – many strongly held by varied parties. Moreover, it is increasingly evident that some of these can be conflicting and contradictory. Given the speed of change in this area, the need is growing to unravel fact from speculation and identify which are the real areas of innovation and opportunity, plus what is hype vs. what is credible.

Beyond this, having ideas, even building prototypes, is comparatively easy, but ensuring they are adopted in the wider community is much more challenging, particularly when it involves changing the status quo and dealing with human interactions. Some suggest, for example, that for AV to get real traction, it may be necessary to turn transport planning on its head, and rather than follow the traditional method of first predicting transport needs, to adopt a more flexible approach. 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 a 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.

Finally, while it is easy to get distracted by current trends and short-term needs, if we look ahead, beyond the immediate transportation problems, and consider the 10 to 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, as well as in the skies.

"The need is growing to unravel fact from speculation and identify which are the real areas of innovation and opportunity."

Summary of Findings

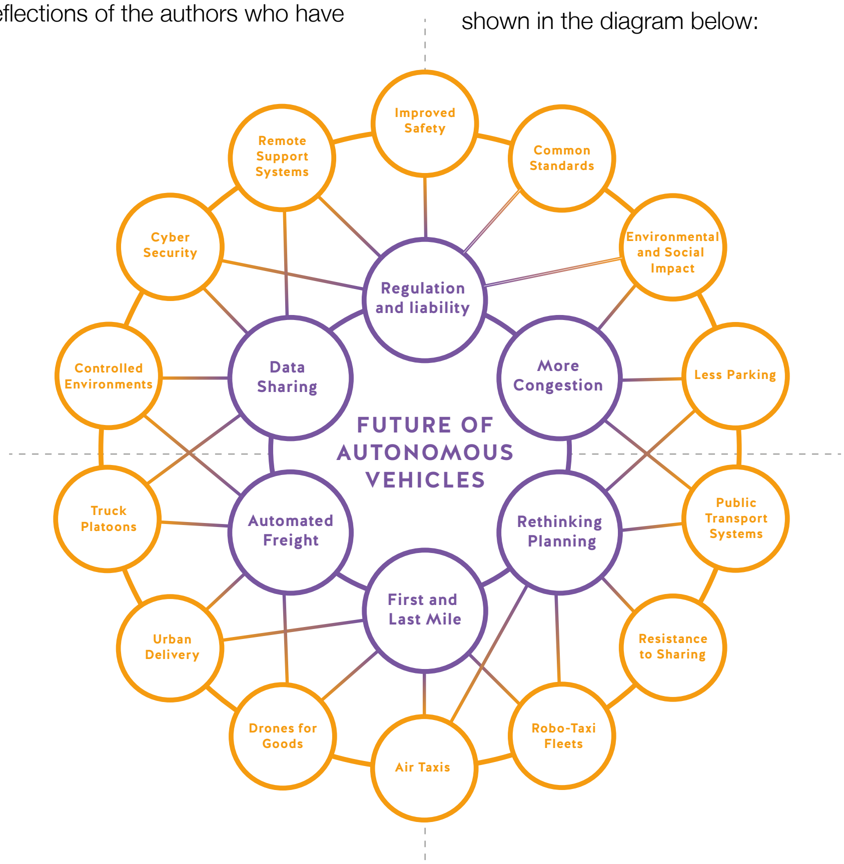
This is a report based on the synthesis of insights gained from a global open foresight project exploring the future of autonomous vehicles that was undertaken throughout 2019 and early 2020. It combines an analysis of existing research with opinion gained from multiple interviews and discussions that have taken place over the past year or so in Shanghai, London, Tokyo, Gothenburg, Austin and Toronto plus a series workshops held in Los Angeles, Frankfurt, Singapore, Wellington, Melbourne, Dubai, Singapore (at the global ITS World Congress event) and, finally, as a finale in Silicon Valley.

The aim is to share the different expert perspectives on how the future of autonomous vehicles will evolve over the next decade and highlight some of the key issues that will drive change. Our ambition is to set the scene for informed debate, highlight the insights gained from our discussions, and then consider some key implications and associated questions for further exploration going forward. The views contained within this document are the opinions expressed by those invited experts who have kindly given up their time to contribute, as well as the reflections of the authors who have organised, facilitated, and captured the research dialogue.

There are many perspectives of how, where, and why autonomous vehicles may have impact. In particular, looking at the next decade, from the discussions in the first batch of workshops, a number of key issues were prioritised, debated, and explored in depth – most in multiple locations. Within these, there are six pivotal high-level macro drivers of change that can be considered to be the focus of greatest debate. These are:

- Regulation and Liability;
- More Congestion;
- Rethinking Planning;
- First and Last Mile;
- Automated Freight; and
- Data Sharing.

Underlying and connected to these, there are also fourteen additional priority topics of focus. These are related to the macro drivers and can be mapped as shown in the diagram below:



Collectively, these twenty areas cover a broad range of the autonomous vehicle landscape, and the comments and feedback gained from the initial workshops provide both detail on how they are being considered, and the level of alignment in the various locations. In summary they are driving multiple changes; we have split them up into four parts for ease of reading:

1: Systemic Considerations

Regulation and Liability

The regions that gain most will be those where regulation acts as a catalyst for AV deployment. Successfully addressing reporting requirements and liability will be critical for adoption.

Common Standards

International standards and commonly shared technologies may be essential for driving global rather than regional AV adoption. Without them, a more fragmented approach will be taken.

Improved Safety

Reducing accidents and road deaths is the political priority behind support for AV. While many benefits can be gained from ADAS, the promise of further major safety improvements is pivotal.

Environmental and Social Impact

Ensuring that autonomous vehicles are cleaner than alternative options may be a pre-requisite in many regions, while the benefit of AVs for wider society is a crucial issue for public endorsement.

More Congestion

Decreasing congestion on the roads is a core ambition for AV advocates, but many recognise that, with mixed fleets operating for several years, we may initially see an increase in urban traffic.

Less Parking

Effective deployment of AVs could mean not only fewer vehicles on the streets, but also that parking spaces are removed enabling narrower roadways and more pedestrian space.

Rethinking Planning

Poor coordination between transit systems, urban planning and solutions may delay AV benefits. For full impact it will be necessary to take a more flexible approach to planning.

2: Moving People

Public Transport Systems

Autonomous buses, shuttles and new mobility solutions to fill transport gaps are introduced. Security, flexibility, reach, interconnectivity and funding are the primary issues for many cities.

Resistance to Sharing

Public support for ridesharing will require a re-evaluation of vehicle design for small groups. Concerns about privacy and safety mean strangers may be unwilling to travel together.

Robo-Taxi Fleets

Robo-taxis are the way forward for passenger transport in suburbs and cities. As part of 'Mobility as a Service' robo-taxis change travel patterns, car ownership, and have to integrate with public transport.

First and Last Mile

Improving the inefficient first and last mile has health, energy and efficiency benefits. In urban environments, scooters, bikes and small autonomous robots all have a role to play.

Air Taxis

Several major cities will support the introduction of air-taxis - initially to allow the elite to bypass increasing congestion on the streets, but later for wider citizen use.

3: Goods Transportation

Drones for Goods
Investment in timely drone delivery services accelerates deployment in multiple locations. Concerns about safety and collisions are overcome with automated UAV air traffic control.

Urban Delivery
Small, slow-moving, autonomous robots offer attractive ROI and act as an accelerator of technology deployment. They enable safe, clean, convenient and low-cost delivery and help to raise public confidence in AV.

Automated Freight
Driverless expressway trucks will transform long-haul journeys and the wider logistics sector. As safety goals are met and haulage costs are reduced, regulatory support evolves with deployment.

Truck Platoons
As the first level of deployed automation, truck platoons help build wider momentum while delivering tangible improvements in efficiency, cost of transportation, energy use and safety.

Controlled Environments
Automation within controlled environments continues to expand steadily. AVs within airports, port terminals and logistics facilities start to venture onto the open road.

4: Data and Security

Data Sharing
Better, deeper and more secure, data sharing is pivotal to enabling the full AV ambition. Mobility brands agree protocols for V2X interaction and support the use of shared data sets.

Cyber Security
With a rising threat of hacks, denial of service, vandalism and theft of data, organisations seek to protect AV through building common approaches for broader, closed but collaborative systems.

Remote Support Centres
Manned support centres initially provide oversight, support and emergency response for all AVs. In the absence of drivers, public transport vehicles require clear remote human supervision.

For our varied discussions it is evident that, across the markets we visited, there are areas of alignment - but also notable nuances in the approach to AVs that are different country to country. We highlight nine key interlocking issues that are emerging as significant:

1. **Fleets are now driving progress:** In terms of the dominant business models, momentum is clearly behind both robo-taxis and truck fleets.
2. **Automated trucks are coming:** Freight has much to gain in terms of efficiency; this has regulatory momentum and wide industry support.
3. **Safety is a pre-requisite:** Expectations are high, but as many advances are already in process, improvements look likely.
4. **Congestion is a conundrum:** While the aim is for less congestion and the role of connectivity is pivotal, user behaviour and Transportation Network Company (TNC) strategies could initially mean more congestion.
5. **Multiple options for the last mile:** There are many alternatives in the mix, all bridging different needs and location gaps.
6. **First vs widespread deployment:** Where and why we see initial AV services may not necessarily align with where mass impact will occur.
7. **Deeper collaboration will be needed:** Moving from partnerships to long-term multi-party collaboration is seen as a critical enabler.
8. **Standards may not be pivotal:** Although comprehensive technical standards are advocated, they are not essential for AV; in some regions, safety standards will support regulation.
9. **Regulators are influencing deployment:** Proactive regulation is attracting companies, but the balance of light vs. heavy regulatory approaches may impact this.

Hosts and Participants

Each of the expert workshops undertaken around the world for this project have been hosted by different organisations, all keen to both bring together informed people in their region or sector to challenge, debate, and define the key future issues for the development and deployment of autonomous vehicles, as well as support the creation of a wider global view. Los Angeles was hosted by LA Metro, Frankfurt by Hochschule Fresenius University of Applied Sciences, HOLM and Deutsche Bahn, Singapore by the Lee Kuan Yew School of Public Policy at NUS, Wellington by the New Zealand Transport Agency and the ADVI (Australia and New Zealand Driverless Vehicle Initiative), Melbourne by Transurban, Dubai by Mott MacDonald, Singapore (ITS event) by WSP and, lastly, Silicon Valley by Siemens.

In addition, as well as discussions with single organisations in Shanghai, Austin, Toronto and Tokyo we have also gained insights from an interim insight sharing session hosted by Drive Sweden in Gothenburg plus a complementary workshop in London supported by Mott MacDonald and UWE. We thank them for all their enthusiasm, help, and guidance.

We would also like to thank the 300 plus individual experts who have taken the time to participate in this project, and who were prepared to voice an opinion and challenge the status quo. Without their insight and help, we would be unable to drive the discussion forward. We thank them all, most sincerely.

A Wicked Problem

As several commentators have recently highlighted, the future of autonomous vehicles can be considered to be a "wicked" problem.[1] This as has been recognised for many years now in the world of public policy and beyond, wicked problems are particularly tricky to address.[2] A wicked problem is

1. Incomplete or contradictory knowledge,
2. The number of people and opinions involved,
3. The large economic burden,
4. The interconnected nature of these problems with other problems.

If we are going to make progress on this, then we need to not only talk to the advocates, but also to the cynics, as well as the agnostics. We have to engage with the innovators, researchers, policy makers, and the human behaviour experts. We should understand the perspective of government, urban planners, and transport networks, just as much as those of the large manufacturers, big tech, and multiple start-ups.

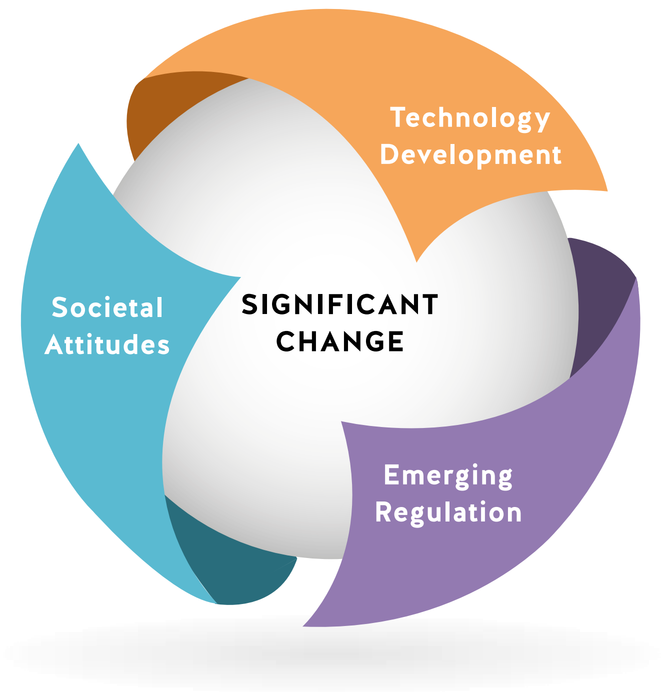
Moreover, we need to recognise that the view in California is not the same as that in Shanghai, Mumbai, or Dubai. Nor is it the same as in Singapore, Tokyo, Brussels, London, and Tel Aviv, or for that matter, between Washington DC or Toronto. Around the world, for multiple reasons, different experts, even within the same area of practice, will have alternative views on the future of both AV development and deployment. In order to gain clarity, we have therefore adopted the Future Agenda Open Foresight approach to anticipating future change for AVs.

"We need to not only talk to the advocates, but also to the cynics, as well as the agnostics. We have to engage with the innovators, researchers, policy makers, and the human behaviour experts."

What is Open Foresight?

Future Agenda uses open foresight to help organisations share their understanding and interpretation of future developments. This methodology, detailed below, is effective in untangling the uncertainties around the significant change which usually results from a convergence of technology development, consumer/societal behaviour, and emerging regulation.

We have found that sharing and building ideas, challenging assumptions and identifying potential pathways with an informed audience in a collaborative manner, helps to both reduce uncertainty about the future, and also enables organisations to design and assess development trajectories toward the future, including scenarios, action plans, and innovation ideas.



Project Approach

Developed in 2010 as an enhancement of previous collaborative approaches to expert-led views of the future, the Open Foresight methodology is based on the idea of bringing together diverse groups of informed people in key locations around the world to debate and build on a key topic of interest. Starting with an initial perspective that is a synthesis of the existing views of potential change, experts in one location critique, evolve, and add to the perspectives from elsewhere, before considering the pivotal areas that they believe will have the greatest impact, and drive change over the next decade in depth. The output from one workshop discussion then becomes the input to the next. By undertaking workshops in different locations around the world, we gain a global view of the key issues that matter and identify regional perspective.

Each discussion is undertaken under the Chatham House Rule, so that no comments are attributed directly to a participating individual or organisation.[3]

However, the insights from every event are made public, and all summary reports and other outputs from the programme are shared under creative commons. Participants gain from immersive interaction with peers on a topic of mutual interest, and everyone benefits from access to the informed views that result. This resulting foresight can then be used by different organisations to challenge strategic assumptions, broaden horizons, highlight new opportunities, and inform future policy, innovation, and investment decisions.

For the autonomous transport topic, we had previously identified potential future changes as far back as 2004 as part of a Shell Technology Futures project.[4] In this programme experts envisaged a 20-year future where "automated highway systems combine magnetic sensors, computers, digital radio, forward looking sensors, video cameras and display technologies in an integrated system to control convoys or platoons of vehicles travelling together."

Three years later as part of a follow-on programme, again exploring a 20-year transition, the vision for autonomous vehicles was that they would “free up passengers to work, communicate with others or simply sit back and enjoy the ride.” It was however recognised that “building such intelligent vehicles is a hugely complex challenge requiring huge amounts of computing power to keep track of the rapidly changing conditions on our roads.” Moreover, key areas spelt out for significant development included sensing obstacles, navigating between locations, steering and avoiding collisions and controlling the vehicles acceleration and braking.[5]

In 2010, as part of the first global Future Agenda programme looking out to 2020,[6] the broader picture of intelligent highways included perspectives that we would see “the introduction of the driverless car – an autonomous vehicle that drives itself from point A to B selecting the best route, avoiding congestion and choosing the speed and distance from other vehicles to ensure that there are no accidents.” It identified the need for “integrated systems needed to allow cars to communicate seamlessly with each other and the ecosystem through which they are moving,” and also highlighted that a “big hurdle is social acceptance.”

Five years on from this in 2015, the advent of autonomous transport was again profiled as part of the second global programme – this time with greater depth on the key drivers of change.[7] This anticipated that “the shift to fully autonomous transport is an evolution via truck platoons on highways and small urban delivery pods. Connected cars create the network and test the technologies for the eventual revolutionary driverless experience.” It also saw that “the advent of cars, trucks and buses that navigate and drive themselves has been a common aspiration. The reality is however getting increasingly closer and, over the next decade, many expect to see some pivotal advances introduced at scale in some parts of the world, though at different speeds in different sectors and in different regions.”

Amongst other points it emphasised that “the key question is whether the next decade will be an evolution or revolution. By 2025, will we see fully autonomous vehicles at scale, or will it be a patchwork approach, where this only happens in certain locations; and, elsewhere, will we see more assisted driving but not the complete autonomous experience?” In addition, commenting on the progress specifically being made by Google (Waymo), it proposed that “the fundamental issue here is whether or not they can pull off driverless vehicles that work in cities, can deal with roundabouts, avoid unpredictable actions by pedestrians and certainly don’t crash.” The conclusion five years ago was that “What remains to be determined are the all-important issues that sit around the core platforms. Mobile operators are already sharing data, but who owns the shared data required to make the whole system work and how it is accessed? This is matter of trust, value and liability and, depending where you are in the world, the balance between government, tech companies and vehicle manufacturers shifts significantly.”

For this latest multinational project, the initial impetus came from discussions in the summer of 2018 held in Shanghai with government and think tanks on the Chinese ambition for leadership in the sector. Subsequent to these, an initial perspective was then developed to map the global landscape, identify the emerging issues and highlight some of the key questions. This was then used to both engage partners, hosts, and lead experts, as well as identify what are the primary centres of innovation, technology development, and AV deployment that should be included in the 12-month project. With initial planning undertaken over the winter, five expert workshops were then undertaken in Q2 of 2019, three in Q3 and the final one in Q1 of 2020.

Starting in March 2019 in Los Angeles, a sprawling mega-city with complex transport needs, operating within a highly diverse technology and policy ecosystem, we first gained a California view on the initial perspective and added additional issues. These were then built on in Frankfurt, a major hub for innovation in the heart of Germany and therefore a key influence for Europe. In June, the project moved on to the densely populated nation state of Singapore, to gain the perspective from this Asian leader, a centre for innovation with a reputation as a pioneer in future thinking and planning, before then heading further south. In Wellington, opinions were added from a relatively sparsely populated country with a proactive perspective on transport challenges and opportunities, before ending the first phase of the project in Melbourne – a recognised leader in multi-modal transport integration on the coast of (with the exception of Antarctica) the world's lowest, flattest, driest, and emptiest continent – but one where the mining sector has, for instance, been a pioneer in automation. After these events an interim report was prepared and shared to summarise the insights gained to date and act as a springboard for the second phase of the project.

In October 2019 two further workshops were undertaken – one in Dubai, the fast-growing Middle Eastern city with major aspirations and associated targets for autonomy on the ground and in the air and another in Singapore with the International Task Force on Vehicle-Highway Automation, an expert group which has been meeting annually for over 20 years as an adjunct to the Intelligent Transport Systems World Congress. After that insights were shared in Sweden, Texas and Toronto as well as with experts in London ahead of the final workshop which took place in Palo Alto in Silicon Valley, the heart of much recent tech innovation, in February of 2020. All in all, across the fourteen events, over 300 experts shared their views and reacted to others' perspectives of what is clearly a fast-changing landscape.

This report details the insights gained from this dialogue and the key implications for the future of autonomous vehicles, especially in the decade ahead. If you have any comments on the points raised, would like to be involved in future discussions, or would like to host an event as part of the next iteration of this programme in 2021, please do get in touch.

"The initial impetus came from discussions in the summer of 2018 held in Shanghai with government and think tanks on the Chinese ambition for leadership in the sector."

The Impact of Covid-19

The final workshop of this project in Silicon Valley took place just as the new coronavirus (Covid19) was moving from being a regional epidemic towards a global pandemic. As such the expert views expressed in the varied discussions did not anticipate the imminent impact of such a major event.

It is possible that post-Covid19 there could be some lasting shifts in society that variously accelerate or decelerate new innovation and transportation behaviours. Commuting patterns may, for instance, change, rush-hours may be spread out and more of us may well continue to work from home more often. Within the world of autonomous vehicles, one could, for example, argue that people will be less inclined to share a robo-taxi vehicle with strangers. Conversely it looks like proof of immunity for individual citizens may be a major shift in many nations that could serve to authenticate both identity and health. As such sharing a monitored vehicle with a validated individual could be seen as a positive incentive for use. There are similar arguments being made both sides on the acceleration of automated local delivery to homes, the shift from global supply chains to more resilient supply webs, a quickening of Chinese international leadership as well as greater government intervention and targeted stimulus in varied economies.

All of these issues are plausible but, as yet, also untested, especially within expert communities across the field of automated transport. As such the authors of this report have not sought to apply personal or dominant media speculation at the time of writing onto the lasting impact of Covid19 to the world of autonomous vehicles discussed in the project. We recognise that there may well be additional future change to those detailed herein but believe that the insights gained and shared from this global project provide a credible guide for how the next decade or so of development and deployment of Automated Transportation Systems (ATS) is a pre-Covid19 as much as a post-Covid19 world.

2.0 Where We Have Come From

Automated Driving

The possibility of developing an autonomous vehicle has been explored for many years – indeed it was part of the GM Futurama exhibit at the 1939 World's Fair. Initially funded by government subsidies and industry consortia in the US, Japan, and Europe, wider interest was piqued through demonstrations and competitions, notably the US Department of Transport in San Diego in 1997, and then DARPA's Grand Challenges in 2004 and 2005. It was, however, the 2007 DARPA Urban Challenge which brought the real possibility of self-driving vehicles into the public arena, and most significantly, captured the imagination of Google executives who went on to launch their own self driving car project in 2009.

Since then, funding and talent has largely shifted from the public to the private sector and has grown rapidly. There has been significant progress in technology development and regulatory freedom to undertake testing on roads. Silicon Valley giants such as Tesla, Uber, and Waymo, the spin off from Google, have all been attracting significant media interest. GM, Ford and other established brands are also working on this and there are parallel developments for automated freight. More recently, China has entered the fray with companies such as Baidu very much part of the collaborations that are moving the sector forward. Expectations around the possibilities of a driverless vehicle near you are running high – but there is uncertainty on exactly how, where and when automated transport will become mainstream.

Development vs. Deployment

The 2010s decade saw massive investments in getting from a basic working unit to a robust, high availability, fail-safe, cost-effective product that the market would accept. This long ongoing incubation period has been due to the need to put in the hard and slow work of getting it right in terms of safety, robustness, and service efficiency. While some observers have been impatient, developers of highly automated vehicles are focused on detailed engineering and testing within a process permeated by careful functional safety analysis and implementation of best safety practices to launch commercial products and services.[8] Completing a comprehensive safety validation process is a key part of achieving regulatory, public, and industry acceptance of new vehicle technology to bring viable solutions to market.

The period 2017-2018 signalled a turning point in intensifying development schedules due to a tragic crash in which an Uber prototype robo-taxi under test in Arizona collided with and killed a pedestrian, even though a safety driver was at the driver controls.[9] Additionally, several Tesla drivers died while using the AutoPilot function.[10] Based on the information available, it appears that in each of these cases, either the safety driver or the vehicle owner was not adequately fulfilling their 'co-pilot' responsibility to monitor the system and intervene when the system capability was exceeded. This raises significant challenges relating to shared human-machine control, and in part motivates the implementation of fully automated vehicles which do not rely on human control.

These have not however significantly slowed testing: Today, we can see myriad locations where autonomous vehicle technology is being developed, and other areas where initial testing is also underway. For example:

- In the US, Ford is testing robo-taxis in several cities and launching a limited ADS fleet in 2021 in Miami, Washington DC and Austin;[11]
- Waymo has a fleet of around 600 AVs in operation, mainly in Phoenix, where it is also working with UPS on local package movement;[12]
- Lyft has provided over 75,000 rides in Las Vegas in partnership with Aptiv as part of the largest US trails to date;[13]
- Walmart and Domino's Pizza are testing autonomous grocery delivery in Houston in partnership with NURO;[14] while
- Peleton is soon launching Level 1 platooned trucks and investing heavily in its Auto-Follower programme;[15]
- In Sweden Einride's electric autonomous system is being used by Coca Cola to transport goods to food retailer warehouses;[16]

Future of Autonomous Vehicles

Where we have come from

- **1939** GM Futurama Concept - World's Fair – New York
- **1945** Cruise control invented
- **1953** RCA Labs test wire-guided miniature car
- **1963** UK TRRL automatic vehicle guidance research project launched
- **1967** Remote controlled car tested at Ohio State University
- **1968** Vienna Convention on Road Traffic enforces driver control of car
- **1977** First Semi-Automated Vehicle Test - Tsukuba, Japan
- **1980** German Bundeswehr tests military robot vehicle
- **1987** EU Eureka Prometheus Project launched
- **1991** US Congress passes the ISTEA Transportation Authorization bill
- **1994** Eureka Prometheus project robotic cars drive 1000km
- **1995** Carnegie Mellon first US coast-to-coast autonomous drive 4500km
- **1995** Mercedes S Class drives from Munich to Copenhagen using computer vison
- **1996** Advanced Cruise-Assist Highway Research Association Demo – Japan
- **1997** USDOT Automated Highway System Demo - San Diego, California
- **1998** Google founded
- **1999** Mobileye founded – Tel Aviv
- **2000** Adaptative cruise control launched by Bosch
- Baidu founded
- **2003** Tesla Founded
- **2004** DARPA Grand Challenge – California
- **2005** DARPA Grand Challenge – California
- **2007** DARPA Urban Challenge – California
- **2008** Rio Tinto launch Mine of the Future project
- **2009** Google Self-Driving Car project launched
- Uber founded
- **2010** TUB self-driving vehicles demo in Germany
- **2011** Nevada authorises AV testing
- Peloton truck AV company founded
- **2012** Florida authorises AV testing
- Google completes 300,000 automated driving miles
- Lyft founded as Zimride
- Amazon acquires Kiva Systems for $775m
- **2013** FlixMobility founded in Germany
- Port of Rotterdam launches automated guided vehicles
- NuTonomy spun out of MIT
- Caterpillar starts robotics trail
- Google completes 500,000 miles of autonomous driving
- Amazon predicts drone deliveries within 5 years
- Tesla announces Autopilot
- **2014** UK Government allows AV testing
- Oxbotica spun out of Oxford University
- Mercedes S Class includes semi-automated features
- Google fully automated prototype tested
- NIO founded in Shanghai
- **2015** Apple launches project Titan
- Uber recruits key talent from CMU robotics centre
- Tesla Autopilot capability introduced
- Audi, BMW and Daimler acquire HERE for $3bn from Nokia
- Volvo launches Drive Me project in Sweden
- **2016** Volvo pledges that by 2020 no one will be killed in a Volvo
- GM invests $500m in Lyft autonomous vehicle partnership
- GM acquires Cruise Automation for $1bn
- Apple invests $1bn in Chinese ride share Didi Chuxing
- Ford and VC firms invest in NuTonomy
- Qualcomm acquires NXP for $39bn
- Toyota and Uber announce partnership

Google | Baidu | Tesla | Lyft | Uber | Volvo

- Lyft announces partnership with NuTonomy
- Peugeot-PSA announces partnership with NuTonomy
- Uber completes 2m miles in automated testing
- Bosch and Nvidia announce AI partnership
- Intel acquires Mobileye for $15bn
- Apple starts testing autonomous vehicles
- Ford invests $1bn in Argo AI
- Audi and Nvidia announce AI partnership
- Daimler and Nvidia announce AI partnership

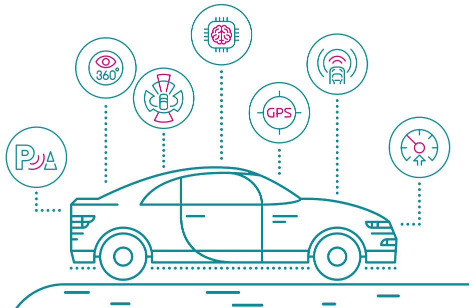
2017

- Intel invests in HERE
- Waymo spun off as separate company from Google
- Amazon drone testing in Cambridge, UK
- Tesla Autopilot completes 300m miles of operation
- US Federal AV policy agreed
- Pony.ai founded
- Samsung acquires Harman Industries for $8bn
- Uber AV prototypes in San Francisco and Pittsburgh
- Drive.ai spun out of Stanford University
- Uber acquires Otto truck start-up

- Starsky Robotics truck technology unveiled
- Baidu announces Apollo AV platform and fund
- US Federal AV policy 2.0 agreed
- Ford Lyft partnership announced
- Lyft partners with drive.ai
- Waymo testing without a safety driver
- NuTonomy acquired by Aptiv for $400m
- Tesla semi-truck announced
- Beijing permits AV testing on public roads

2018

- US Federal AV policy 3.0 agreed
- Waymo semi truck announced
- Self-driving Uber car kills pedestrian
- Baidu completes 140,000 km of self-driving in a year in Beijing
- Volvo launches Vera autonomous platform
- Lyft completes 5,000 self-driving car rides in Las Vegas
- China permits city governments to issue AV road licences
- Baidu begins mass production of Apollo self-driving bus
- Uber shuts down AV truck project
- Waymo completes 5m miles of testing



2020 and beyond

- Didi Chuxing spins out self-driving car unit
- Ford acquires Journey Holding and Quantum Signal AI
- Baidu completes 1m miles of test driving
- Toyota partners with Baidu's Apollo platform
- Amazon announces launch of drone delivery for Prime
- Apple acquires Drive.ai
- Volvo and Uber launch self-driving production car
- Lyft IPO
- Uber IPO
- Rio Tinto starts autonomous truck mining with Caterpillar Inc
- Tesla 'Autonomy Day' announcements

2019

- Tesla driver killed in Autopilot mode
- Port of Rotterdam tests autonomous navigation
- California DMV grants permit to Waymo for testing
- Apollo shuttle bus trial at Shanghai Expo
- Waymo subsidiary established in Shanghai

- In France, NAVYA and Air France have deployed autonomous baggage transportation at Toulouse airport;[17]
- In the UK, as part of the Human Drive project, Nissan and partners have set a record for the longest autonomous journey to date;[18] and
- Oxbotica is working with Addison Lee to launch self-driving taxis in London in 2021;[19]
- In Germany, initial tests of platoon trucks have been completed by MAN Trucks, DB Schenker and Fresenius University.[20]
- In China, Baidu has secured permission for testing of self-driving cars in several cities including Beijing;[21] plus
- NIO and Intel-owned Mobileye are partnering on launching robo-taxis in Shanghai;[22]
- In Japan, Toyota has announced a new city with only autonomous vehicles in operation;[23] and
- In Singapore, the government have given permission for testing of AVs to take place on all public roads on the Western side of the island.[24]

Around the world, momentum is clearly building. The challenge however is when and how does development and initial testing move to wider deployment. A key role will be played by the existing automotive sector leaders, known in the industry as OEMs (original equipment manufacturers).

"Around the world, momentum is clearly building. The challenge however is when and how does development and initial testing move to wider deployment."

The OEM Position

From a car industry perspective, the advent of vehicle automation is now a 'given' but the timescales and end-state are presently both core uncertainties. At the core is the strong belief that, not only can many of the elements of the ideal road trip be fulfilled by automation, but mobility can also be expanded for the disabled, elderly, and others who cannot presently drive. The recent heights of investment, testing, and product development across robo-taxis, robo-trucks, robo-buses, and robo-cars, are at a remarkably high level. Never before has there been such intensive and focused funding in the automotive sector and, as for many, automation is becoming aligned with electrification, the potential impact is being amplified.

As early start-ups began attracting significant venture investment, the OEM business case for shared and automated mobility progressively gained more momentum. It was especially brought into focus for many by the former President of GM and currently Cruise CEO, Dan Ammann, who, in 2017, asserted that the lifetime income generated by one of its automated vehicles could, over time, be in the 'several hundred thousands of dollars' compared to their average of $30,000 in revenue from one of their traditional products.[25]

In 2018 the autonomous industry was widely seen as being on the cusp of transformation. So much so that Mary Barra, CEO of GM, suggested that "we will see more change in the next 5 to 10 years than we have in the past 50." The sector, with revenues of over $2tn per annum, was expected to reposition its focus from product sales to becoming a service delivery, and in so doing, revolutionise the way people, goods, and services move about. This is such a significant shift that some have seen that 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.

The Business Opportunity

Given all the activity and investment underway, in recent years, many analysts have, unsurprisingly, been working hard to quantify the opportunity:

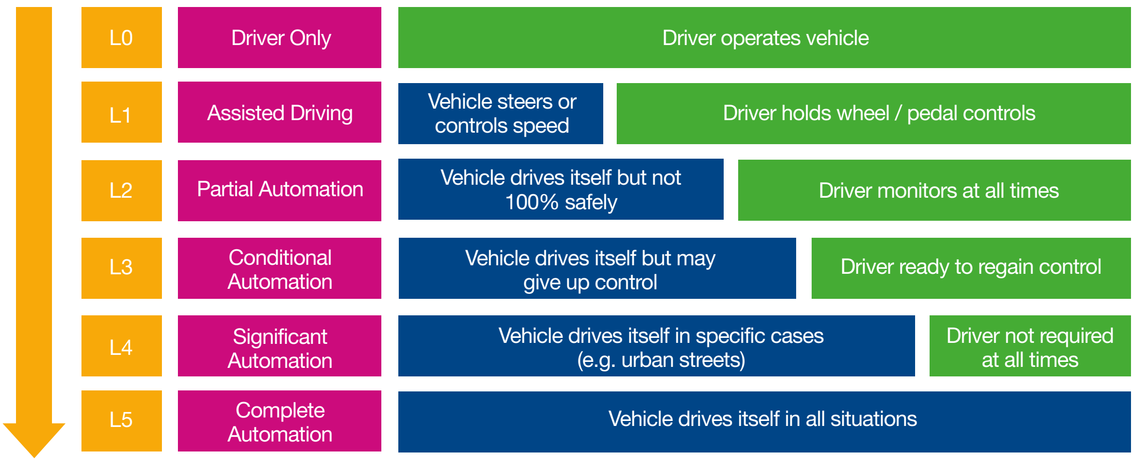
- In a frequently quoted assessment, Goldman Sachs forecast the global AV market to be $96bn by 2025, and that by 2050, the total annual economic benefit of AV adoption could be over $3.5tn;[26]
- In 2016 McKinsey estimated that up to 15% of all new vehicles sold in 2030 could be fully autonomous;[27]
- A year later Accenture suggested that by 2035, as many as 23m AVs will be on the US highways – just under 10% of all registered cars and trucks;[28]
- BCG predicted that by 2030, the shift to "shared, autonomous, and electric vehicles" will account for 25% of all US journey miles;[29] and
- Catching the attention of many investors, in 2017 Morgan Stanley anticipated that by 2030 Waymo's annual revenues would exceed $200bn.[30] A year later the company's value reached the same figure.

Based on the premise that substantial new sources of profits will result from individuals extensively accessing low-cost automated mobility, total investment reached tens of billions of dollars, with more expected to come. In early 2019, the VDA, for instance, estimated that Germany's car industry alone would invest €18bn in 'digitisation and connected and automated driving' by 2021.[31]

The AV Roadmap

Within the field, the most commonly used definition of automation levels remains 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.

While widely adopted and so useful in order to discuss the various approaches to automation, some suggest that the 6 levels should not 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. That said and recognising that while some feel that L5 may not happen within the next decade, for this research project we have used this terminology throughout the associated initial perspective, interim and final reports.



3.0 The Forward View

2019 – A Reset Year

During the course of this project a number of key influencers of opinion changed stance on the speed of autonomous deployment, and we have seen a noticeable change in sentiment compared to when we shared the initial perspective in late 2018. There is still confidence in overall direction, but greater uncertainty about the specifics of how we get there and time to impact. Although, for example, Waymo recently raised $2.3bn from a group of outside investors, the value of the company has fallen in 18 months from $200bn to $30bn. Some assert that automated driving has now proceeded past the Gartner Hype Cycle 'peak hype' and may be heading towards the 'trough of disillusionment'.[32] Indeed, in many eyes 2019 emerged at a "Reset Year" for ADS plans and expectations.

Several industry leaders, such as Cruise Automation, who previously announced that driverless mobility services would be available in 2019, could not get there and have not yet stated an updated deployment timeframe. In addition, Apple's autonomous vehicle testing program saw a significant decrease in 2019, with its fleet driving 72,201 miles less than it did in 2018 – a 90% reduction.[33] On the other hand, in 2019 Waymo went ahead and launched 'true driverless' robo-taxi services in Phoenix, Arizona, with service ongoing as of the time of writing. Equally the ever-expanding Tesla feature set continues to add pressure for passenger car OEMs such that leading companies are poised for launching L3 or higher autonomy in the next few years.

However, having caught the vision and while still strongly embracing the promise of automated driving, much of the automotive industry and investment community has recently entered into a strategic re-prioritization. "A year ago, many industry executives exuded much greater certainty. They thought that their engineers had solved the most vexing technical problems. Companies like Waymo and GM now say they still expect to roll out thousands of self-driving cars — but they are much more reluctant to say when that will happen."[34]

For some, this has propelled a complete reformation of what it means to be a vehicle manufacturer, for others it has questioned some core brand propositions. For example, to catch up with some of its peers Toyota has invested hundreds of billions of Yen in Uber,[35] while Korean Hyundai is spending $35bn on autonomous and electric vehicles with an ambition to be a major supplier to robo-taxi fleets.[36] In the US, GM Cruise's CEO Dan Ammann is also bullish: "If you don't have thousands of engineers working on this, and billions of dollars of capital to spend, and deep integration with a car company, then your chances of success are very, very low. As of right now there is only one company—which is us—that has all of those things in place."

By contrast, others have withdrawn from their previously proactive positions and have come back to focus on the basics of building highly capable cars for traditional markets. Several major OEMs are now moderating autonomous ambitions and so managing expectations:

- Volvo CEO Hakan Samuelsson sees that automated driving "is a bit more challenging technically than we originally thought,"[37] while Alex Hitzinger, CEO of VW Autonomy, is "confident in VW's ability to make a Level 4 autonomous vehicle" but also recognises that full L5 automation may well not happen anytime soon.[38]
- Daimler CEO Ola Kaellenius has shared that his company will 'right-size' its spending level on robo-taxis due to increased costs and regulatory hurdles, noting that "there has been a reality check setting in here; ensuring that self-driving cars are 100% safe in crowded urban areas is proving to be a bigger challenge than engineers had assumed a few years ago."[39]
- Ford has similar views. In the same year that it expanded its AV partnership attracting extra investment from VW into Argo AI, CEO Jim Hackett stated that "while Ford still plans to roll out autonomous vehicles in 2021, the use cases will be limited. We overestimated the arrival of autonomous vehicles; applications will be narrow, what we call geo-fenced, because the problem is so complex."[40] More optimistically, COO, Jim Farley, hopes to convince Wall Street that the company is still crafting a high-margin business, with potential for significant profits from its autonomous vehicle unit and emerging mobility services. "Those are going to be the proof points for the sustainability of Ford's transformation; we believe in it."[41]

GM CEO Mary Barra now sees a bigger picture for mobility.[42] "Once you start to believe in the science of global warming and look at the regulatory environment around the world, it becomes pretty clear that to win in the future, you've got to win with electric and driverless vehicles. This is what we really believe is the future of transportation. If we don't take the steps to keep the company healthy for not just the next few years but the next few decades, then shame on me."

Moving Forward

Most of the major OEMS are still looking at spending an average of around $10bn each on bringing automation to the highway. However, across the sector as a whole there are varied approaches now being supported: some are ramping up sales of robo-taxi fleets; some are directly implementing the service model; while others are sticking to the traditional model of selling cars to people.

While there is still growing enthusiasm and increasing investment, 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 without 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 have been suggesting more than 20 years as the minimum for significant change in the total fleet.[43] Others consider that it may be quicker, as perhaps we have already reached ‘peak car’ volume in the US and Europe. In 2017 BCG suggested 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.[44] In the UK, the Government has an objective to see fully driverless cars on public roads by 2021. According to KPMG, by 2030, 75% of the UK motor-park (vehicles in use) will comprise connected vehicles, of which around 40% will be partially automated, but less that 10% will be fully autonomous. Other experts have advocated changing the benchmarks and, instead of focusing on targets for vehicle volumes they are looking at the number of trips served. Some companies are also now arguing that the best way to get more self-driving vehicles on the road is by using them in controlled settings and situations.

BCG’s assessments proposed 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 the US (30% by 2035).[45] Today, opinion is moving towards Asia deploying faster, with the likes of McKinsey envisaging that China will start mass adoption of highly autonomous vehicles in 2027.[46] The Economist concurs.[47] As ever, government plans set the pace, and a mandate from the Chinese central government requires that 50% of all new vehicles sold in China by 2020 must have partial or full autonomous functions.[48]

Globally, according to Goldman Sachs 2019 analysis, over $120bn of VC funding in new mobility solutions has been invested in the past ten years, with $100bn in past 4 years alone.[49] An increasing share of this is anticipated to focus on automated driving which attracted $10.3bn in 2018 alone.[50] Although investors have ‘sobered up’ and are more discriminating, significant venture capital is still flowing into ADS enabling technologies. While big-tech and the large OEMs are making significant investments and acquisitions, major investors such as Y Combinator, Techstars, ZhenFund, Plug and Play, Qualcomm Ventures and Sequoia capital continue to be active in start-up funding which alone now amounts to over $15bn.[51]

“Over $120bn of VC funding in new mobility solutions has been invested in the past ten years, with $100bn in past 4 years alone.”

Realistic Expectations

Around the world, there are clearly still great expectations around AV, but more are now asking how will this potential change actually occur, and at what speed? A significant number of elements need to align, so many believe it will take more time than some would wish. If you compare this to other transport innovations, automatic transmission took 50yrs to scale, GPS took 35yrs, while airbags took 25yrs.[52] However, none of these innovations provided drivers with the ability to do something else while on a journey and this could be a pivotal catalyst.

Reviewing recent analysis, varied organisations are now sharing more considered views for the next decade:

- For wider mobility context, Goldman Sachs predicts that ride-hailing will expand at 5% CAGR and so the number of vehicles per licenced driver in developed markets will decline from 2028;[53]
- More specifically for automation, KPMG suggests that roughly half the cost of on-demand private hire vehicles relates to the driver and as a result, estimate that AV MaaS provision could be up to 40 percent cheaper than private vehicle ownership by 2030;[54]
- PWC considers that adoption of AVs in major cities for 'high-utilisation' applications will be the first segments where the economics will make sense;[55]
- Exploring the demand side of the equation, recent WEF-supported consumer research across ten countries has suggested that nearly 60% of people are ready to ride in a self-driving vehicle; and[56]
- Waymo believes that "we are able to do the driving task, but the reason we don't have a service in 50 states is that we are still validating a host of elements related to offering a service. Offering a service is very different than building a technology."[57]

Meanwhile across the sector the key technology suppliers are confident. For example, Aptiv CEO Kevin Clark is seeing 'soaring demand' from automakers for more basic semi-automated driving features and estimates orders from robo-taxi firms to generate $500M revenue in 2025. Meanwhile Mobileye CEO, Amnon Shashua, has an ADAS to AV strategy "that will enable us to address key segments of a significant Total Accessible Market (TAM) for ADAS and data of $72.5 billion and an estimated $160 billion TAM for robo-taxis by 2030."[58]

Freight

Although car manufacturers have variously had a recent period of self-reflection, the same cannot be said for their freight counterparts. Having led the autonomous development field in the past, truck OEMs are now again at the forefront of automation. More than any other sector, over-the-road trucking is emerging as the centre of re-invention and momentum continues to build steadily. First it was truck start-ups going it alone, now OEMs such as Daimler, Volvo, Traton and Paccar have all ramped up L4 programs and funding. The potential for impact is significant: Globally the freight industry represents a $3.8tn market and $700bn in the US alone.[59]

BCG, for one, now expects that while only 10% of new light commercial vehicles (LCVs) may be autonomous by 2030; in contrast approximately 20% of new heavy-duty trucks (HDTs) will be AVs.[60] As well as growing confidence in the technology, the ability to run vehicles 24/7, and so not be constrained by driver rest periods, is a major commercial attraction. Moreover, in markets such as the US, the expected driver shortage is noted as a key additional factor that favours support for freight AVs. Also, whereas in some eyes autonomy in passenger cars is linked to the roll out of EVs, in commercial vehicles automation and a shift in energy platforms are decoupled. Therefore, many AV trucks will initially be adaptations of traditional diesel-powered vehicles. Priority use cases are envisaged to be medium and heavy-duty trucks for intercity delivery and long-haul transportation plus controlled environments such as logistics yards.

4.0 Certainties and Uncertainties

As with other topics we have explored recently such as patient data, digital identity and the value of data, the future of autonomous vehicles is indeed an area where there are many variables in play. Across the field there are a wide range of different development pathways being discussed, pivotal technologies being tested and assumptions about business models and user interaction being evolved. Foresight projects always have to grapple with what is possible, what is probable and what is plausible and, from there, build a clearer future perspective. Foremost for many is to differentiate between what is certain and what is uncertain and then explore the uncertainty through focused interrogation and interaction.

What We Know

While there are multiple ongoing debates, there are nonetheless, five main issues around which many in the autonomous vehicle field agree. These are not 100% guaranteed, but they are as close as we can currently get to 'certainties' upon which assumptions and future scenarios can be based.

AVs will Initially be Expensive: With all the up-front investment as well as the additional technology that will be embedded within the vehicles and the wider intelligent infrastructure, the price of AVs will be significantly higher than today's cars and trucks. Over time, costs will reduce but there will continue to be a premium. Fleet operations will thus dominate the early years as the economics rely on Return on Investment.

High Utilisation is Critical: For the target cost-per-mile to be viable, AV fleet business models assume high daily use of vehicles – potentially up to 24/7. Each AV will drive between 100,000 and 300,000km a year and so will more follow a consumer product lifecycle than a traditional long-term transportation model. Updates and upgrades will be frequent.

China and the US in the Front Seat: Given the size of the domestic market, technology development already underway, the level of investment underway, government support and proactive regulation, alongside the US, China and Chinese companies will also play a major role in the field. In the US the regulatory environment enables private funding to drive early deployment. A China discussion highlighted that the central government had given Shanghai alone $50bn to invest to be a world leader EV and AV.

Monitoring is Assumed: While highly automated and able to eventually operate autonomously, all AVs will be monitored by both people and machines. Human supervision, either in the vehicle or remotely, will be required by regulators and expected by users in the early years and, over time, as trust builds some of this will be undertaken by machines.

Autonomous Vehicles will Look Different: Although much of the testing is taking place with adapted conventional cars and trucks, when they are deployed at scale by fleets AVs will be distinctive. Autonomous trucks will eventually be cab-less while autonomous robo-taxi cars will be designed for multiple person shared occupancy. Prototypes such as Volvo Truck's Vera[61] and Cruise's Origin[62] are good examples. For privately-owned passenger cars, coming in significant volumes after 2030, interiors are also likely to evolve substantially. While these are five issues are largely agreed upon, there are however many other areas of debate.

"Foresight projects always have to grapple with what is possible, what is probable and what is plausible and, from there, build a clearer future perspective."

Key Questions

In the 2018 initial perspective, *'Autonomous Vehicles: Mapping the Emerging Landscape'*, we reviewed many of the key recent developments and issues raised in and around the field. As well as exploring the various potential benefits of AVs and the multiple use cases across goods transport and people movement, we also looked at some of the specific opportunities and concerns. These included urban delivery, platoon and fully automated freight, passenger vehicles, public transport, as well as the application of AVs at sea and in the air. Across this, we also considered many of the pivotal drivers of adoption from the impact on safety, public opinion, regulation, and insurance to both the key technologies and the associated matter of technology readiness. We also examined some of the common misconceptions that are being made between connected vehicles and autonomous vehicles. All of these are detailed in the initial perspective document, and from them, we identified a number of key questions. These are some of the major points that need to be answered if all are to have a better view of the field, the opportunities, and the attendant timescales to impact.

The twelve original critical questions that were proposed as pivotal for how the future AV landscape will emerge, were:

1. Where will be the key hotspots for AV development and deployment?
2. Which socio-political 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 of 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 various systems needed to enable AV to operate?
12. Who will customers trust more to deliver a safe, reliable, and comfortable AV experience?

As we then moved forward to engage in the series of expert discussions in key locations around the world, exploring the key uncertainties and so gaining a rich, informed, and credible view, these twelve questions have become the cornerstone of the starting point of the dialogue. They, along with the supporting insights, became the 'stake in the ground' on the future of autonomous vehicles, that we then invited multiple experts to challenge, amend, build up, and refine in the various workshops.

At the halfway point, after the workshops in Los Angeles, Frankfurt, Singapore, Wellington, and Melbourne, plus additional parallel discussions in Japan, the UK, and the Netherlands, we collated a number of different, informed views on what experts across many key regions think are the answers to these questions and the future of AVs. In addition, we added twelve further questions to explore in the second phase of the project. These were:

1. What lessons can be learned from other sectors?
2. How much will AVs be tied to EVs, and therefore intertwined with charging infrastructure roll-out?
3. Will air-taxis have impact beyond a few niche locations?
4. How will drones used for parcel delivery integrate with drones for other purposes?
5. How will planning evolve to become a public/private partnership?
6. Will private companies contribute to the cost of the infrastructure, and will public sector agencies allow for this?
7. Will the growth of AVs mean more open/liveable/walkable urban public spaces?
8. How will cities adapt today's public transport systems in an era in which automated MaaS overlaps their mission?
9. How will designers overcome resistance to sharing rides with strangers?
10. For what types of routes and freight will Level 4 truck automation happen first?
11. How will supply chain approaches be transformed by Level 4 truck automation?
12. What effect will growth in AV urban/suburban parcel/grocery/food delivery have on other road users?

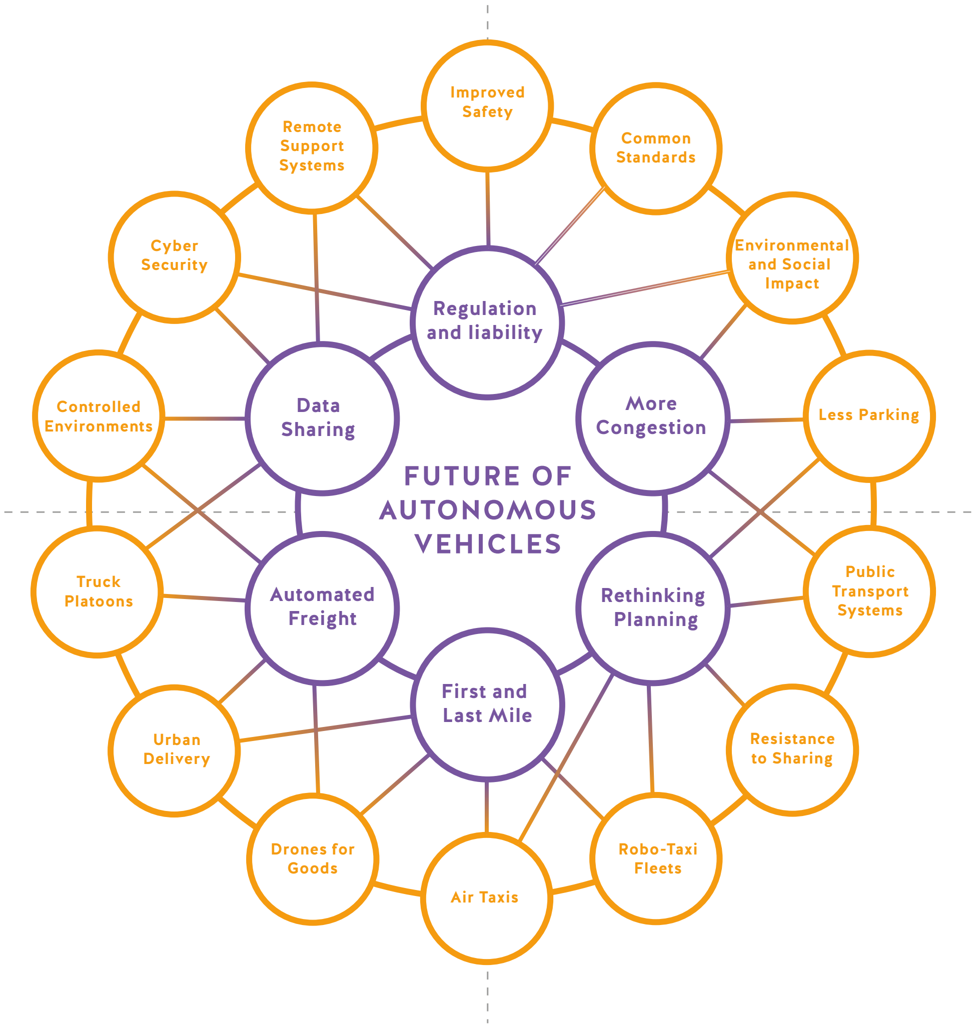
In the following main section of this report we have sought to both playback what we heard about the future of autonomous vehicles from all the expert dialogue as well as to address these core questions.

5.0 Key Insights

From the discussions across the workshops, a number of issues were explored in depth – most in multiple locations. From these we identified six high-level macro drivers that were considered to be the focus of greatest future change. These are:

- Regulation and Liability;
- More Congestion;
- Rethinking Planning;
- First and Last Mile;
- Automated Freight; and
- Data Sharing.

Underlying and connected to these, were fourteen additional priority topics. These are related to the macro drivers and can be mapped as shown in the diagram below:



Collectively, these twenty areas cover a range of subjects across the autonomous vehicle landscape. We have split them up into four parts for ease of reading:

1: Systemic Considerations

Regulation and Liability
The regions that gain most will be those where regulation acts as a catalyst for AV deployment. Successfully addressing reporting requirements and liability will be critical for adoption.

Common Standards
International standards and commonly shared technologies may be essential for driving global rather than regional AV adoption. Without them, a more fragmented approach will be taken.

Improved Safety
Reducing accidents and road deaths is the political priority behind support for AV. While many benefits can be gained from ADAS, the promise of further major safety improvements is pivotal.

Environmental and Social Impact
Ensuring that autonomous vehicles are cleaner than alternative options may be a pre-requisite in many regions, while the benefit of AVs for wider society is a crucial issue for public endorsement.

More Congestion
Decreasing congestion on the roads is a core ambition for AV advocates, but many recognise that, with mixed fleets operating for several years, we may initially see an increase in urban traffic.

Less Parking
Effective deployment of AVs could mean not only fewer vehicles on the streets, but also that parking spaces are removed enabling narrower roadways and more pedestrian space.

Rethinking Planning
Poor coordination between transit systems, urban planning and solutions may delay AV benefits. For full impact it will be necessary to take a more flexible approach to planning.

2: Moving People

Public Transport Systems
Autonomous buses, shuttles and new mobility solutions to fill transport gaps are introduced. Security, flexibility, reach, interconnectivity and funding are the primary issues for many cities.

Resistance to Sharing
Public support for ridesharing will require a re-evaluation of vehicle design for small groups. Concerns about privacy and safety mean strangers may be unwilling to travel together.

Robo-Taxi Fleets
Robo-taxis are the way forward for passenger transport in suburbs and cities. As part of 'Mobility as a Service' robo-taxis change travel patterns, car ownership, and have to integrate with public transport.

First and Last Mile
Improving the inefficient first and last mile has health, energy and efficiency benefits. In urban environments, scooters, bikes and small autonomous robots all have a role to play.

Air Taxis
Several major cities will support the introduction of air-taxis - initially to allow the elite to bypass increasing congestion on the streets, but later for wider citizen use.

3: Goods Transportation

Drones for Goods
Investment in timely drone delivery services accelerates deployment in multiple locations. Concerns about safety and collisions are overcome with automated UAV air traffic control.

Urban Delivery
Small, slow-moving, autonomous robots offer attractive ROI and act as an accelerator of technology deployment. They enable safe, clean, convenient and low-cost delivery and help to raise public confidence in AV.

Automated Freight
Driverless expressway trucks will transform long-haul journeys and the wider logistics sector. As safety goals are met and haulage costs are reduced, regulatory support evolves with deployment.

Truck Platoons
As the first level of deployed automation, truck platoons help build wider momentum while delivering tangible improvements in efficiency, cost of transportation, energy use and safety.

Controlled Environments
Automation within controlled environments continues to expand steadily. AVs within airports, port terminals and logistics facilities start to venture onto the open road.

4: Data and Security

Data Sharing
Better, deeper and more secure, data sharing is pivotal to enabling the full AV ambition. Mobility brands agree protocols for V2X interaction and support the use of shared data sets.

Cyber Security
With a rising threat of hacks, denial of service, vandalism and theft of data, organisations seek to protect AV through building common approaches for broader, closed but collaborative systems.

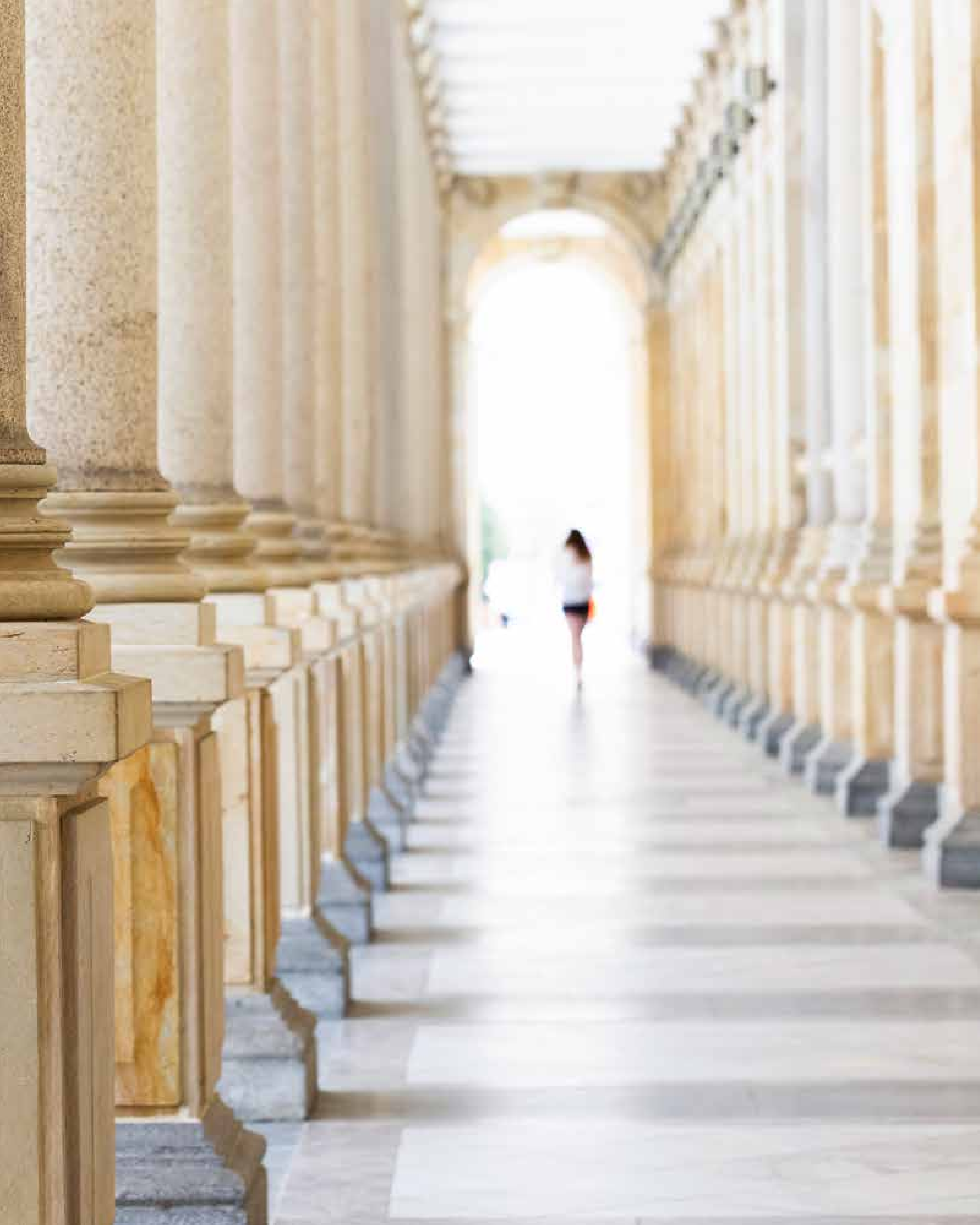
Remote Support Centres
Manned support centres initially provide oversight, support and emergency response for all AVs. In the absence of drivers, public transport vehicles require clear remote human supervision.

The comments and feedback we gained provide both detail on how they are being considered, and the differing levels of alignment across the various locations we visited. These are all explained in the following section of the report.

For each area we have provided:

- Context including a summary of some recent developments,
- Details of what we heard in the workshops,
- An assessment of the potential shifts that were identified,
- A perspective for progress by 2030, and
- A summary map illustrating the geographic perspective on impact.

Part One: Systemic Considerations



Regulation and Liability

The regions that gain most will be those where regulation acts as a catalyst for AV deployment. Successfully addressing reporting requirements and liability will be critical for adoption.

Context

In addition to technological development and business models, creating an appropriate regulatory environment will have a major impact on how, where and when AV is rolled out. Without it, for example, liability insurance could be impossible in some regions. Policy makers are keen to take up the challenge. In 2018 an EU survey found that 87% felt that action around AV was the top regulatory priority; more than for medical robots, drones, human enhancement or human care robots.[63] In particular ensuring alignment with other developments is a growing area of focus for many governments, cities, and companies, particularly for those in the main regions for AV deployment. Approaches vary but proactive engagement is already underway in several locations, such as Sweden, Dubai and Singapore.

Modifications of existing legislation is clearly necessary. Consider, for example the 1968 Vienna Convention on Road Traffic, which has been ratified by 74 countries and stipulates that "a human driver must always remain fully in control of, and responsible for, the behaviour of their vehicle in traffic." Although the US is not a signatory, Germany and the UK, both keen to explore the opportunities presented by AV, are. Alongside this, a range of nations have introduced, or are introducing regulation, for AVs on public roads; Canada, parts of the US, several European countries, the UAE, Russia, China, South Korea, Japan, Australia and New Zealand are all exploring different approaches, many focused on testing but some on deployment as well.

Broadly speaking Europe is being especially pro-active around AV policy and regulation. For example, in 2019 the EU introduced an exemption within its Type Approval process in order to enable AV functions in specific countries; Germany now allows Level 3 vehicles. Europe has also recently significantly revised its 2019 General Safety Regulation (GSR), for the first time in 10 years.[64] The process involved the European Commission, the United Nations Economic Commission for Europe (UNECE), the European Parliament and the European Council. The mainstay within UNECE is Working Party 29 which includes both industry and government officials from around the world. Europe's timeline calls for the implementation of the new safety regulations including, for instance, driver drowsiness and attention warning systems by May 2022 for new type-approvals and May 2024 for all new vehicle registrations.

In an unprecedented move worldwide, the GSR also addresses automated vehicles at SAE Levels 3, 4, 5 (where the human is out of the loop for some or all of the time). These AVs will be required to have "systems to replace driver control" and "driver readiness monitoring" (for Level 3 where driving responsibility is shared with the driver), plus event data recorders (to indicate whether the human or system was doing the driving so as to establish legal responsibility in a crash). However, implementation dates are not yet prescribed for the ADS items.

Australia's National Transport Commission is spearheading an AV policy approach, initially for cars only, which defines an Automated Driving System Entity (ADSE) that would be fully responsible for safe operation and must be registered with the government.[65]

"Creating an appropriate regulatory environment will have a major impact on how, where and when AV is rolled out."

Integrated to the regulatory shifts is the question of how vehicles and people will be insured. In terms of profitability, one HBR article highlighted that "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."[66] In addition, with more fleet owners there will be increased 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.

It is certainly clear that auto insurance, historically one of the most profitable areas of the insurance sector, is facing a major disruption.[67] 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. But where does responsibility lie in the new world of AV? Also, if the likelihood of a car crashing is significantly reduced, so too will be the need for insurance. The vehicles that have ADAS or are truly autonomous may only require minimum coverage and will probably have little need of personal accident insurance. Various approaches are being considered and, in some countries, such as the US, this changes from state to state. In the European Union, particularly in Germany, there is a move towards a stricter liability system.

Agreeing liability is a key factor. Indeed an OECD study claimed that it will remain the most important barrier for the manufacturers and designers of autonomous vehicles.[68] Back in 2015, Volvo and Mercedes Benz stated they will assume liability when the human is not in charge of driving, but these statements have not been re-affirmed recently. Tesla has extended insurance to purchasers of its vehicles but has not assumed any more liability for crashes than other OEMs. Rather than fully pre-defining liability parameters, the US legal system sees responsibility being worked out case-by-case within the courts.

With the advance of the robo-taxi model, things may however evolve further. When fleets of AVs are providing services the personal insurance questions change significantly as the likes of Uber, Lyft and Grab could well self-insure. Insurance for personally owned vehicles is heavily regulated in the EU and US, such that insurers are inhibited from innovating due to boundaries set by state regulators. However, in a robo-fleet world, insurance could be a B2B relationship that is highly flexible, possibly similar to that used now for private bus companies. Another option debated in the UAE is maybe for the government to self-insure the initial deployment of AVs.

What We Heard

Around the world, the impact of regulation was consistently rated as one of the most important issues for the future of AV deployment. Taking the ten-year view, one comment in Silicon Valley was that by 2030 we could well be *"stuck at level 3 due to a lack of progress with regulation"* or even *"at level 2.999 grappling with liability."* Those in Singapore agreed with a view that *"globally there will be limited progress due to regulation and liability."*

Although there have been a number of recently announced alliances, our initial discussion in Los Angeles highlighted that there is a great need for better engagement on this topic. This is not just sharing information and dialogue between OEMs, regulators and technology developers, but deeper collaboration across the board: between public and private systems, around emerging infrastructure needs and on business models: *"profit motives will need to become aligned with public good."* There was recognition that today, many cities / states / nations are operating *"with a patchwork of regulations that are seen as ineffective."* Moreover, if we are to see *"smart regulations that support AV* *deployment,"* then, as was proposed by some in LA, alongside the regulators, ultimately there may need to be "an oversight entity as part of a public/private consortium" that can both *"inform about city-wide plans and also ensure alignment of future transport visions."* This view did not get universal support, however, as some experts felt that more practical, less extreme options may be adopted.

A primary issue is *"the need to establish belief in the necessity for collaboration, as at the moment, there is no incentive across private brands to partner with each other."* Regulation can potentially play an important role here, in forcing key relationships and, specifically, including public-private partnerships (P3) to be part of the AV roll-out. They can align all the players to the value chain and *"ensure that MaaS is an end-to-end system for buses and taxis alike."* In Singapore, the government has been designing the regulatory environment to *"create the collaborative space that is not available elsewhere in the world."* The UAE has similar ambitions. The Swedish regulator has an independent mandate and has set up policy sandboxes to enable better dialogue. In a Gothenburg discussion, this sandbox approach was specifically endorsed *"as key accelerator for AV in Sweden, especially around such issues as safety and liability."*

In Frankfurt the perspective was that *"we are at a crossroads with some nations restricted by old regulation, some fragmented, and others wanting harmonised regulation,"* and that *"by 2030, we need coordinated and flexible regulations that are enabling and testing AV implementation."* Fundamentally, a closer relationship between industry and policy makers is vital – one that supports greater technical synchronisation (including standards), particularly on V2V and V2I, and *"also seeks to align liability and insurance."* The potential positive role of *"an EU wide approach"* was specifically seen as a means to *"unlock what could be a source of big differences between different countries update of AVs."* Several in Silicon Valley also felt that, even while early automation services scale up quickly in the US due to its 'light touch' regulatory approach, by 2030 the EU would be leading the process of establishing comprehensive regulation.

Alongside regulation the liability topic was seen as paramount in Singapore, where it is a key issue for deployment, as currently *"there is no common understanding of what should be insured."* Whereas fleet operations largely use business-based insurance, for private vehicles there is a conundrum. Insurance companies are, for example, debating whether premiums should increase or decrease. In some markets, there are already discounts for vehicles fitted with ADAS because the chance of crashing is reduced, but others consider that in an AV-world, premiums could rise, as *"although there are fewer crashes, the cost of an accident and repair may be high."* While insurance (risk) per mile may go down compared to today, cover per vehicle will probably increase.

From a regulatory perspective, there is the need to clearly define who covers what, and where are the limitations on liability. For example, *"if an insurance company does not provide cover for hacking of AVs, is that covered by the government?"* Maybe it would be the case in Singapore, but not everywhere else. Moreover, if we are to have more information to support claims for liability, *"will all AVs require a black box, like planes"* to provide the necessary confidence and traceability? Many OEMs are already planning for this, but few regions have made it a required part of regulation. Since privately-owned vehicles will lag behind fleet vehicles in moving to higher levels of automation, the personal auto insurance questions have the advantage of being able to benefit from a learning phase during initial robo-fleet deployments. As Singapore seeks to be an enthusiastic adopter of AV, the standard-setter for ASEAN, and so the regional first mover, *"clarity over liability"* is a priority. That said, we heard some suggest that *"China will lead the field because it will have regulation in place by 2021."*

In New Zealand, policy makers see that a major shift is required, from a focus on products and services to one that *"looks at risk and outcomes."* The view was that *"UAV regulation in New Zealand is already moving from prescriptive guidelines to risk-based approaches,"* and the same may apply to land-based AVs.

However, in order to develop a comprehensive new approach for all levels of automation, then *"there has to be both more collaboration with the private sector and an associated capability development."*

In Melbourne, it was suggested that government should take an *"ROI perspective,"* where *"the return for AV deployment is going to have to work at a private and public level."* For private, commercially driven models, *"we will see many trials ahead of pilot deployment in niche markets, and from there it will be possible to scale-up and optimise."* For the public city-driven scenarios, *"the priority will be to develop and agree frameworks including road use pricing."* The view was that the "tension between public and private sector ROI" needs to be overcome. One expert asked: *"why should the private sector make money and not the public sector? What is wrong with government making profits?"*

In Dubai it was expected that *"manufacturers will work with the RTA to help with regulation and maybe co-regulation,"* while in Silicon Valley it was felt that it will be *"cities which expect to have the greatest benefit that will lead."* In several locations specific mention was made about how European cities are limiting access to non-electric vehicles. Many made the assumption that this suggests that support for electric AVs could follow.

What We Think

The leading countries/regions are largely taking a "cars first, trucks later" regulatory approach. This is understandable but unfortunate. The deployment of automated trucks and robo-taxis has significant commercial momentum, and each bring societal benefits. Regulations for these should therefore be addressed in parallel.

We see that for early deployment, the most progress will be made where the regulatory burden is least. Currently, this type of 'light touch' can be found in the US. The downside of this is the increased likelihood of rogue players that have a poor safety culture testing on public roads, a situation we saw with the 2017 Uber crash.[69] Industry momentum has since resumed, but another crash while testing, or in early deployments, could be a significant setback.

In the mid-term, Australia's in-depth work to define the ADSE approach for automated passenger mobility may well provide a model for the rest of the world to consider. In contrast to the US, more deliberative processes of the UNECE / Europe and others will be vital for the longer term. These are highly collaborative processes involving government and industry.

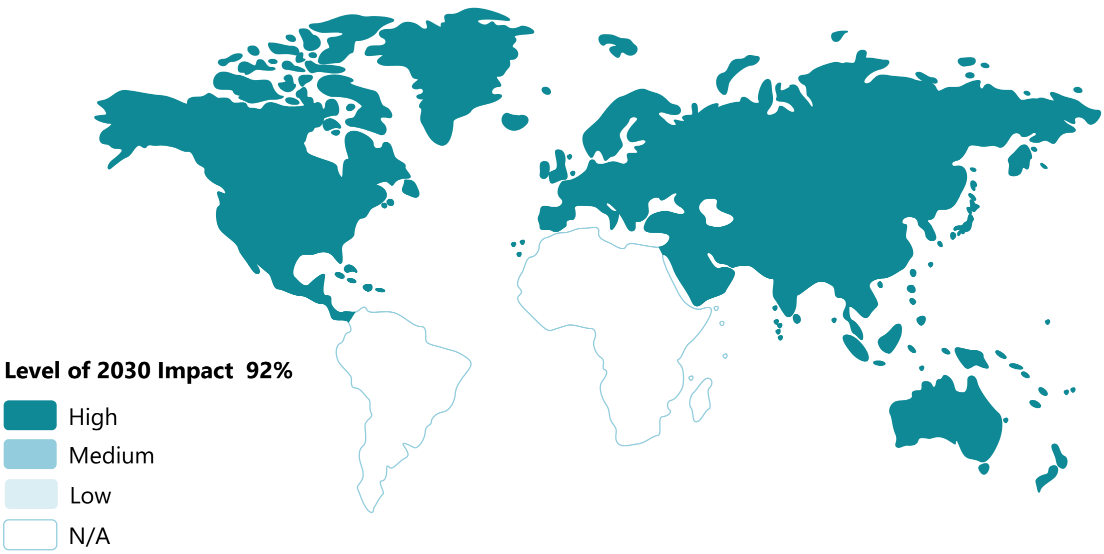
For insurance, it is unavoidable that the entity providing L3+ automated driving capability for public use - in fleet operations or privately-owned - must take on the responsibility for safe operation and the associated liability of not doing so.

Progress by 2030

By 2030, Level 4 fleet operations will be fully allowed in all the major markets – largely due to significant efforts by the global automotive engineering community working with regulators. Plus, in many markets the necessary regulations will also be in place for privately-owned AVs. We are optimistic about progress due to well-resourced industry collaborations and consortia which have arisen recently and are engaging with regulators, insurers, and others addressing safety responsibility. Examples are the Partnership for Automated Vehicles Education and the Automated Vehicles Safety Consortium.[70,71]

Despite some views expressed regarding limited progress, we believe that by 2030 many stakeholders will have grappled with the issues within pockets of deployment, so offering a model to others. Nevertheless, we will still be in the early stages of full deployment, for both personal mobility and freight mobility. For robo-taxis, the scale of operations will track with trends towards city-living.

Insurance will not be a hindrance; it will be a B2B process in which risk is assessed and priced, as is done in some fields today. The liability factors are likely to be sufficiently clear for commercial launch as well. Leading car OEMs, seeking competitive advantage, will choose to take on responsibility but probably with significant constraints on the



Common Standards

International standards and commonly shared technologies may be essential for driving global rather than regional AV adoption. Without them, a more fragmented approach will be taken.

Context

The harmonisation of regulations and standards removes the complexity and cost to conform with varying local standards. These are set and agree ways of doing something and are designed to provide a reliable basis for people to share the same expectations about a product or service. Standards help to facilitate trade, provide a framework for achieving economies, efficiencies and interoperability and enhance consumer protection and confidence. Without them there can be massive duplication of effort, lower margins, unnecessary competition and, ultimately, unhappy consumers. Failure to agree can be costly. VHS vs Betamax is probably the most famous lost opportunity but there are also many others; Blu Ray vs HD DVD in consumer electronics as well as electric car charging points in transport. Estimates vary but different regulations and standards add more than 20% to the cost of trading between the EU and US.[72]

It is imperative to understand distinctions within the standards domain for road vehicles.

- Technical standards address how a product is made, focusing on components and engineering approaches.
- Safety standards focus on how a vehicle is designed to interface with and protect occupants, as well as how it behaves in traffic when in automated driving mode.

Regulators publish safety standards which are legally binding for operating vehicles within a specific market, whereas technical standards are more industry oriented, driven by business efficiency, and generally voluntary. Telecommunications standards, a subset of technical standards, can in effect be mandatory as a company's product must be interoperable with those from other companies, as it the case with mobile phones. Safety standards may be required for AV deployment in some areas due to the regulatory structure. Technical standards are, by contrast, not a prerequisite for deployment.

Standards are set by both international and regional bodies. For autonomous manufacturing these include the Japan Automotive Standards Organisation (JASO) and Korea Motor Vehicle Safety Standards (KMVSS), as well as the Society of Automotive Engineers which is relied upon in many markets. The International Standards Organization (ISO) develops their own standards and coordinates closely with other bodies. Although they are onerous and time consuming to negotiate, care and consideration in their development is vital. Too rapid standardisation can give unfair advantage to first movers and potentially constrain innovation in the long term.

In some regions, such as the EU, regulation and safety standards go hand in hand. Safety standards are tied tightly to the International Standards Organization which interacts with the UN Economic Commission for Europe (UNECE) Working Party 29. All EU countries participate in the debate about the appropriate standards to adopt although, given its dominant position within the European automotive sector, some would argue that Germany plays the most significant role. Once the common standards have been agreed they are frequently used by other national and regional regulators.

The US takes a different stance. Sometimes termed the 'Wild West' approach, the focus is on speedy deployment and encouraging innovation across all the different states. Industry technical standards are only introduced once the market has reached a level of maturity. Safety standards will come eventually but for now 'self-certification' of safety is the norm. In January 2020 the US government introduced its AV Policy 4.0 which aims to ensure a coherent and coordinated approach to AV. However, this plan keeps adoption voluntary, despite calls for specific regulations.[73]

Elsewhere most action has been around agreeing AV safety standards at a national level.[74] Several countries, such as the UK, are seeking to set new standards for CAV safety as part of a national economic agenda to give sector leadership.[75] Meanwhile China has already deployed a set of national AV safety standards for testing that supersede previous regional government guidelines.[76]

Many are keen that AV safety standards should become global as soon as possible. On the technical side, there are significant questions on which approaches should be adopted. A key area of technology focus here is direct connectivity between vehicles, which requires standards to achieve interoperability. There are overlapping yet different approaches in US, EU, China and Japan. As globalised trade is challenged by some nations keen to put themselves 'first', several see that AV technical standards relating to communications may well become a key lever in future trade negotiations.

What We Heard

Overall discussions from multiple workshops addressed both technical and safety standards. Participants from around the world envisage that by 2030 *"we will still be struggling with a lack of [safety] standards."* Certainly, the need for common standards for AV had very different reactions. Not everyone, for example, agreed that *"international [safety] standards will be essential for driving global rather than regional AV adoption".* Those in Dubai rated the issue comparatively low while in Singapore, the opinion was that *"we may see consistent approaches in one location (e.g. Japan), but that does not mean that they will be the same everywhere."* Moreover, *"global agreement will be difficult to achieve, and so will take a long time (if it ever happens)."* Some went on to ask, *"why should China and the US have the same [safety] standards?"*

In New Zealand, it was suggested that given technology is moving faster than standards, perhaps we need a change of perspective. As systems, rather than people, increasingly make decisions, perhaps we should licence the vehicle to operate rather than the driver, and so *"shift from testing drivers and giving them a driving licence, to having [safety] standards for AV systems to meet."* Although not all standards will be accepted by every region, this will mean encouraging OEMS and other Level 4 system providers, such as robo-taxi and AV truck service firms, to define new international safety standards. In addition, it is about *"an increasing integration of standards across vehicles, roads, and telecoms"* – which means more collaboration across sectors is necessary. Within this context, there is recognition of the need to *"ensure that the infrastructure keeps up,"* which may mean more shared functional standards. Here, *"there may be several lessons from the likes of the GSMA[77] on how the mobile industry has been able to manage [technical] standards without constraining progress."* Although the mobile sector took a while to get alignment in the early years, many consider that common agreements have helped smooth 3G, 4G and 5G roll-out.

Elsewhere, others see that common standards as a big ask. Those in Dubai felt that the *"ideal is that standards are global, but this is unlikely any time soon."* Some in the US flagged the issue of Intellectual Property Rights, and their ownership, as a potential barrier which could move the technical standards focus from how capabilities are implemented to how the vehicle behaves in traffic.

In Los Angeles, several highlighted the need for *"the creation of comprehensive data models that can support [technical] standards development."* If *"by 2030, we envisage global common standards and open data sets"* to enable MaaS at scale, then the key challenge is *"how best to ensure data sharing with common communication standards between AVs and everything else – public infrastructure, other vehicles, and the wider transport networks".* This will require a change of priority for mobility providers, as the *"companies will have to be willing to share data (and not focus only on monetising it)."*

In Silicon Valley one view was that achieving *"international [safety] standards are unrealistic by 2030"* but *"we do need to think globally"* as *"a lack of [safety] standards is the biggest block to mass deployment."* They acknowledged that "China and EU will set [safety] standards for themselves at scale" and expressed concern that these could become the global norms and most nations *"will be driven by EC type approvals that have influence."* This raised the question of *"whether the US sets [safety] standards for itself, but not for the world."*

"As systems, rather than people, increasingly make decisions, perhaps we should licence the vehicle to operate rather than the driver."

What We Think

All vehicles on the road, not just automated vehicles, will require increased data sharing and common communication standards between themselves and the wider infrastructure, other vehicles, and the broader transport networks for greatest benefit. The development of common technical standards around AV is one of many issues in the normal course of business. When the economic pain from a lack of technical standards is felt broadly enough, standards processes will begin in earnest.

New technologies often start with fragmentation and are driven by business dynamics to later create technical standards for inter-operability. Regional technical standards can also apply to AVs because they are not particularly portable (in comparison to mobile devices for example).

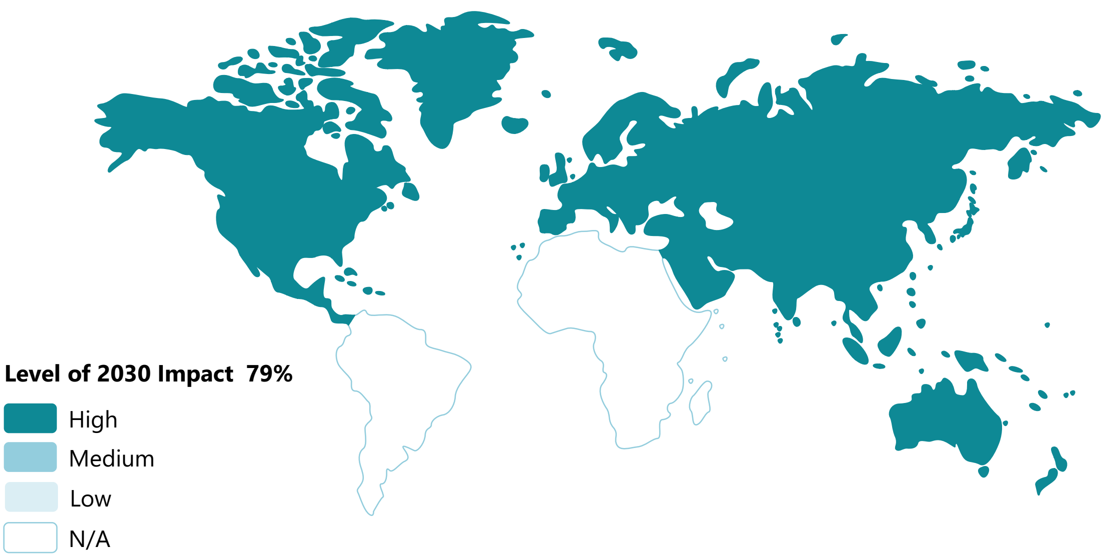
The integration of technical standards across vehicles, roads, and telecoms may well be driven by the market dynamics that already exist in the vehicle and telecoms industries. In the US the public sector road operator players have historically been challenged to keep up, so we can expect private road operators to lead the way; elsewhere we can expect a more collaborative approach.

Safety standards are a completely different endeavour. These have a strong regulator component and are being developed bottoms-up by individual countries and regions (US, China, Europe). In many cases, this being done in close coordination with tech developers, who are at the leading edge in developing safety best practices and approaches to safety assurance. Over time, governments in the major automotive markets will align and harmonize their safety standards.

Progress by 2030

Regulations and safety standards development are tightly coupled for much of the world. While admittedly their processes are slow, over the next ten years we expect significant maturing of key safety standards needed by government agencies to set enabling regulation. This is particularly important to Europe and other type-approval nations with processes relying on UNECE and ISO.

AV deployment is not dependent on technical standards. As a business-driven process, technical standards will proceed as elements of the technology approach matures. This will take time, but tech developers are keen to take advantage of the business efficiencies that standards can provide. The process occurs across a delicate balance of 'not too soon' and 'not too late'. Generally, however, this process is deeply embedded within the vehicle technology industry and will proceed in an orderly fashion.



Improved Safety

Reducing accidents and road deaths is the political priority behind support for AV. While many benefits can be gained from ADAS, the promise of further major safety improvements is pivotal.

Context

Globally, according to the WHO, over 1.35m people die on the roads each year and road traffic accidents are the primary cause of death among people aged 15 to 30 so the potential from 'cars that don't crash' is substantial.[78] This has motivated the traditional vehicle industry to develop and introduce a steady stream of active safety systems aimed at assisting humans to avoid crashes. Beginning in the late 1990s with warning-only systems, these evolved to active control intervention in the 2000s. By 2010, a well-equipped premium vehicle had adaptive cruise control, automated emergency braking for forward collisions, lane departure prevention, blind spot monitoring, night vision with pedestrian detection, sign recognition, and drowsy driver detection. Today a $30,000 car in the US can be purchased with all this and more. For several car manufacturers such as Volvo, Mercedes, and Toyota, active safety features are now standard on most of their models.

Expectations that AV will substantially reduce crashes are very high. The US DOT, for instance, has estimated that self-driving cars could reduce traffic fatalities by up to 94% and eliminate accidents that are due to human error.[79] Some would say this a creating an unrealistic challenge for AVs which may well have been at least in part created by the over-enthusiastic assertions of some car and tech industry executives around the impact of AI and machine learning.[80] The OECD point out that the claim that a 90% reduction in accidents from AV use is untested.[81] Also, even if it is partially true, questions are being asked about whether potential safety improvements will be down to full autonomy, or whether they will be delivered by innovations that are being introduced via increasingly intelligent and connected non-automated vehicles anyhow. Although everyone advocating AV claims huge safety benefits, the majority may well come from ADAS.

Europe has long led the way with a regulatory approach to safety.[82] For decades, European transportation officials have been setting ambitious goals which have guided policy. For instance, in 2011 the European Commission agreed a target of 50% reduction in road fatalities by 2020 (recently extended to 2030).[83] In 2017 it set another goal of 50% reduction in serious road injuries by 2030.[84] In parallel, the European vehicle industry is strongly driven by the European New Car Assessment Program (EuroNCAP).[85] Although not a regulatory body, this five-star safety rating system for consumers has aggressively defined challenging timelines for new ADAS systems, spurring automakers to develop and offer these systems, not only to Europeans but across their major markets worldwide.

Everyone across the transport sector is striving to achieve fewer accidents, less deaths and a higher level of safety. The question for AVs is what additional benefit they will bring above other improvements already in the mix. They need to be able to prove they are as safe or safer than human-driven vehicles. Addressing this is pivotal – not only for the claims that will be made by manufacturers and the TNCs, but also for the policy and regulatory support the governments around the world seek to provide.

What We Heard

Improved safety, and especially a reduction in road deaths, was ranked as having significant future impact in many discussions. However, some key questions around how perception and reality may align were raised.

In Los Angeles, the opening view was that *"while we expect net accidents to decrease with AV, the psychological effect of an AV vehicle crashing (and the driver not being responsible) will cause issues."*

Media coverage of single deaths is skewing the debate on system safety compared to existing ADAS options. In Silicon Valley it was suggested that the industry *"should account for the number of lives saved rather than the number of deaths."* In Germany, questions were asked about the extent to which people will trust the technology., while in New Zealand, the focus was on public and political perceptions. In a country where *"200 deaths from an earthquake in Christchurch led to rapid change in regulations, we have 350 road deaths a year, but have no change in relevant areas."* Action follows media and political focus. Therefore, many consider that *"this is all about public perceptions of risk and the ability to do something about that."*

In Australia consensus was *"the core focus for AV safety will be to reduce deaths and injuries."* If there are large scale trials, more driver education, and there is *"a verifiable reduction in road deaths, then public confidence in AVs will grow."* Moreover, while many see that 'lives saved' and 'crashes avoided' will be a key message for driver education, stakeholder engagement and help to build public trust, this needs to be evidence-based. *"We will need new guidelines and standards"* and *"all of this will be underpinned by new, deeper safety research."*

Building on the success of ADAS, more trials, new regulation and international safety standards, then the social acceptance of AVs will grow: *"as technology matures, we will see improvements in safety with the enabling infrastructure and the associated institutions aligning."* However, to achieve this, there needs to be more government input, agreement around the principles framing the ethical debate, and better understanding of the role of virtual simulation in safety validation. In order to deploy and learn at the same time, at some point it will be necessary to take a measured risk. Indeed, there may be lessons to be gained from how clinical trials are used in the pharmaceutical sector, or even from the introduction of jet airliners in the 1950s without proof data.

Another concern raised in Melbourne was whether in the long-term, humans will have the knowledge and *"ability to take control of a vehicle if needed – in the event of an emergency or a system failure."* Will we become "so dependent on the technology and lower our situational awareness, that we both lose the capability to drive and so also lack any skills to deal with vehicle failures?"

"In order to deploy and learn at the same time, at some point it will be necessary to take a measured risk."

In both Silicon Valley and at the global ITS event in Singapore, the challenge of crash avoidance was specifically broken down into four levels, all of which are *"linked to changes in behaviour"* and "rely on ADAS as a baseline." These comprise:

- **Mitigation** which addresses advances such as driver monitoring to alleviate the very significant problems of driver distraction and impairment through alcohol and fatigue; [86]
- **Reactive** approaches such as (intelligent) emergency braking that determines that there is a risk of colliding with a vehicle or pedestrian in front of the vehicle, alerting the driver but also activating the brakes if the driver doesn't respond
- **Detection** of potential obstacles via low-cost LIDAR and high-resolution radars; and
- **Proactive** risk minimisation using AI systems and HD maps to better position a vehicle in case something untoward might happen – such as a pedestrian or cyclist changing direction – and doing so well ahead of a time-critical crash situation developing.

The general opinion was that all four will *"have to be used collectively"* and *"success will be dependent on improved data sharing between vehicles and with a more intelligent infrastructure."* The crux is whether the systems can operate by warning others (pedestrians, cyclists, other vehicles etc) that an AV is present as well as its' intentions - so that they are able to adapt, or whether the AV itself is able to navigate through complex areas *"like a Wal-Mart car park"* without driver control. The primary technical challenges here lie in *"dealing with lots of false positives; LIDAR differentiating between a solid object and a person; flexible communication between systems; and modelling systems to cover all scenarios."* Whether this can be achieved by 2030 was questioned with the proposal that maybe *"it is more realistic to expect improved human driving aided by ADAS warning systems."*

This view closely links with another area of in-depth discussion regarding driver training and education. If the 2030 horizon is more about Level 2 / 3 rather than more fully autonomous L4 vehicles, then in Silicon Valley it was argued that *"drivers need to be aware of the capabilities (and limitations) of (semi) autonomous vehicles."* A growing need for better driver training and education, whether delivered by automakers or government, *"will rely on a clear unified taxonomy"* plus market incentives such as *"lower insurance premiums and the threat of liability."* This aligns with the question from New Zealand as to *"whether or not in the future it is the vehicle and not the driver that has to pass a driving test"* and so what may be the implications for certification.

"The crux is whether the systems can operate by warning others that an AV is present as well as its' intentions - so that they are able to adapt, or whether the AV itself is able to navigate through complex areas."

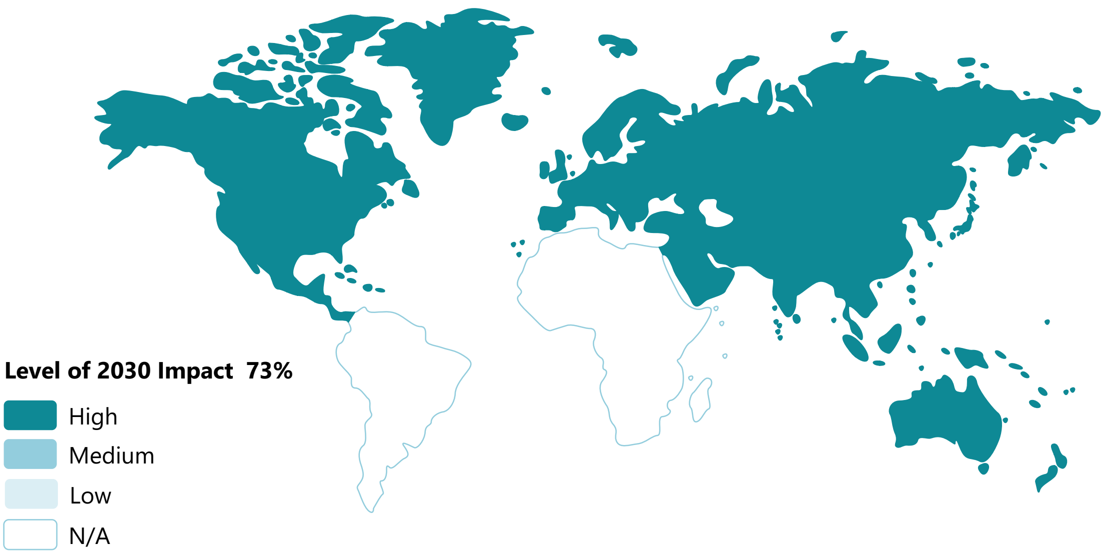
What We Think

Although maybe a distinction that is important only to specialists, ADAS and AV are discrete in terms of capability and market forces. ADAS is now common on new vehicles and the share of ADAS-equipped vehicles on-road is growing every year. Those developing government policy should keep ADAS foremost when aiming for reductions in crashes.

AVs will incorporate crash avoidance capabilities in addition to capably driving in benign conditions; for AV technology developers, ADAS-level crash avoidance capability (or better) is a given. Potentially however, automated driving can eliminate crashes due to poor choices by human drivers such as speeding, tiredness and intoxication.

Progress by 2030

The majority of vehicles on-road in developed countries in 2030 will have extensive ADAS capability. In turn, crash rates will trend strongly downwards. As AVs come into use, their safety performance in crash-imminent situations are expected to be equal to or better than non-AV vehicles.



Environmental and Social Impact

Ensuring that autonomous vehicles are cleaner than alternative options may be a pre-requisite in many regions, while the benefit of AVs for wider society is a crucial issue for public endorsement.

Context

There are expectations that increased use of AVs will lead to a tangible improvement in both the environmental and social impact of transportation. As yet there is little real-life evidence available, so how this can be achieved is, as yet, unclear.

Looking first at the potential environmental impact a recent report by the University of Texas suggests that, there will be an overall net energy saving of between 11% to 55% versus current US ground-transportation conditions, depending on CAVs drivetrain electrification. But, at the same time, there may be an increase in vehicle-miles travelled which could counter the savings made. "This is due to the potential for non-drivers to travel independently, empty vehicles repositioning themselves, and more low-density land development at the periphery of regions." [87] At the University of Michigan, CAVs are predicted to vastly reduce the time cost of travel which may consequently increase the amount of travel and therefore possibly increase congestion and energy use. [88] "Decreased congestion is likely to lead to increased vehicle-miles travelled, limiting the fuel consumption benefit," and "higher fuel economy reduces the energy required per mile of travel, but it also reduces the fuel cost of travel, incentivizing more travel and causing an energy rebound effect. [89] Similar views can be found in Europe. In the UK, for example, AV researchers have concluded that "the only certainty is that the impacts of automation on energy demand and carbon emissions are highly uncertain." In Singapore, potential energy savings are linked to more shared rides and the assumption that AVs will be electric which in turn benefits the city through reduced emissions and quieter transport.

Opinions also vary around whether AVs have the potential to have a positive social impact. Alongside fewer accidents and road deaths, most governments advocate adoption on the basis of net job creation, improved mobility as well as broader access and civic participation for the elderly, the poor or the disabled. But researchers in The Netherlands suggest that although AVs "offer great potential to improve efficiency on roads, reduce traffic accidents and increase productivity, they have also seen resistance from different groups which claim that they are unsafe, pose a risk of being hacked and will threaten jobs."[90] Others point to the advantage of greater privacy and shorter, more direct, journeys than can be offered by existing public transport systems.[91] In the US, SAFE conducted a study of traffic patterns and job locations which found that the deployment of low cost and efficient AVs in some economically depressed regions could lead to improved access to large job markets.[92]

Policy makers certainly need greater clarity of impact – but different scenarios reveal multiple outcomes. Recognising that the majority of social science engagement has been concentrated on a narrow spectrum of issues such as the legal and governance aspects of licensing and standards for autonomous vehicles, in Australia there are calls for sociologists to contribute much-needed critical voices to debate.[93] Despite the lack of evidence, major investment decisions are nevertheless being made on the basis that overall AVs will have a positive impact. In the UK, for example, the expectation is AVs will create 320,000 new jobs by 2030.[94] But is that true? Are these good jobs and can they be filled by potentially redundant taxi and truck drivers? And what really are the wider implications?

What We Heard

Unsurprisingly the expert standpoints were also mixed. A shared environmental outlook is that while *"current technology performance suggests that robo-taxis may well be hybrids,"* in the longer term, the majority of cars and delivery trucks will be electric vehicles (EVs). In many regions, the transition to AV and EV may take place in parallel; *"AVs will be EVs"* and *"the future of AVs will have to navigate the same environmental maze"* in parallel. As such, the concerns about the environmental impact of EVs – source of electricity, batteries, recycling, charging infrastructure, and long-term energy storage – may well be applied to AVs. Some in Silicon Valley were concerned about *"the energy requirements of fleets of AVs"* given the potential for extra miles travelled as well as increased CO2 emissions. In London, where concerns around the ability to provide the necessary infrastructure for all the planned EVs is already high, the potential of the *"net extra energy demand"* for AVs was raised as a constraint to adoption. In the UAE, however, 'The Self-Driving Transport Strategy' aims to transform 25% of the total trips in Dubai to autonomous mode by 2030 and to *"reduce environmental pollution by 12%."*[95]

In terms of social impact, there have been common questions about inclusivity and access. Everyone agreed that AVs should *"provide a service for all, not just the urban elites."* However, there was less clarity about how this can be achieved. In Los Angeles, the primary concern was about how to ensure that cheap, ubiquitous mobility can provide transport access to the poor, low-income neighbourhoods, as well as the middle-class suburbs. In a city where some felt that *"there are areas that taxi drivers refuse to go to,"* they wondered whether realistically AVs will be able to *"provide equal opportunity access for all, and so act as a catalyst for wider empowerment and social change?"*

Singapore's strategy is to ensure all citizens have access to good public transport, with AVs as part of the mix, while for both Australia and New Zealand, issues of social equity and access were both expressed in the context of rural, as well as urban residents. In the UAE the focus was more on the impact on quality of life: *"How will passengers use the time? Will this hugely improve productivity? Will people get more personal time back? Does this improve wellness? And what about happiness – a key UAE government target?"*

Part of the attraction of AV deployment for many EU regulators is that *"it will have the greatest appeal for those without access to affordable mobility, or who are uncomfortable about driving - the young, elderly, and disabled."* But in Singapore, it was suggested that specific targeting on certain sectors might "be seen as a negative by the mainstream." Instead, it was proposed that, *"AVs need to be designed for everyone from the start, and not segmented."* In LA, the view was that *"in the future, all AVs will be designed to accommodate everyone."* Moreover, *"creating AVs for individual elderly/disabled people is adding yet more single occupancy vehicles onto the roads."*

"The concerns about the environmental impact of EVs – source of electricity, batteries, recycling, charging infrastructure, and long-term energy storage – may well be applied to AVs."

In order to make AVs accessible they have to be affordable. In Australia consensus was that *"AV has to be cost-competitive."* There was some concern in several locations that *"personal AVs will cost more than human-operated vehicles, so, other than for the wealthy, public adoption will lag several years behind ride-hailing and taxi services."* In Singapore, this was supported by a discussion about the potential higher cost of insurance. However, in Australia, it was noted that "*in mining, the price difference between an automated and a normal truck was initially $1m ($4m vs $3m) – but as the tech developed, this dropped significantly*". Robo-taxis were consistently seen as a stepping-stone whereby OEMs develop efficiencies and economies of scale, so the eventual rollout of highly automated vehicles for private ownership is realistic.

In London questions were raised about whether driving jobs will be eliminated and, if so, how quickly this might happen – whether years or decades. In Dubai, job losses were not considered a major concern *"as migrant workers can always go home" or, in such a fast-growing city, find another job. However, in Silicon Valley the "impact on jobs and workforce"* was highlighted as a key future issue and in LA, questions were raised on how the workforce can best be retrained, and how we can *"ensure the replacement for the jobs that AV make redundant."* For example, will bus drivers become non-driving support supervisors on AV shuttles? In New Zealand, passenger safety and confidence were considered to be further reasons why, in the early years at least, this may be on the cards. In Singapore the elimination of jobs was not a great concern, but there was also recognition that *"bus drivers may become conductors."* Similar views were expressed in Germany where today there is a shortage of drivers.

"Primary concern was about how to ensure that cheap, ubiquitous mobility can provide transport access to the poor, low-income neighbourhoods."

What We Think

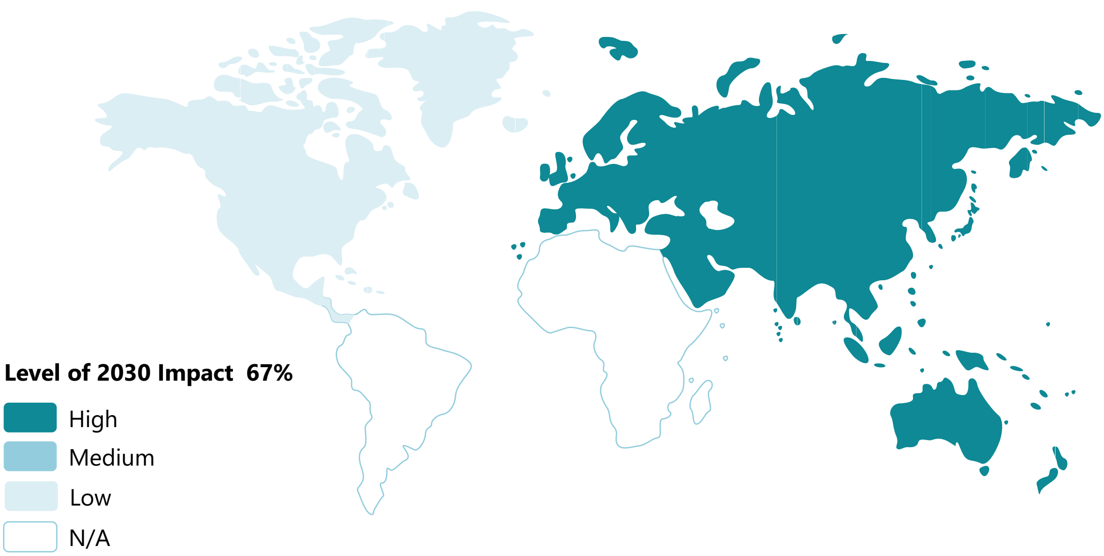
Whether all AVs will be EVs is an ongoing matter of debate. In our view, these decisions will be market-driven, dependent on the most cost-effective powertrains and legislation around environmental impact.[96] It is hard to imagine cities or governments requiring a specific powertrain for AVs only; whatever energy/emissions rules are in place should apply to all vehicles. Policy measures within specific cities could, however, encourage zero emissions robo-taxis and delivery vehicles and so accelerate EV integration.

We see jobs evolving over a couple of decades, and there are many examples of society successfully adapting to job displacement at this type of slow pace.[97] But will people really be happy to share rides with people they don't know? This is key to both environmental and social issues and is discussed in detail below.

Progress by 2030

By 2030 AV deployment will be hugely influenced by public perception. As long as the public sees themselves as safe with AVs on their roads, then AVs will be considered just fellow traffic participants.

Currently, we are in a time of cautious acceptance, in a number of markets. As AV trucks gradually become an accepted part of the commercial freight world, so too will public trust in the technology - barring any significant ADS-caused crashes. The key is for the tech developers to deliver on their promises.



More Congestion

Decreasing congestion on the roads is a central ambition for AV advocates, but many recognise that, with mixed fleets operating for several years, we may initially see an increase in urban traffic.

Context

In many countries one of the top reasons for the adoption of AVs is to reduce congestion - most calculations on ROI improving productivity are linked to improving traffic flow. In a frequently referenced Goldman Sachs assessment, it was proposed the global economic benefits from autonomous vehicles could amount to $3.5tn a year by 2050.[98] 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 – both of which assume less congestion.

Estimates abound. For example, a 2017 report estimates that by 2030 the gains from reclaimed driving hours alone will boost global GDP by around $1 trillion.[99] Researchers at Cambridge University reckon that driverless cars could improve traffic flow by at least 35%.[100] 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.[101] Much of the non-safety savings come from a reduction in travel time due to assumed drops in congestion and the associated cost of travel.

However, in several locations there are doubts as to whether less congestion will happen any time soon. In Europe, and parts of North America, some think we have reached 'peak car' use. If that is the case, and if TNC vehicles do convert to become AVs, they argue it means adding more vehicles on the roads which will increase and not decrease traffic.

We should therefore plan for more congestion – particularly if you add to this the possibility, in some eyes, that self-driving cars won't need to park so will potentially clog many city streets.[102] This theory is based on observation of New York, London, Los Angeles and other cities where the arrival of Uber and other TNCs or MSPs (mobility service providers) has led to a net increase in vehicles.[103] Indeed, in London the average speed in the city centre has already been slowed due primarily to the number of Uber and Deliveroo vehicles competing for road space alongside delivery trucks and public transport. As a consequence, congestion and air pollution have both increased; this despite a congestion charge and the introduction of an Ultra-Low Emissions Zone.[104] Fundamentally, this debate hinges on the existence of TNCs, regardless of whether their vehicles are driven by humans or computers.

Researchers in Adelaide, Australia, predict that "driverless cars could worsen traffic congestion in the coming decades, partly because of drivers' attitudes to the emerging technology and a lack of willingness to share their rides."[105] This is a point explored in more detail later.

Elsewhere, and especially across Asia, where car use is on the increase pretty much everywhere, a future of more congestion is already the default for many planners. In densely concentrated cities such as Manilla, Kuala Lumpur and Yangon, the negative impact of congestion on their economies accounts for billions in losses to the economy every year.[106] Given the above, perhaps the real shift in transportation resulting from AV is really only about increasing traffic density.

What We Heard

While many expect that twenty or thirty years ahead when the vast majority of vehicles could be autonomous and urban mobility may be more efficient, but in the next decade most believe we will see slower traffic. A good number of experts agreed that *"the introduction of AVs to existing infrastructure will initially increase urban congestion – especially with fleets of ride-hailing robo-taxis."*

In New Zealand, where some challenged whether *"we know enough for certain about the number of vehicles that will be on our streets,"* several concurred that for the first years of AV deployment, *"with mixed fleets, we will have more vehicles for a time - it will be worse before it gets better."* Likewise, in Australia, some felt that, while *"less congestion is an important aspiration for future cities,"* but *"we are not likely to achieve it by 2030."* Others, however, have different views. In London and Shanghai discussions some argued that, *"as endless driving will consume significant energy, operators will look for other options with a better ROI,"* and hence less congestion.

In Dubai, the RTA's AV strategy is 'to transform 25% of the total trips in Dubai to autonomous mode by 2030, involving 5 million daily trips, saving AED 22 billion in annual economic costs' mostly based on the assumption of better traffic flow.107 However, many at our workshop felt that *"road-based congestion would be getting far worse in the years to come"* and especially if *"many vehicles will be moving around empty without occupants."* Although one hope is that *"flying taxis can release the streets"* - so for the lucky few air-taxis will provide a means to travel over congestion. In the next decade the UAE perspective is that, most Middle Eastern cities *"are designed around roads,"* so deliver less congestion *"would need a major culture change"* and *"we would have to change the basis of the economy."* As in many other fast-growing urban areas, *"CAVs pose an opportunity to reduce traffic and infrastructure but also potentially increase it."*

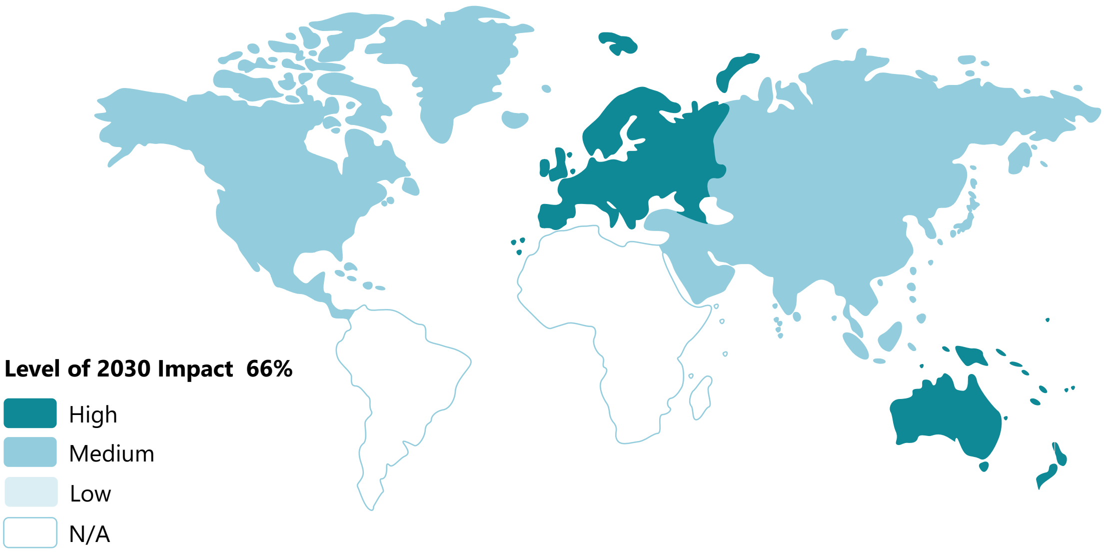
Those in Silicon Valley felt that overall *"the next 10 years will be messy"* with *"no central management of congestion in most locations."* Although *"20 years out there may be mitigating measures"* the consensus was that there are some cultural behaviours that will be hard to shift. For example, in the US *"car sharing is not the answer for most,"* but people may be willing to *"endure the pain of longer (duration) commutes"* if they, for instance have the ability to do more work – or make the journey part of the workday. It was argued that *"in Germany adding to commute time is a negative – but not in the US: Spending 9 weeks a year in a vehicle is not acceptable for most cultures."*

What We Think

Agreeing with London and Shanghai discussions, we do not envision an environment where robo-cars will roam around constantly, clogging city streets.[108] The energy cost would, for instance, be prohibitive for the fleet operators. In addition, cities can levy taxes based on vehicle occupancy, emissions and other social levers to address and encourage ways of operating that are good for society. to both environmental and social issues and is discussed in detail below.

Progress by 2030

By 2030, in the leading locations where robo-taxi and robo-parcel operations are highly developed, the companies managing these fleets will find it worthwhile to invest in means to reduce congestion via direct cooperation between vehicles. Moreover, where cites are proactive, there can be close cooperation between vehicles, traffic signals and other infrastructure elements to improve flow. The technology to accomplish this exists largely now but hasn't been implemented yet as many urban regions have been waiting for the next generation of vehicles to be available. Ultimately dense robo-fleets in cities will represent an entirely new type of connected driver all under one cyber-umbrella, possibly moving beyond historical barriers. This creates a very interesting and potentially significant opportunity to address congestion.




range

Less Parking

Effective deployment of AVs could mean not only fewer vehicles on the streets, but also that parking spaces are removed enabling narrower roadways and more pedestrian space.

Context

In Singapore we heard a strong argument to support the view that AVs will reduce the amount of land needed for roads. This was also supported in cities across Europe and, in Asia, where a number of experimental cities are being developed with this in mind – these include Woven City in Japan and the Xiongan New Area 100km southwest of Beijing.[109] In the US, NACTO (the National Association of City Transportation Officials) has published a blueprint for Autonomous Urbanism.[110] This includes several perspectives of how, in well-designed cities, AVs can transform public spaces, with an aim to reduce the amount of space needed for vehicles. This means narrower roads with consequentially wider pavements (or sidewalks) for pedestrians as well as more cycle routes.

In addition, it is hoped that there will be less need for parking space because AVs will be on the move. A typical car spends 95% of its time parked.[111] This takes up an extraordinary amount of land in some countries. More than 6,500 square miles (17,000 km2) of the US is currently car park – equivalent in size to an area slightly smaller than the state of New Jersey. In contrast, many Asian cities suffer from inadequate parking provision – in some there are more than ten times as many vehicles as there are formal car parking spaces leading to yet more congestion. How can AV solve these problems? There are two main benefits being explored.

- If they are mobile nearly 24/7, other than for recharging / refuelling and cleaning, shared AVs may not need to park in busy urban areas. The downside here of course is the unlikely possibility that fleets of vehicles roaming around empty will add to congestion.[112] Others suggest that those not in use can park up further out of the busy city centres and CBD areas and so free up road space in town.
- Researchers in Toronto have calculated that as AVs will be able to make more efficient use of space and will self-park closer to each other than traditional cars. Therefore, AV parking lots could accommodate 62 to 87 percent more cars than those for conventional vehicles and lead to smaller parking lots.[113]

The declining need for parking space is seen as an opportunity for real estate companies. They are studying how to repurpose existing car parks in key locations, including in the CBD and at key hubs such as train stations and airports. There are business model implications for this; airports on average generate up to 20% of profits from car parking (which has already been affected by travellers using TNC's rather than parking their own car). In cities, some developers are exploring how existing multi-storey car parks could be retrofitted for other uses such as hotels, micro-flats and retail centres.

What We Heard

In Singapore, the adoption of AVs is integrated into a masterplan to increase public transport usage from today's 67% to 80% of journeys by 2040.[114] There is a strong belief that AVs will not only lead to less congestion, but if new plans are implemented, then *"by 2030, we will already have fewer roads, fewer parking spaces, and more efficient travel flows."* Moreover, *"with smart connectivity and smarter traffic management, Singapore will provide more flexibility for transit system consumers, and a more inclusive infrastructure."* This means less traffic on the streets, narrower roadways and parking spaces reclaimed and repurposed. *"Pivotal ingredients include the upgrading of traffic lights and lane control systems, enhanced software management systems, and the introduction of real-time pricing for roads and vehicles, coupled with more flexible lane use at different times of the day to help maximise flow. Accommodating more public and private connected vehicles and an increased flexibility of pick up and drop off points will be essential."*

With a central role for government, the alignment of connectivity standards as part of the wider IoT ambition of a global Smart City, the necessary data for and from vehicles and traffic flows to deliver efficient AV operation will soon be in place. Others, however, are concerned that *"there may be a tension between policy that accelerates deployment, and too much regulation that limits attracting AV providers to the nation."* Although recognising the need to *"accommodate a changing mix of AVs, EVs, and regular cars for the next decade or so,"* in the workshop, there was firm belief that *"we will have a significant reduction in the number of vehicles even by 2030."* As such, *"congestion will decrease significantly"* and *"we can have less parking."*

In the discussions in Texas, Dubai, Shanghai and California, the idea of less road any time soon was largely dismissed. In Los Angeles it was highlighted that a major new public building had recently been opened with *"just as many car spaces as ever"* - so maybe in the eyes of architects and planners there is little expectation of a change from the impact of AV any time soon. However, in Melbourne, Gothenburg, Toronto and London it was not entirely rejected. Although unlikely in the short term, *"as part of wider adoption of cycle lanes in key temperate urban areas, roads are already getting smaller."* In London some see that this is adding to the current congestion problem, but in Wellington they considered, *"AV use provides an opportunity to reduce the space required for parking, and so giving land back – which changes density options"* and *"wider pedestrianisation of parts of the CBD is on the agenda"* a broad set of options are being considered.

In Toronto where Google's Sidewalk Labs programme is in development there was specific mention of the potential implication for road width and use.[115] Although these had recently got mixed up with plans for private roads and data collection issues at the time of our discussions, overall the target for the Toronto waterfront development is for *"AVs to enable more streets with room for broader sidewalks."* Sidewalk Labs aims to address such questions as: instead of teaching self-driving vehicles to operate on today's streets, can we take advantage of new technologies to fundamentally redesign the street - with narrower, safer streets that still get people where they need to go.[116]

"Can we take advantage of new technologies to fundamentally redesign the street?"

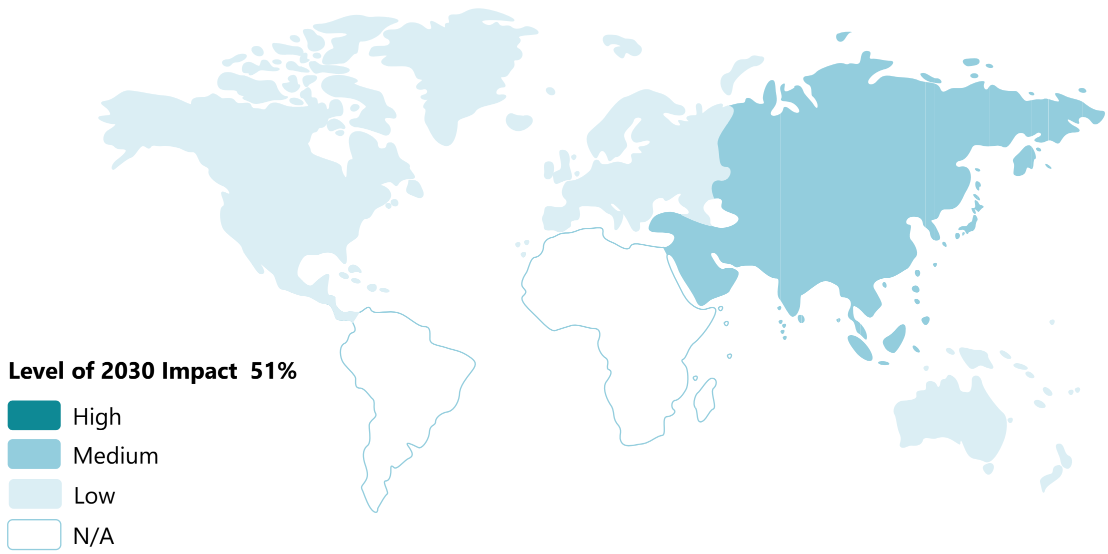
What We Think

The timescales for this shift are highly uncertain regarding when AV will be ubiquitous enough to justify reducing road space for cars in favour of pedestrians. It is true that automated parking in garages can allow tight packing of cars and thus greater capacity, but the market forces haven't come together to make this happen. Daimler/Bosch have taken a proof-of-concept to an advanced stage at the Mercedes Museum in Stuttgart, yet commercialisation requires a deep integration with parking garage operators - a very untraditional partnership. Plus, features in mass market cars need to benefit virtually all customers, yet only some people's lifestyles have them regularly using parking garages. Although this concept looks great on paper, we don't see it coming soon except in purpose-built smart cities, such as Toyota's Woven City that was announced at 2020 CES.[117]

Airports are already re-purposing carparks due to the rise in TNC's handling transport to and from terminals. Robo-taxis will accelerate this process. In general, the question of better use of space is being motivated by today's TNCs, which will be intensified by automation.

Progress by 2030

The numbers of AVs will be steadily growing by 2030, but not enough for broad societal effects. In places where ride hailing has already affected personal travel patterns, and where the weather is fairly benign, we will see the greatest deployment of robo-taxis. Key examples would be California, Singapore and the UAE. As deployment starts to scale in the pioneering cities, then we may see some re-purposing of road space. .



Rethinking Planning

Poor coordination between transit systems, urban planning and solutions may delay AV benefits. For full impact it will be necessary to take a more flexible approach to planning.

Context

The NACTO Blueprint for Autonomous Urbanism is just one future perspective that includes a number of positive views of how AVs can impact US cities.[118] These cover a wide range but have significant planning implications such as dedicated lanes, coding the curb, future street sharing between vehicles and people as well as thoughts on road pricing and data sharing. Other countries have developed similar scenarios – some more joined up than others. The Singapore Land Transport 2040 masterplan is highly detailed and based on extensive public consultation.[119] It links together land use, transport planning, zoning and facilities in a coherent and integrated outlook. A similar approach is evident in the New South Wales Government Future 2056 CAV plan.[120] Elsewhere there are plans - but less joined up: for instance, ambitions for future land use and transport planning in Dubai are both highly detailed but are not yet aligned.

What all these point to is that with the advent of autonomous vehicles at scale, there is an opportunity to fundamentally rethink planning of urban and suburban areas. As well as repurposing car parks and a redistribution of street space between vehicles, cycles and pedestrians, after a century of designing cities for cars not people, there are three major opportunities:

- **Distributed Suburbs –** If AVs can provide effective, comfortable journeys where people can work and relax more easily than with existing transport options then a longer, but more productive, commute becomes possible. As such we can live further away from work, which itself will be increasingly remote. Planners can therefore take advantage of cheaper land values to create affordable housing in areas where there is more space. Greater use of electric vehicles will minimise environmental impacts of more miles travelled.

- **Higher Density Living –** If AVs are part of a feeder system for access to local hubs and public transport networks then the ambition can be met of a 15- or 20-minute town or city where work, education, healthcare, leisure and housing are all within easy reach. As the leaders of cities such as Paris envisage, every resident should be able to meet their essential needs within a short walk or ride.[121] With everything on hand, denser living is possible.

- **Curb Access –** As MaaS and shared AV platforms expand then, as well as road pricing, expect to see an increase in the control and remunerate use of curb space. To prevent congestion as passengers are dropped off and picked-up curb access can be planned and efficiently managed to serve shared vehicle passengers along with other uses.[122]

What We Heard

As well as being embedded into the Singapore masterplans for new towns, the potential for AVs to act as the catalyst to reinvent our approach to urban planning was discussed in both New Zealand and Australia. Much existing town and transport planning were seen to be *"a closed system"* that is typically *"long-term but with little flexibility."* There was agreement that this needs to change. In Melbourne, for instance, the current plans (prepared in 2016) do not include AV. With car parks full, and growing demands on public transport capacity, the need for a rethink or a reimagining of planning is therefore seen as a priority.

In Wellington, the proposal was for a more *"proactive method to fully integrate AVs into the planning world."* This would involve wider partner involvement, including from the private sector, and the development of *"more agile approaches to planning, complemented by more adaptable infrastructure."* As such, and as already shown to be effective in cities from London to Medellín, planning could *"no longer solely be a government-led activity but would become an industry/system partnership."*

In Australia, again a more collaborative approach involving the private sector is advocated, but there was also a suggestion of a change in ambition. Perhaps *"2030 future mobility planning will be focused on economic impact, where mobility outcomes are tied to economic growth."* There could be *"targets for 25% active transport, 25% AV, 25% personal transport and 25% public transport vehicles."* With the potential for the removal of some car parks and the creation of new public open spaces, *"new city designs can have more proactive sustainability targets."* Potentially there could be a *"national diverse mobility authority could have oversight,"* with more *"state-based direction influencing revenue, productivity, and mobility."* With its integrated approach, this is a direction that others see Australia as being able to accomplish. Citing examples including the Western Sydney Aerotropolis[123] and Melbourne's active transport planning,[124] key implications could include changes to road pricing that becomes more dynamic and linked to a wider view, different mobility choices, and the end of the two-car household.

Opinion in Silicon Valley was that *"whatever we do going forward the main rule is that we should not make things worse for anyone."* More specifically, *"by 2030 planning should be an agent of change with specific targets that could be, for example, to shift a mode of travel."* These targets may be to shift 5% of commuter traffic to walking / bikes / shared mobility. By implication this requires different targets for delivery as *"pivotal to a faster pace of change will be to shorten the planning horizon from 25 years to 10 years (strategic) and 5 years (operational)."* It was further suggested that probably the planning process needs to adapt: *"We need to make planning more integrated as a field."* Portland was noted as a leading example. Also, as a side comment it was pointed out that *"China has only 10,000 lawyers in the whole country – that may be why they can make such progress."* Certainly, the centralised government model makes it difficult to challenge planning decisions. In our initial Shanghai discussion this was reinforced with a tour of a future AV-ready district at Lingang.[125]

In the UAE ambitions for AV impact are high. The ambition is that *"in 2030 only 10% of all trips in the UAE will be by private car and there will be an end to sprawl and infill development."* Achieving this, however, requires significant changes with more cross-government cooperation, *"an integrated transport and land use framework – linking them for the first time"* and *"a clear mandate for the RTA for frictionless mass transit mobility."* Within this many recognise that *"CAVs are not a solution but a means to the solution"* as there needs to be major shifts in planning such as "no new roads or infill development" and targets so that *"Dubai could have CAV-only suburbs."* Most significantly for some was the recognition that there is a requirement to add a new discipline to planning: In the UAE *"current modelling is not fit for purpose to handle uncertainty and rapid changes." As such "transport planning is transitioning from a predict and provide to a decide and provide approach where scenario planning is the key to handling uncertainty."*

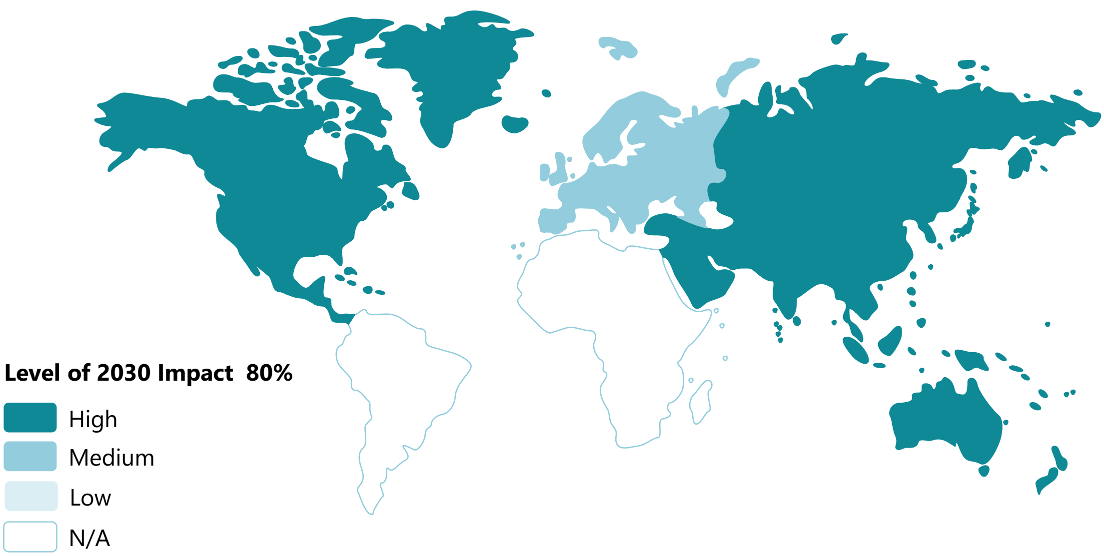
What We Think

Planners have long been skilled at creating top-down utopian visions of a city, and AV speculation has triggered more of this. Sometimes there are pragmatic, joined-up concepts but other times the AV implications are impractical. Singapore, as one example, has a very good track record for setting visionary goals and accomplishing them. We therefore agree that transport planning should become both more strategic and tactical, including shortening the planning horizon as suggested by some. Due to the uncertainty brought on by AV deployment, a nimbler approach is evidently needed along with an openness to experimentation.

Road pricing is a powerful lever here. As with other C40 actions, leading global cities such as Paris, London, Shanghai and Melbourne may well pioneer the way and act independently of nations and states.[126] Although widely discussed as long ago as 2010, in the US implementation has been minimal: we do not see that AV's alone are likely to trigger an expansion of road pricing at least at the national level.

Progress by 2030

As noted above, changes in transport patterns and associated effects will most likely occur in pockets by 2030 - but broad effects will come later. In many markets, as driverless transit increases transit options in suburbs where service is minimal or absent now, we can expect to see the two-car household diminishing in suburban areas. Although the effect of this will be modest at best by 2030, expect change to accelerate in the following decade.



Part Two: Moving People


Federation Square
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FAMOUS
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& SALAMI
3518
You're in the
FREE TRAM ZONE

Public Transport Systems

Autonomous buses, shuttles and new mobility solutions to fill transport gaps are introduced. Security, flexibility, reach, interconnectivity and funding are the primary issues for many cities.

Context

In An effective public transport system is a key enabler for a better quality of life, less inequality and improved productivity. This explains why most liveable cities worldwide have an efficient public transport system at their heart – Berlin, Vienna, Copenhagen, Stockholm, London, Singapore, Hong Kong, Shanghai, Tokyo, Seoul, Melbourne, Toronto, Vancouver and Paris are some of the most prominent examples but other locations including Bogota, Santiago, Kuala Lumpur, Hanoi and Cape Town are also well regarded.

However public transport is not so popular in the US and the Middle East. Sometimes this can be ascribed to a lack of funding, other times it is more about culture, status and inequality. Think of Indianapolis, Tampa and Jeddah as a representative sample here. Attitudes are changing however and, today many of those that have fallen behind in the liveability league tables recognise the benefits of improving public transport. Some see that early AV adoption may be part of playing catch up and are exploring how autonomous taxis, buses, shuttles can all play a role alongside the adoption of more cycles and scooters to provide connectivity to more multi-modal hubs.

There are evidently questions around funding and profitability. In many locations public transport is seen as a public service paid for by city or state taxation. The focus is on accessibility rather than profitability. In others the need to at least break even is a prerequisite for any civic investment. Moreover, the role of the private sector in driving a more effective public transport system is, in some European cities, looked upon with reservation. Should, for example, TNCs be considered as part of the wider public transport system or a competitor to it? Many technology advocates see that the advance of automated transport is set to change many long-held beliefs.

What We Heard

Around the world the significance of AV in the future public transport mix was widely recognised but with many different responses. The opportunities for AVs to help improve public transport efficiency, quality and reach are clearly multiple and noteworthy. In Singapore, where the plan is to move from *"67% public transport use to 80% by 2030, the role of AVs in enabling this is significant."* In Los Angeles, there is recognition that *"we don't want to go door to door for everyone,"* and that *"200m to 300m walks are important for improved public health."* New Zealand sees *"a shift from inefficient public transport to an intermodal mix of seamless, safe journeys,"* while in Australia, the view is that *"by 2030, we should aim for equal access to mobility."* In London, *"integrating AVs within the public transport network to ease congestion"* was considered a priority and in the initial Shanghai discussions, the role of AVs as part of the wider system was emphasised. Notably different, in the UAE we heard that *"moving Dubai to be more public transport focused is a major challenge – is there a real public need and, in a city designed for the car, will people want this?"*

While each location has different priorities, across all the workshop four key themes emerged.

Attracting Users

Foremost in Singapore, the big issue was how to make public transport more attractive to those currently using their own cars. "*Most significant for AV adoption by many who prefer personal travel (currently in their own vehicles), will be how to allow more personalisation of public transport systems – be that robo-taxis, AV buses, or other parts of the network."* This can be enabled by the *"digital configuration of spaces in small vehicles (robo-taxis), as well as in larger systems (trains and buses),"* accompanied by physical *"new form factors, enabling vehicles to morph for different use cases."* So, as already explored in several recent design concepts, the size and shape of passenger spaces could flip between alternative modes to fit varied needs throughout the day. This could accommodate different numbers of people at key times, while also *"recognising dynamic needs for different vehicles with associated market pricing."* Opinion was that this flexibility would help embed AV user experience as part of the public transport system and is part of the trials already underway in new AV towns such as Punggol and Tengah.[127, 128]

In the US, where the public transport is often underfunded and poorly utilised, the prevailing view was that there is *"no incentive for the public to change their habits."* Used to making their own way, some wondered whether AVs will further undermine the public transport system, *"Will US cities still want to have public transport systems when robo-taxis are here?"* The example of Google buses in San Francisco gives some useful insight. *"When Google asked public transport systems to provide a service to bring employees to Mountain View there was no interest from the providers in adding extra traffic."* Instead *"Google runs its own fleet with direct services from within 5 mins of the majority of employees' houses"* so, *"everyone has easy access" and "once on the bus, the employees can start work and that counts as the start of the day."* Private buses are increasingly common in other countries – especially across Asia - but in the US this is a rare exception.

Funding

For governments the benefits of a good public transport system are clear. Since 2013 Estonia, for instance, has been making public transport free – this has added to GDP growth and the extra tax income from this is 3 x the cost of public transport subsidy.[129] Similarly public transport in Melbourne's CBD has recently become free and this has both reduced traffic as well as stimulated the economy. However, we heard a debate as to *"whether this will continue to apply given that personal transport may become cheaper in an AV world because of reduced* *labour costs, so there may be more funding in the overall system."* The response from others was that public policy should address this because *"it is critical to have government policy driving us away from private vehicle use."* The growth of MaaS and last mile solutions are seen as a key addition by 2030. While much of this may be provided by corporate platforms, there was recognition that *"we may need to leverage the private sector to help with the lower socio-economic segments of the population,"* and that *"government subsidy may be key."*

A central focus for discussion in Silicon Valley was how best to fund public transport as *"most US transit agencies are not profitable and are lucky to get paid for 20% of their services"* while, *"globally, public transport runs on very small margins (and so is not attractive for investors)."* Not only do *"thin margins mean few are attracted into this area"* but *"public transport vehicles are not currently of interest to OEMs and VCs."* One perspective here was that *"transport systems should not go to the public for more money but, instead, should run be more like a business."* To achieve this, it was argued, we should support *"the privatization of existing public transport and / or making private AV services available to the public."* An aligned view in Dubai was that if public transport were to be further developed then *"there has to be a business case without government subsidy."* Exploring funding options in more depth, one comment in the US was that *"bonds are not a good solution – they are like a mortgage - Much of the money is spent paying off interest and so they don't last as long as planned."* As such, a different approach is required.

One potential solution aired in several locations was the better use of public private partnerships (P3). Strongly endorsed in Australia as well as in a parallel discussion in Mumbai, a US view was that, given *"public money is difficult to access as there is not much of it,"* public-private partnerships are the way to go for introducing AV into public transport systems. However, while a federal approach is the ideal, the reality is that *"cities with power will see most traction"* and by 2030 it will be *"locations like Australia and UK that will move forward faster."*

Buses

A key component for successful AV impact in public transport is the adoption of shuttles and micro buses. In Tokyo, for example, there is a government policy to introduce AV shuttles to improve mobility for the ageing population. If micro-buses are to get traction, in the US it was thought that there may be need for much broader access; expect *"a host of 'feeder' solutions to provide extended reach."* A critical element here will be *"the routing of shuttles to maximise utilisation and impact."* In the absence of fixed bus stops, *"virtual options, often driven by mobile apps and passenger co-location will be important so that we can ensure a cost-effective service."* This will enable the 'best routes' to be determined for energy efficiency, passenger convenience and travel time.

While in Singapore, Wellington, London and Melbourne, buses are very much part of the established public transport mix, in the UAE there were fundamental questions about whether citizens will want to switch from cars for AV convenience. Moving the UAE to be more public transport focused is considered to be a major challenge. *"Dubai has been designed for the car and retrofitting public transport systems on it is not straightforward. As the population increases to 8 to 10m over the next few years, there needs to be a clearly defined plan for 2040."*

Some wondered whether the future AV public vehicle will be a bus, a shuttle or even a robo-taxi. Many hoped for flexibility. In the US comment was that *"buses cannot be simply replaced by lots of AV shuttles."* Rather *"we need big buses at peak times – small shuttles don't work at scale in cities."* This raised the question of whether there is enough public appetite for AV buses. Given how poor the margins are many thought it unlikely.

One challenge here is that *"buses are yet to attract major AV interest."* Bus fleets are, for example, *"small compared to trucks and also less profitable for investment."* As such it is anticipated that *"rather than be in the lead, autonomous buses may follow behind the logistics sector, learning from and adopting some of the technologies."* Another issue is that, unlike trucking, the cost of a bus driver is not likely to be replaced in an AV scenario albeit their roles might be different: Driver wages and vehicle costs were both also identified as major drivers of change at the ITS global event in Singapore.

Finally, one major obstacle is the length of time it takes to drive change. There is a very long sales cycle in many cities. For example, *"NYC is buying diesel buses through to 2028."* As each bus lasts over 15 years the speed of transition for the fleet is going to be slow. An alternative route could be that *"we need to change the evaluation and performance criteria for government to spend their money – but that is highly unlikely in the US – it may work in Europe but not here."*

Integration

Time and again we also heard that AVs will be part of the overall transport system that *"connects with public transport rather than competes with it."* In some locations, such as Singapore, LA and Silicon Valley, plans are in place for autonomous cars and shuttles to play a key role in the first / last mile of connecting people to the transit system. Similar ambitions, but with longer distances involved, were heard in New Zealand, Germany and Toronto. It was only in Dubai that public transport was seen as potentially an independent system from the first phase of AVs.

All this will take time to embed. For those in New Zealand, motivation for the *"intermodal mix of seamless, safe journeys"* requires more trials, better network planning and *"more research around emerging use trends and mobility needs of the population."* Within this topic concern remains about the implications of removing drivers from a passenger safety perspective. The security of the *"last passenger on the bus"* challenge, especially late at night, was highlighted as something that may well need human oversight – initially, at least, in person.

In Los Angeles the need to establish *"a single mobility payment system"* that can provide door-to-door transport across multiple modes of travel was raised. Similar approaches have already been rolled out in cities like London, Hong Kong, and several European capitals. The next step is to include private providers such as the TNCs. With *"single consolidated fee provision for customers,"* collaboration and data sharing are essential between all parties. This was highlighted in Dubai, Melbourne and Shanghai.

If AV for public transport beyond the Dubai Metro and similar systems is going to have much traction in the UAE, then it was felt that *"proving success via trialling is going to be key to help drive changes in governance and regulation for AVs – this will inform certification."* Here *"the focus will be on enabling AVs to operate in mixed traffic."* Such trials *"will also be significant in building consumer acceptance," and clearly, "as with all things here, there needs to be a business case at the fore."* However, as this is part of the UAE 2030 Vision, there is strong political pressure to make it happen.

At the global ITS event it was argued that integration needs to accommodate *"more flexible vehicle sizes and arrangements"* and will rely on *"effective digital infrastructure being introduced in every city,"* so that there can be *"system level management of automated transit with a priority for public transport."*

What We Think

In the next few years, we agree that AVs will be part of the overall transport system that connects with public transport rather than competes with it. Public transit vehicles will become smaller and more adaptable as EV/AV comes in, creating a blurring of boundaries between ride-hailing and buses. As questioned in Silicon Valley, the key point is perhaps whether or not public transport can be more attractive than ride-hailing, and especially when future automated robo-taxis are designed for seating multiple passengers comfortably. We also note that the move in Melbourne and elsewhere to offer public transport free for all in the CBD is a model for the future, especially as AVs reduce labour costs.

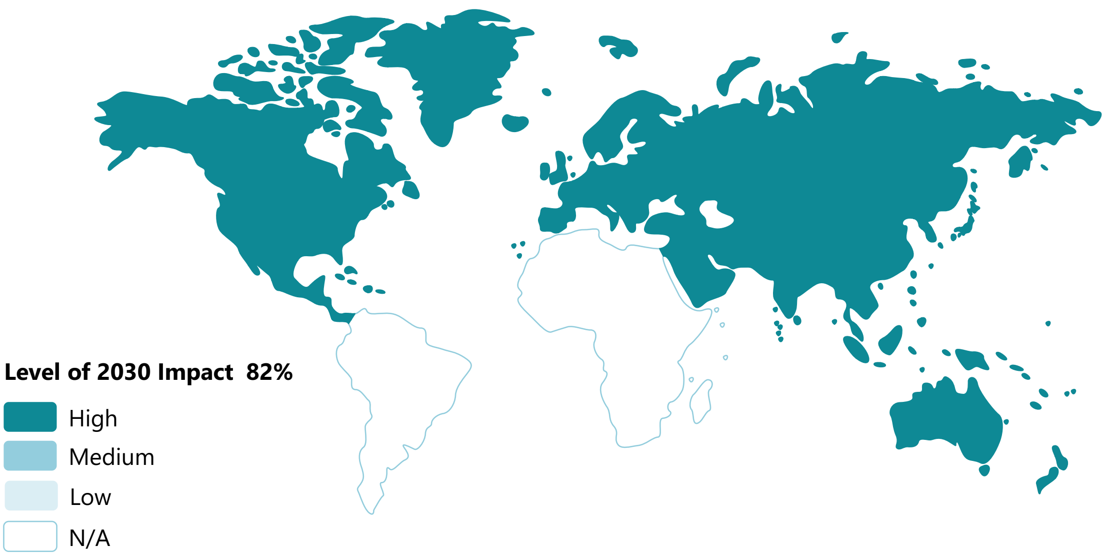
Traditional transit subsidies in many locations indicate a market failure where the public sector has to step in to ensure mobility for all. Does the landscape change with AV? And is there a way to make public transit interesting for investors?

Mobility has proven to have some investor interest in recent years, but it is not clear whether this will be sustainable and whether this has been fully thought through in terms of public transport funding. We are intrigued by the possibility of greater privatisation of services traditionally provided by public transit.

There are substantial issues that must be addressed, such as how to provide passengers with the feeling of security that a driver offers. Given the substantial number of companies seeking to launch robo-taxi services, we see these as key issues given the need for customer acceptance.

Progress by 2030

By 2030 we see AVs taking a strong role serving mobility needs in pioneering locations, through a combination of commercial and publicly funded services. The next decade will be one of intense experimentation to find the right mix for the specific needs of various cities and cultures.




FLUX
FLUX

Resistance to Sharing

Public support for ridesharing will require a re-evaluation of vehicle design for small groups. Concerns about privacy and safety mean strangers may be unwilling to travel together.

Context

A central assumption for many in the AV world is that for multiple use cases, people will be sharing the same vehicle at the same time. This drives more efficient use of infrastructure, energy and, hopefully with less congestion, time. However, underpinning the assumption are several factors about vehicle design and human behaviour. A crucial unknown - particularly for robo-taxis as part of the transport solution - is the willingness to share rides by the majority of users.

If people are to migrate from their current personal, tailored, branded own-car experience to a shared vehicle, then, alongside the convenience of AV, it has to offer a great experience. From a design point of view, a universal, or at least common, experience seems sensible, particularly for robo-taxis and shuttle buses. Having familiar user interaction will make it easier for passengers to become sufficiently familiar with the service – just like existing public transport systems. This is particularly important for the elderly or disabled. From a brand perspective, however, there needs to be a veneer of differentiation as they compete on the characteristics of the experience they can provide. Product differentiation is going to be more important for Ford, BMW and Toyota than for the likes of Uber, Lyft or the Shanghai Municipal Transport and Port Authority.

Beyond this the major challenge is how to develop new product designs that encourage two or more strangers to share the same space – maybe for quite some time, perhaps late at night and possibly involving taking one or more of them to their home address. Personal security and a degree of privacy are fundamental and, as an early indicator here, Uber Pool has had limited success. Although a far cheaper service than UberX, less than 20% of rides are currently via Uber Pool and mostly these are when people are already clustered into a group such as, for instance, those wanting to travel from an airport to a downtown or CBD location. Encouraging strangers to share on more ad-hoc routing is a problem and, in some locations, shared usage for Uber is well below 10% of rides. Given this, Lyft, which runs around 35% of trips as shared rides in key markets, is advocating a longer period of transition with human drivers very much in the mix for the next decade or so. Indeed, whereas Uber has been one of the leaders for the acceleration of unmanned vehicles, Lyft's current strategy envisages a combination of human and self-driving vehicles right through to deployment of fully autonomous vehicles and beyond.[130]

Timing, design and approach to sharing rides all matter because, for many regulators and urban planners, the viability of future AVs is implicitly linked to the idea of multi-person occupancy. Filling cars may be essential for cost and congestion but achieving this is evidently not straightforward.

What We Heard

While the sharing of individual vehicles by multiple people sequentially is possible (it is implicit within MaaS and the 'access not ownership' business model), the willingness to share an AV with a stranger, but without a driver, is more of a challenge. *"As many people enjoy their personal space, some see that public interest in a significant rise in sharing vehicles may not be as high as expected."* Here, however, *"we need to be clear that a shared ride is not the same as micro transit"* – it could be a more intimate experience. In New Zealand the *"last person on the bus"* challenge was highlighted as a common issue for transport agencies and so with autonomy *"keeping a driver / conductor / supervisor on board for the next 5 to 10 years"* would be a wise move. In a smaller vehicle the issue is amplified.

One common view across several locations was that *"this may well be a generational issue,"* and "*it is very much age-specific – the young are ok, but not others."* A number suggested that *"population density is key here – in San Francisco, it works because we know people are heading in the same direction."* In LA one perspective was that *"this is very much an urban dynamic – and does not work in rural areas."* In Frankfurt, parallels were drawn with other shared spaces: *"if you look at (unsupervised) fitness studios, there is no resistance to sharing space – it is all about the price point – and cleanliness."*

Several agreed however that there would have to be changes in vehicle design. In LA, it was voiced that *"Uber-Pool is not designed for sharing – the vehicles we use put people too close together and in future, AVs will be better configured to give passengers more space – we will not be using existing vehicle designs – how they are configured will be key to overcoming people not wanting to share."* Others felt that technology could solve this: *"There is an algorithmic routing challenge to make this work – the Uber Pool problem is all about the time."* Once that is addressed then *"automation for sharing is all about reducing cost (but without extra inconvenience)."* Also in LA it was suggested that *"there is a high back end cost to operating this model – funding it at scale and at a price that works for all (competitive with current public transport) will require considerable subsidy – but sharing models will be robust if the price is right."*

What We Think

We agree with those who pragmatically see AV-based mobility as being a consumer offering which is ultimately driven by market demand and competition. What AVs 'should do' will be reflected in user demand. Some locations will choose to dictate this top down but in more open societies it will be left to the market and addressing the resistance to sharing will be an important factor in product differentiation.

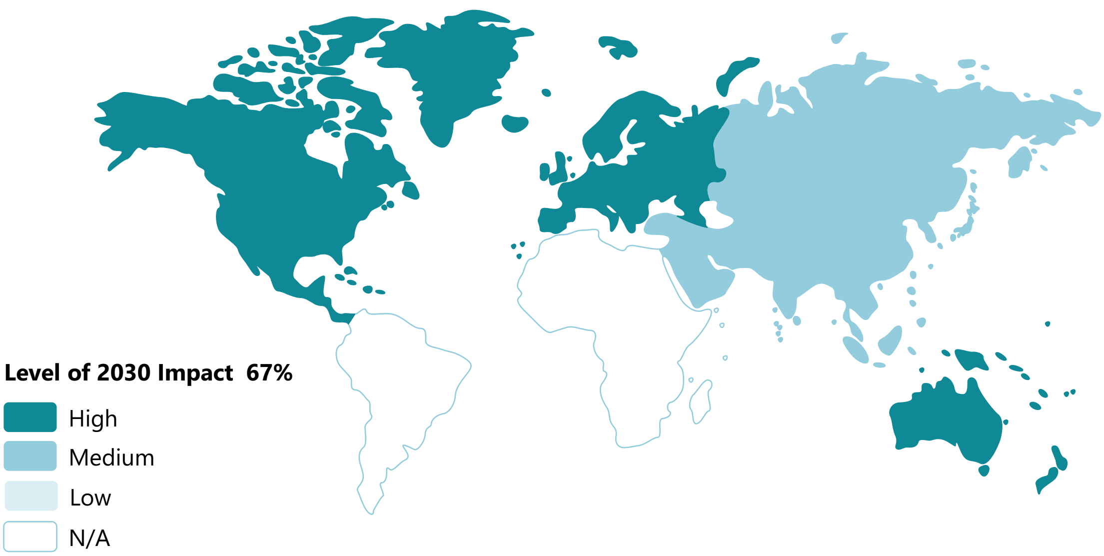
A potential answer for first generation auto-mobility can be found in the Cruise Origin vehicle, revealed in early 2020, the result of intensive design efforts plus focus groups.[131] Another is the Quarter car from multi-disciplinary transport design studio Seymour Powell.[132] Whereas the Cruise Origin tackles the challenge by giving passengers far more space than in a standard car, the Quarter car is focused more on 'private shared' mobility with flexible physically segregated zones more akin to business class on a plane. Ultimately it may be that, just like aviation, robo-taxi users who consider their personal space a priority can pay for more isolation. Those who pay for more isolation. Those who consider convenience and trip price a priority can share space.

Another potential technology overlay could be the adoption of proof of identity platforms that are emerging as part of the wider personal digital identity shift. While not revealing full details of an individual, if uses as a means of enabling access to a shared vehicle, they could both validate the passenger as being 'trusted' as well as reinforcing that remote monitoring is underway. Clearly there are privacy concerns in some cultures and open questions on who owns, and can therefore potentially monetise, the enabling data. However, this or similar may provide a technological solution to a human behaviour challenge.

Lastly, we heard from our many discussions, that the viability of future AVs is implicitly linked to the idea of multi-person occupancy. We counter by noting the potential to re-design personal movement with new vehicle approaches that don't create the congestion that today's TNC's do. We agree with the Singapore view seeking "new form factors enabling vehicles to morph for different use cases"

Progress by 2030

Enabling more shared personal space is very challenging to deal with and so may well be slower to evolve than many hope. More innovative design and technology solutions will evidently emerge that seek to give the necessary level of trust between two or more strangers to share an AV ride, but, for now, it looks very much that, as Lyft, for one, suggests, for the majority the next decade will be about both human drivers 'and' self-driving technology. We expect to see steady progress on this topic due to extensive experimentation by major players in mobility services, much of which is already underway.




WAYMO

Robo-Taxi Fleets

Robo-taxis are the way forward for passenger transport in suburbs and cities. As part of 'Mobility as a Service' robo-taxis change travel patterns, car ownership, and have to integrate with public transport.

Context

Perhaps the most significant change in recent years across the autonomous vehicle landscape has been the growing support for the robo-taxi model. For many this has been built on the extending reach and impact of the TNCs such as Uber, but it is very much underpinned by the long-term shifts across society from ownership to access where mobility has been at the fore. "Why own an expensive depreciating asset like a car that is stationary for most of the day" has been the question supporting the adoption of a wide range of services from Zipcar and Car2Go through to the, now ubiquitous, city-bike schemes and e-scooters from the likes of Bird and Lime.

Implicit within the business model of many of the prominent mobility service providers around the world has been the need to shift towards being cash positive. Uber and Lyft are both still making heavy losses as is China's Didi, while other Asian peers such as Ola and Grab are gradually edging towards profitability in some markets. For some, the switch to realising investor ambitions is improving margins and a fundamental component for many is to reduce driver costs. Embedded within this is automation. Hence, we have the idea of robot-taxis: driverless, self-driving taxis that could be one of the most rapidly adopted applications of autonomous cars at scale.

The capability to manage city-wide fleets of AVs is seen as both financially attractive and an efficient means of addressing the urban transportation challenge by others beyond the above TNCs. In recent years a number of OEMs have fast-tracked into the robo-taxi model with significant investments by Ford, GM and others. However, during 2019 several that were previously bullish about future prospects such as BMW, Volvo and Toyota have pulled back from becoming leading robo-taxi operators, while Hyundai has shifted stance to be a supplier to Uber. Of the others GM is staying the course via its Cruise business and probably the strongest advocate. Ford is still a solid supporter, but increasingly focusing more on goods delivery for now, while VW also seems to still be in the game.

"Why own an expensive depreciating asset like a car that is stationary for most of the day?"

What We Heard

Across several discussions the consensus was that *"fleet is increasingly seen as the way forward for passenger vehicles - this could change both travel patterns and car ownership decisions."* Having started via the TNCs, in Los Angeles, the view in early 2019 was that *"OEMs are now driving this. The fleet opportunity is very important, and it is providing rapid AV learning for OEMS."* It was felt that integrating them into the wider transport infrastructure, especially at key intermodal hubs, is critical. In Frankfurt, several had faith that *"robo-taxis could help to lower congestion in some areas,"* while others envisaged more urban traffic. As discussed earlier, there is mounting uncertainty over this issue with the key questions related to the number of additional vehicles added to the overall fleet, and how many people there will be in each one at a time.

In New Zealand, the role of robo-taxis as a key part of MaaS was explored in depth. Here, opinion was that *"the future of seamless transport services is clearly driven by both the product availability and the willingness of current drivers to switch to a subscription service provided by the TNCs."* A central assumption is that *"to have a viable and affordable subscription model, you need to have lots of customers contracted to paying a small amount at an agreed frequency."* While integration with other forms of (public) transport including scooters, bikes and associated single ticketing systems as well as APIs were again seen as vital, *"delivering the value proposition to the consumer for both cost and experience"* was considered as a lever to result in a step change. *"When subscription services become cheaper and provide a better service than the private vehicle, then this will take off exponentially"* and, in the AV context, the use of robo-taxis is fundamental to this. However, it was recognised that MaaS can work well without AVs, and a switch to AV is not certain. Although the likes of Uber and Mevo[133] could break-even in cities with human drivers, for rural areas it was suggested that AV will be critical to making MaaS economically viable – with or without government subsidy.

In Singapore, as the late 2019 'reset' became evident there was focus on how the robo-taxi model can deliver cost reduction per km, and several felt that *"the overall net benefit will be making travel and transportation cheaper per mile -even if some elements of the system cost more than today's equivalents."* But others asked, *"what is the AV business model? Who is paying for it? What is driving deployment?"* One response was that *"many OEMs have not been planning far enough ahead, by making current vehicles suitable for robo-taxi deployment, whereas Tesla has increased the cost of its vehicles by including 'future proof' sensors in existing models."* Those in Australia also questioned price and ROI for robo-taxis, and whether or not the *"cost of obsolescence"* is being properly factored into business cases.

What We Think

We agree with the observations raised in New Zealand. Robo-taxis can alter lifestyles and car ownership for many in cities and spread-out urban areas, but certainly not for everyone. For each individual, this depends on the nature of their trips, size of family and their travel demands for work.

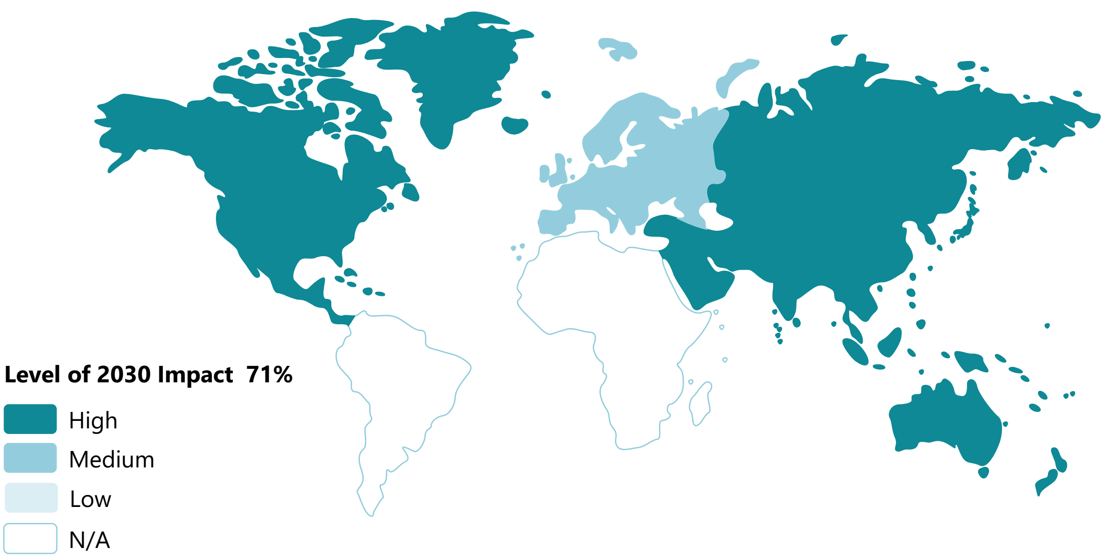
The bellwether is with today's TNCs and the large portion of people who do not find Uber / Lyft pricing a burden, living in areas where a pickup takes only a few minutes. Have they made a substantial shift in their lifestyle? Although the global market is growing, car rentals certainly appear to be down for business travellers in the US. How does this interact with availability of parking, congestion, and other factors? We now have enough TNC deployment to begin to study the data and answer these questions; in fact, in-house analyses are well underway within companies like Uber, Lyft and Grab.

The interlocking relationship with parking is an important one: cities could apply permitting measures to encourage or restrict robo-taxis, or define policy aims such as high occupancy and use of public transit and link operating fees to this. Short term there may be congestion, but longer term there could be the transitioning of parking areas to other uses and a reduction of the needless driving people do now to find spaces. Changes in planning guidelines in some key European and North American locations may well be a notable signal of this.

It is interesting to consider the Silicon Valley comment that “people are not thinking deeply enough about this.” The recent OEM pullback from robo-taxi appears to reflect that more deeper thinking may well now be in progress. This is indeed a game for deep pockets, and we have that now in Waymo, WeRide, Cruise, and others. As mentioned earlier, as Cruise CEO Dan Amman shared in September: “If you don’t have thousands of engineers working on this, and billions of dollars of capital to spend, and deep integration with a car company, then your chances of success are very, very low. As of right now there is only one company—which is us—that has all of those things in place.”[134]

Progress by 2030

By 2030 robo-taxi services will be increasingly commonplace in cities where TNC usage is already high, as long as complexity of driving is relatively low and there is good year-round weather. Elsewhere, robo-taxi services will be limited to the simplest routes. The industry will have matured sufficiently that robo-taxi services will be more available across a wide range of geography, and not just in the good weather areas; however, they may not operate in certain weather conditions. This will create frustrations for users, but human-driven TNCs will handle the demand. This, and many other factors relating to the complexity of a particular trip, will result in a hybrid human-driven and robo-driven ride hailing offering in the vast majority of locations.




BIRD

First and Last Mile

Improving the inefficient first and last mile has health, energy and efficiency benefits. In urban environments, scooters, bikes and small autonomous robots all have a role to play.

Context

A primary opportunity for AV for both people and goods is in bridging the first and last mile. Whether for getting from home to access public transport, connecting to work or leisure destinations, or for the delivery of goods, the first and last mile has been seen as an area for greater efficiency for some time. The arrival of AVs seems set to address this.

Five years ago we saw that "in the complex world of logistics, vast improvements have already been made in the efficiency of moving goods around the world. Although the speed at which packages are sorted, loaded and transported has increased substantially over recent years, the main efficiency challenge is in the last mile – from distribution centre to final destination, be that a home, an office, a car or an individual. This, costing typically up to 50% of distribution, is the most difficult and expensive leg of a package's journey. Proposed solutions lie mostly in drones or autonomous delivery vehicles."[135]

Today it is evident that with myriad solutions being trialled and introduced globally there is both investment and momentum in the local movement of both people and goods. While drones are an emerging option (addressed in the next sections), other alternatives are already being tested and deployed.

For **people,** effective last-mile options continue to be walking or cycling. They set the standards by which many benchmark new innovations. Both are low-cost, zero-carbon, healthy and mostly safe means of getting to a destination or a bus, train or tram stop that have no future technical risk and are available 24/7. While city-bike schemes are evolving into e-bikes in some locations, perhaps the most ubiquitous change in several urban / suburban landscape are the new electric scooter services from the likes of Lime, Bird and Uber. Although at the moment these are steered by the user, autonomous models are on the horizon. Uber is just one of the firms developing robotic versions of its dock-less scooters.[136] As well as self-driving functionality, the ability for fleets of scooters to automatically come to users on demand is a central part of the proposition. Small people-carrying pods are also part of the mix.

For **goods,** the default in many markets is the courier, be they on a cycle, motorbike or van. Indeed, some see that we have been moving towards 'white van' cities with an average market growth of over 70% in the past 20 years.[137] The potential for automation here has therefore been attracting considerable attention. As explored in more detail later, early movers have included Starship Technologies whose six wheeled delivery robots have become a common site on several corporate and university campuses which are being used as testbeds. A common question for these and the larger autonomous vans also being launched concerns secure unloading at the destination. If a customer is able to access their goods from a self-driving robot on the street, then all works fine. But what if they are not at home or busy? How do we deal with elevators and steps? What about security? These are some of the design considerations for the future currently being tackled by many who see the financial prize in solving this global opportunity.

What We Heard

As some suggested in Frankfurt, *"freight and people movement have the same overall conditions, but a different execution. They require better hub infrastructure, embedded processes, and the right vehicles."* However, others see two different use cases. *"For people, this is about bikes, buses, scooters, etc., linked to multi-modal hubs; for goods, it is connecting to logistics depots."*

For people movement in Los Angeles, distinction was made between urban and suburban locations, where time between home and hub may be significantly greater. *"Often, suburban is a 20-mile round trip, which is not efficient for single pods/robots."* Rather, "you need bigger vehicles for multiple delivery/drop offs (like the current human driver approach)." By contrast, *"the scooter model doesn't work in the suburbs – they are never where you need them to be – it is very much an urban/dense living model – so what works in urban areas does not necessarily work elsewhere."* In Silicon Valley however there was confidence that more providers will deploy scooters that automatically reposition themselves so that they are in the right place for users most of the time.

On the negative side, there was concern in LA that *"AV scooters could cripple/grid-lock the system."* Notable, however, both here and in Frankfurt, was that people seem fine to 'drive themselves' on scooters and bikes in order to bridge the gaps. In Germany, there were also calls to *"differentiate between the urban and rural context."* Parallel discussions in Tokyo reinforced the fact that for Japan, providing transport access for ageing rural populations is a key part of the government's AV strategy.

In New Zealand, where "first/last mile transport is currently fragmented across user choice/payment systems with little cohesion," it was proposed that, in addressing this challenge, from a public sector perspective, *"we need to rethink the purpose of many local and personal transport options to be about herding people towards the right hubs, from where they can access mass systems and the CBD,"* and also look more at the *"cost/benefit of getting people onto public transport."* In addition, there were calls for better AV/public transport integration, customised services with lots of user choice, and maybe a *"single digital identity"* for transport access.

In Singapore, the national strategy is for AVs to be concentrated very much on the connection between home/work and public transport, and in Australia, there is more of an initial focus on the need for *"changing consumer behaviour away from car ownership,"* perhaps by *"educating the public on cost per mile,"* as well as by providing *"better integration of timetables, ticketing, and payment systems"* so that consumers are able to see AVs as *"a logical transport choice."* A key question raised was *"how to drive patronage of last mile AV to be viable for everyone – not just the few."* In the UAE there was confidence that by 2030 *"the first / last mile problem will be addressed."*

For goods, those in LA again considered that, urban and suburban areas require different solutions. For both use cases, for the first/last mile there were several warnings about how best to implement AVs. In Germany, it was clear that *"nothing will change unless the regulation changes,"* while there was US concern about funding, as *"new (TNC) companies are all trying to exploit (publicly funded) infrastructure at no cost – they have to change their view on how they will make a contribution."* Maybe, it was suggested, *"the city should tax AVs and robots using its roads and pavements (sidewalks) to help pay for infrastructure."* Those in Melbourne proposed that, if we are expecting between 20% and 30% of vehicles to be autonomous by 2030, then for business models to be viable at scale, regulation will also play a role to *"ensure that public contracts involve data and billing platform sharing."*

What We Think

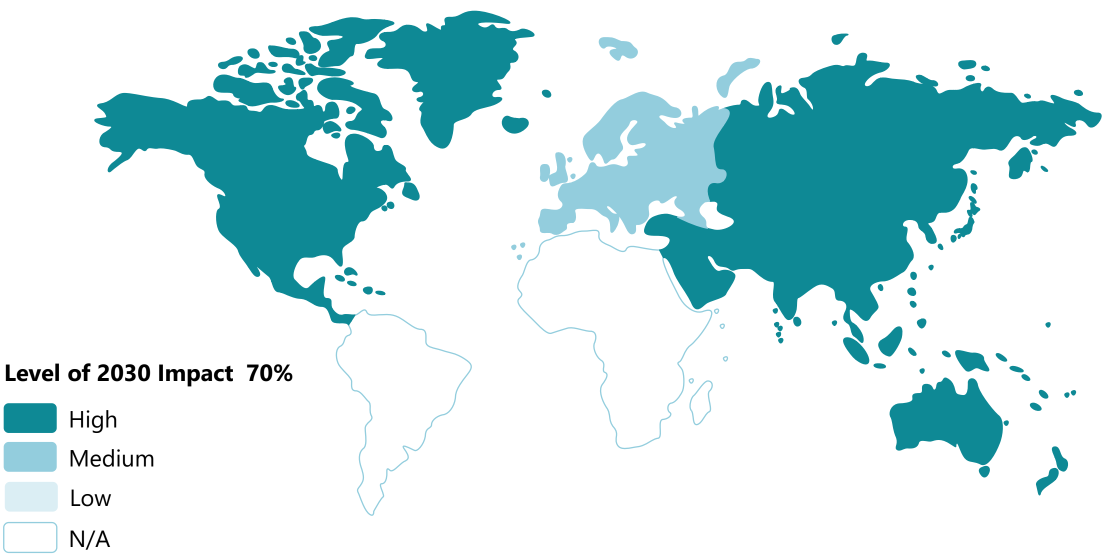
Even though there were calls for better AV/public transport integration it should be recognized that AV services are mostly coming from the private sector which will respond to customer demand, not the wishes of public transport advocates. However as noted previously, cities can apply fees to robo-taxi services linked to policy incentives, such as zero emissions and trips starting/ending at public transport hubs.

One key question raised was how to drive patronage of last mile AV to be viable for everyone – not just the few. We would suggest that the entire point of AV's is to enable low cost services, so these options are available to all. Last mile services are being used now extensively by the well-to-do with today's TNCs. AV is key to expanding access.

We would perhaps challenge the notion that the city should tax AVs and robots using its roads and pavements (sidewalks) to help pay for infrastructure, simply because all sorts of commercial services have used roads for years without being singled out to pay for infrastructure. All road users should pay for use of the road, and they already do via fuel taxes and other measures. Moreover, in a growing number of locations there are city taxes for vehicles operating on pavements.

Progress by 2030

Addressing the first and last mile has progressed immensely in the last decade due to the rise of TNCs, and much has been learned already from real-world operations for both people and goods. TNC's operating robo-taxis will greatly expand access by offering mobility at much lower cost. By 2030, the effects could be profound in regions where the robo-taxi providers choose to deploy. Many cities want to be chosen, but, as well as a workable regulatory regime for AVs and road safety, this will depend on a fee structure that is not onerous. Deployment will still be modest in terms of global trips, but when the vision of low-cost automated mobility is fully tested the results will set the course for the decade beyond 2030.



Air Taxis

Several major cities will support the introduction of air-taxis - initially to allow the elite to bypass increasing congestion on the streets, but later for wider citizen use.

Context

Whether seen as large, people-carrying drones, automated electric helicopters or vertical take-off micro-planes, air-taxis are an increasingly frequent representation of a niche area of autonomy. Having been a common ingredient in futuristic views in movies from Metropolis and the Jetsons to Bladerunner and Total Recall, flying taxis are now a popular depiction of a nearer-term future being pushed by a number of significant corporate PR machines.

Industry experts at the major companies developing much of the enabling systems for air-taxis consider that “flying over traffic jams and in-between high-rise buildings is likely to be possible in a few years.”[138] Today, a number of varied design options are being explored - some by major organisations. They include:

- **Uber** which is the largest corporate investor in air-taxis. It is targeting 2023 as the year its service will first become commercially available and is focused on testing in mild-weather locations such as Dallas, Dubai, LA and Melbourne. The current vison is that each plane will be capable of a speed of 240kph and a range of up to 100km with one pilot and four passengers on board. The vehicles will run on electric batteries, require fast charging and operate from large sky-ports dotted around urban areas. **Hyundai** created a flying taxi division in 2019 and has recently joined up with Uber for an aerial ride-sharing partnership.

- **Airbus** has been flying Vahana, its prototype single-seat electric VTOL aircraft, for the past couple of years. It is fully autonomous with no pilot on board and operates at 190km/h - four times the typical speed of cars. After 80 test flights, some commercial versions are set for launch shortly.

- **Alphabet**-funded, **Kitty Hawk** is now part of **Wisp** - a joint venture with **Boeing**. It has three different products in testing. The Kitty Hawk Flyer is a single-person plane designed to take-off and land on water; the Cora is a two-person fixed wing VTOL with 100km range; while the Heavyside prototype is focused on quieter flying.

- Germany’s **Volocopter** is promoting a multiple rotor design that can carry two passengers for 30 minutes up to 25km. With initial support from **Intel**, this is getting a lot of media coverage as it has made the shortlist for Dubai’s air-taxi fleet.

- Guangzhou based **EHang** has been testing its fully automated quadcopter and claims over 1000 flights to date. Although initially China-centric, agreements are now in place with partners in Nevada and Austria and testing is also underway Dubai.

With over 200 electric plane projects now underway, many of which are focused on air-taxis, there is clearly momentum, but questions are being asked about the realities of deployment at scale. Will the technology work? can we manage the airspace? and who will be the customers? are just three of the most common queries.

What We Heard

There was mixed support for air taxis. In Germany, several actively involved in the field felt that progress would be tangible in the next decade, but others highlighted that air-taxis *"don't really solve the problem for many."* Moreover, given the noise and space constraints, the suggestion was the *"top use case is for Asian mega-cities."* In New Zealand, where Alphabet / Wisp has been undertaking initial testing of its Kitty Hawk prototypes, there was general agreement that *"these are high cost options - only credible for replacing helicopters for the wealthy."*

In Melbourne, our workshop took place the day after regulatory approval for initial testing by Uber.[139] However, participants considered that this area was *"over-hyped"* and with the "high cost of engineering" and limited current use of helicopters at scale, it was felt that the services *"will not be widespread by 2030."* Singapore experts concurred that *"there will be a high price point for this, so limited application (e.g. Dubai) – but we may see use in several cities of very high congestion (like Sao Paulo),"* where helicopters are already part of the established transport mix for the elite.

In Silicon Valley, the view around air-taxis were also mixed. One expert felt that *"this is the area where we would see most progress over the next decade"* as existing models such as those of the US FAA are adapted for managing the airspace. Indeed, NASA is partnering with the FAA to come up with certification standards.[140] The majority however felt that, for the next decade, any large-scale impact would be low – considering that *"the maze of regulation, safety concerns and energy use will all be mitigating factors."*

However, as expected, opinion was more upbeat in Dubai where there was greatest support for the concept – one endorsed by government targets. With projects underway with the Dubai Roads and Transport Authority, several felt that soon *"flying taxis can release the streets (or some of them) for people."* Many agreed with *"the need to change the rigidity of the city"* and saw that air-taxis can be a key part of this. Some even envisaged that by 2030 *"up to 50% of mobility needs could be provided above or below ground"* with air-taxis the majority. However, when challenged about how it would be possible for half the population to move independent of road and rail, clarification was made that *"this would be for half the Emirati population"* and so not for the other 90% of those living in the UAE.

Across several workshops, and especially in Singapore, the issues of noise, space, traffic management and energy use were regularly raised: air traffic control for drones was frequently highlighted as a major development challenge. But, in other parallel discussions on electric aviation generally, including a workshop in Norway, the energy concerns of making air-taxis operational were largely allayed. With zero emission flying a growing area of development focus across the aviation sector and beyond, it was felt that *"lower mass, higher efficiency batteries would soon be available"* and so enable the target flight times.

What We Think

Many current designs of air-taxis aim to carry up to two people therefore they will initially be seen as replacements for helicopters. However, there are indications that, as drone development escalates, payload capability is doubling every couple of years or so - and therefore we can expect to see a transition to an associated increase in passenger capacity over the decade.

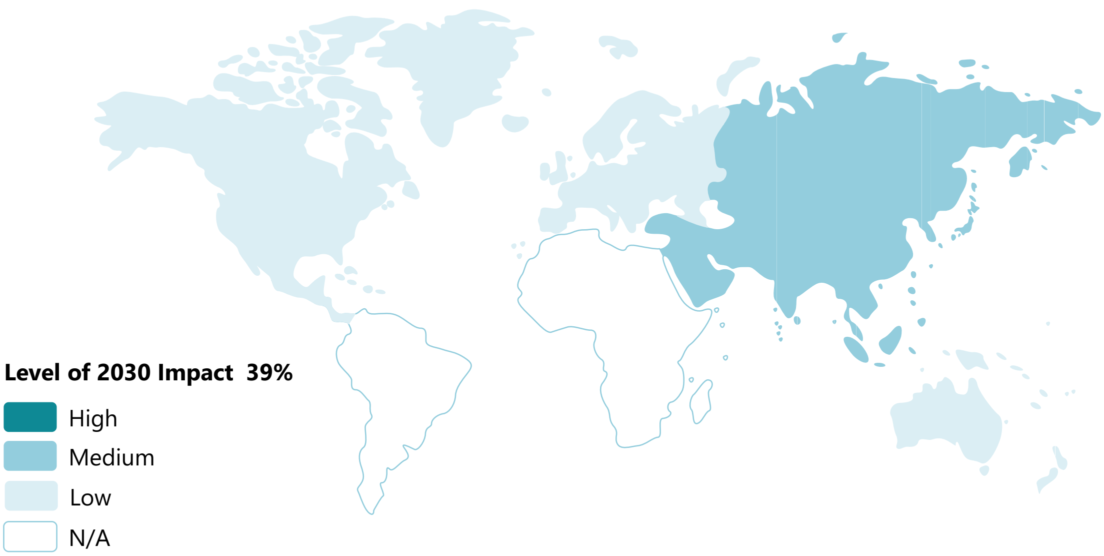
Air taxis should not be dismissed by throwing down the 'only for the wealthy' card. EVs were once only for the wealthy too, as well as cars equipped with ADAS. The question is "will we see a democratisation of access to air-based mobility and, if so, when?" We would suggest that any mobility service that takes cars off the road deserves serious consideration.

It will be interesting to watch niche applications deploy in the next few years. New corporate campuses or re-designed city centres could be configured in a park-like manner, integrating remote parking served by air taxis. With the projected available battery efficiency and capacity, short hops such as this could carry more passengers.

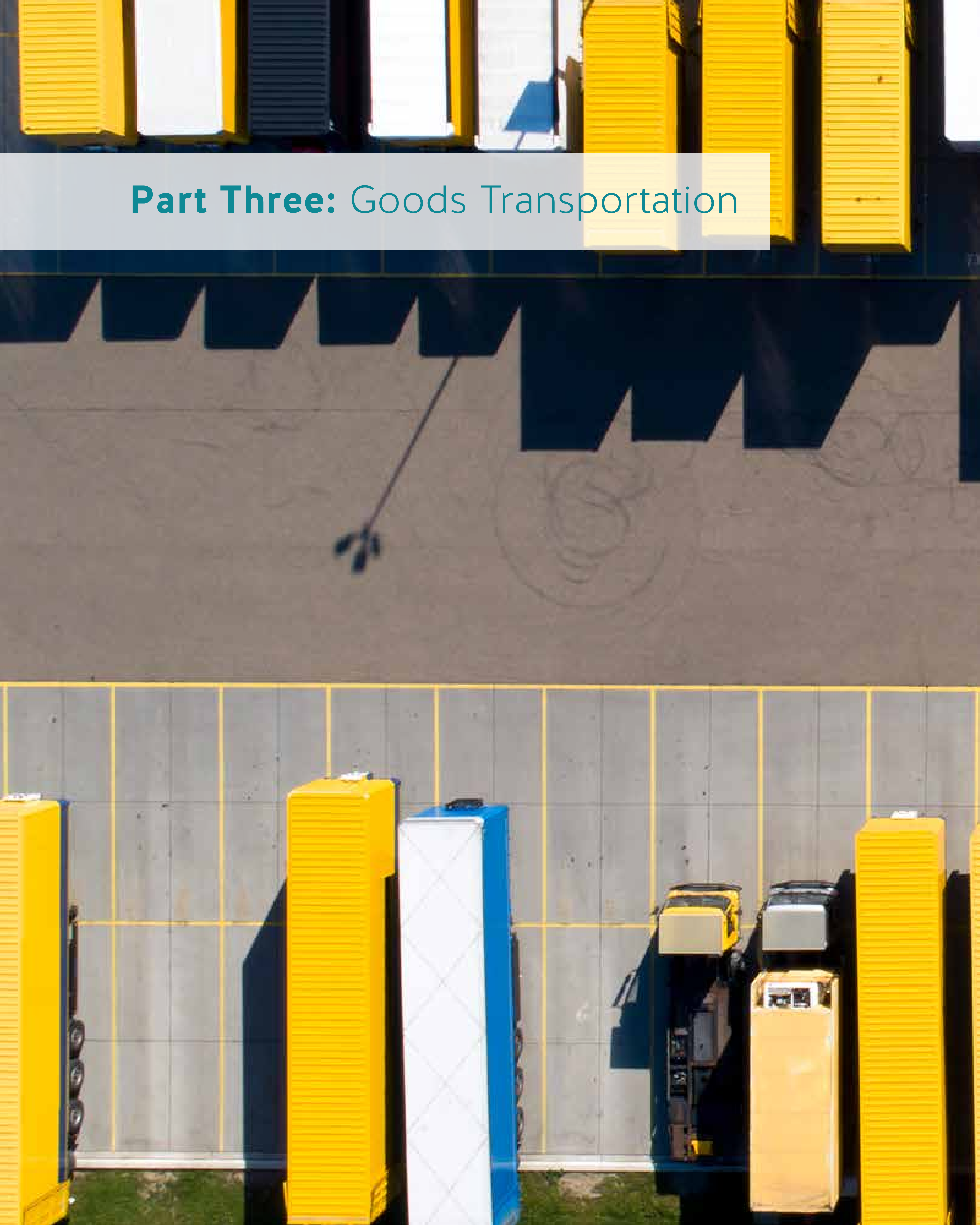
Progress by 2030

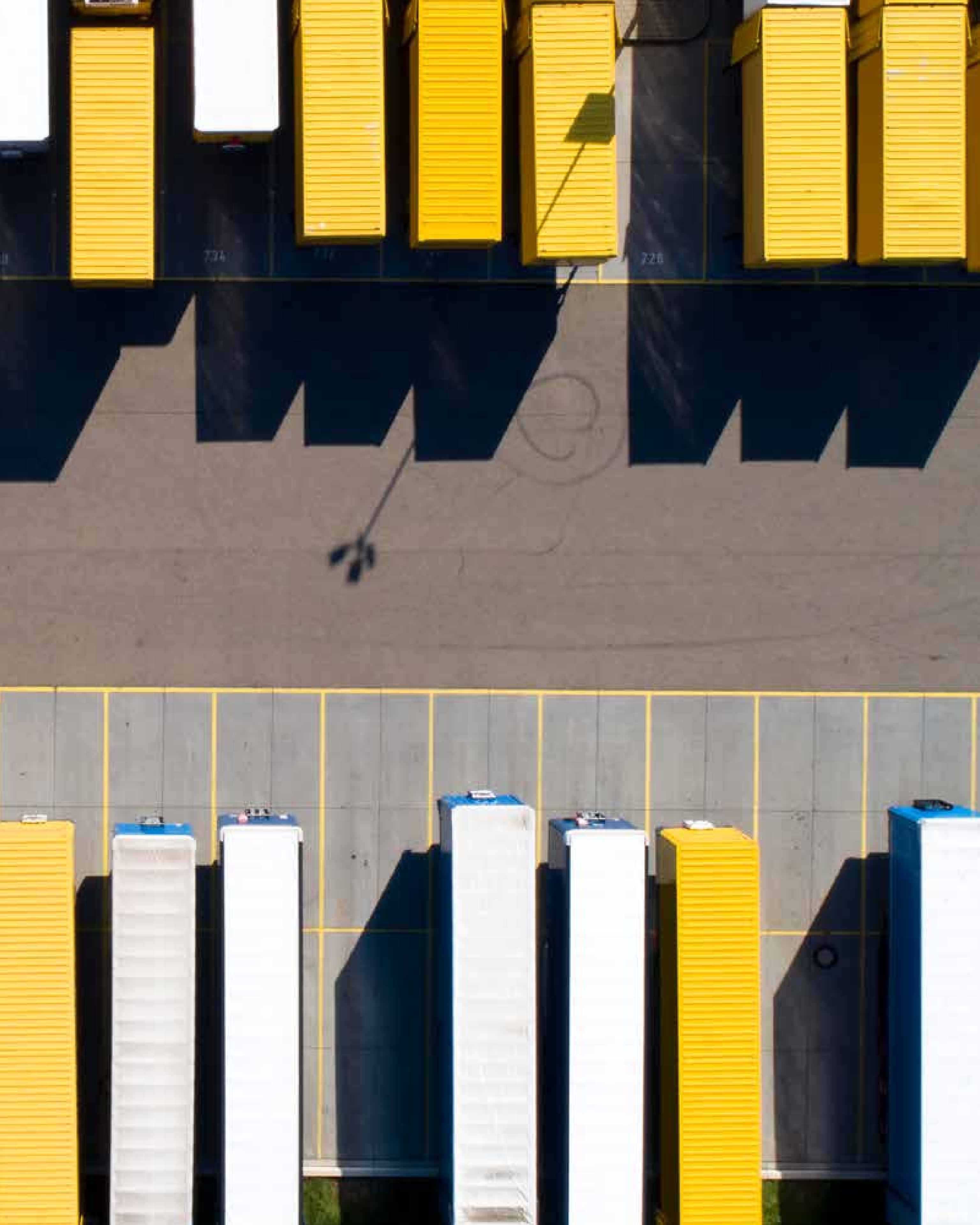
Given the multiple initiatives already underway, commercial services are expected to launch in the next couple of years. As such air-taxis will likely be operation in a number of cities by 2030. These will, however, be only in locations where severe congestion, proactive regulation and targeted investment have all aligned to provide the supporting environment. Beyond Dubai, Shanghai and several other Asian mega-cities where there may be hundreds, but not thousands, of autonomous air-taxis chauffeuring the wealthy as a commercial service, regulatory concerns about noise, safety and liability will have limited deployment to numerous small-scale trials across a wide range of additional cities.

An intermediate step, likely to have been completed by 2030, is to assess just how profitable such services really are. If a positive outcome, we should not discount leverage created by the push from commercial sector players who see significant profits in air-taxis, thus accelerating deployment rates.



Part Three: Goods Transportation





Drones for Goods

Investment in timely drone delivery services accelerates deployment in multiple locations. Concerns on safety and collisions are overcome with automated UAV air traffic control.

Context

The potential for drones to have a substantial impact on how we move and deliver goods is a field of growing media attention. It captures the imagination, plays to multiple ideas of speed, convenience and technology sophistication but also makes some major assumptions about how they are going to operate safely and securely. Of all companies involved, Amazon's Prime Air automated testing in 2016 started the large-scale view of what might be possible in the near-term. Its ambition is to launch a 30-minute delivery services for packages up to 2kg.[141] With development centres in the US, UK, Austria, France and Israel, "safety and security are top priorities as we look to incorporate small drones into the airspace." The company is working with regulators to "design an air traffic management system that will recognise who is flying what drone, where they are flying, and whether they are adhering to operating requirements."

Amazon is not alone. Other major innovators in the field include UPS and Alphabet. UPS was for example the first to receive certification and the important Part 107 waiver from the US FAA in October of 2019. These collectively serve as significant regulatory gateways to entry into the drone delivery market, open up the ability for unlimited scaling, and release governmental control over the types of flights a company can operate. Alphabet's Wing is close behind but in principle UPS has first mover advantage in the US. Other significant players in the sector include Northrop Grumman and AeroVironment.

While these are largely aimed at the mass market and have a major role in logistics for the future, others have been focused on more niche applications such as healthcare. NASA has been running trials since 2015 and the government of Rwanda has notably giving permission for Zipline to deliver blood and pharmaceutical products since 2016. The idea of using drones to deliver critical products such as vaccines to remote places has since further expanded with similar operations in Congo, the Pacific Islands and mountain regions where traditional distribution is slow, risky and expensive. Taking a global view, DHL for one, considers that drones will not replace traditional ground-based logistics. "However, they will provide value in operating safely in remote, potentially dangerous-to-access locations."[142]

Looking ahead, with food delivery also part of the mix in some urbanised areas, concerns are growing not just about the safety and security of thousands of drones in the skies, but also the liability and risk from hijacking and vandalism. Managing a shared air traffic space is becoming a priority, while the use of the same technology for smuggling drugs across border and into prisons is also providing new challenges for government agencies.

Back in 2016 Goldman Sachs predicted that the drone industry will generate $100bn in 2020.[143] With some conservatively projecting drone delivery to be a $30bn sector by 2030, accounting for a third of the revenues of the automated last-mile industry, investment is evidently growing.[144] PwC reckon that in the UK alone over the next decade over 70,000 drones will deliver £42bn in GDP growth, £16bn in savings for the economy and create more than 600,000 new jobs.[145] Expectations are high.

What We Heard

In the past decade drone technology has moved rapidly forward and, while thousands of smaller drones may soon be delivering multiple packages, the rate of progress is evidently raising questions about coordination. How multiple automated systems can work without collision, is highlighted in the repeated calls for some sort of *"air-traffic control for drones with a flight control network able to self-manage UAV air routing."*

In Frankfurt in particular, there were several voices in support of drones for goods; *"this is super-important for the last mile."* In particular there was endorsement of the fast movement of time-sensitive goods, - especially for body organs, such as kidneys, and other medical supplies. With companies such as Zipwire scaling in Rwanda and beyond, some also envisaged wider application in other locations, where *"from an infrastructure perspective – drones are cheaper than a new road."* Equally in mountainous regions, such as the Alps, or highly congested urban areas, others in Germany saw potential benefits in terms of time and cost.

The expectation is that military applications and internal logistics, used within the controlled environments of large factories and warehouses, will continue to drive technology development and cost reduction for drone delivery. With the likes of Amazon busy undertaking trials, and UberEATS joining in for fast food delivery, several major players driving the initial commercial business cases were identified. Considered views, however, suggest that the support for a broad range of applications is *"best for fast-growing mega-cities, especially those in Asia,"* and that, wherever they are used, *"the need for regulation is clear."*

One of the global ITS discussions in Singapore focused specifically on the policy implications for drone delivery and highlighted *"the need for channel regulation around where and when they could operate."* Although development funding was seen to be forthcoming and regulations are increasingly in place or under review in many nations, the concerns on liability, insurance and airspace management were again raised.

In the final workshop in Silicon Valley, there was criticism of the media support for the idea of autonomous drones, while also recognising that it is a narrative that easily captures the public imagination. Foremost were the concerns that *"this is an invasive technology (and a dangerous one)."* Utmost *"drone AV safety is a big concern – as soon as one falls from sky, the hype will stop."* Liability and insurance could both be barriers for adoption in many cities. Moreover, as they get bigger, *"moving stuff by drone may require more energy and so efficiency has to increase dramatically."* One conclusion was that drones are *"only really good for remote / rural / lower density populations and not applicable for cities where most of us live."*

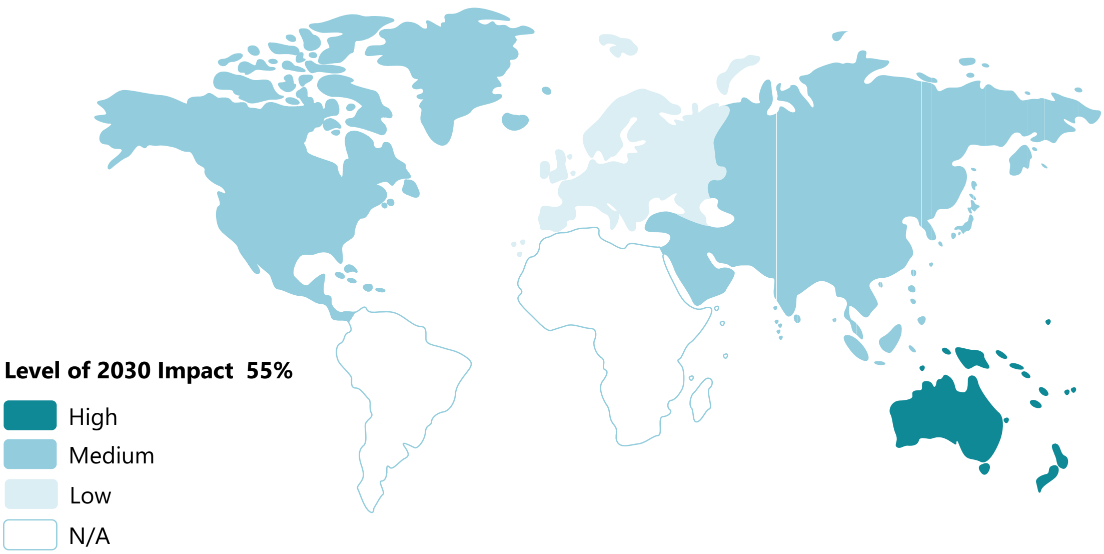
What We Think

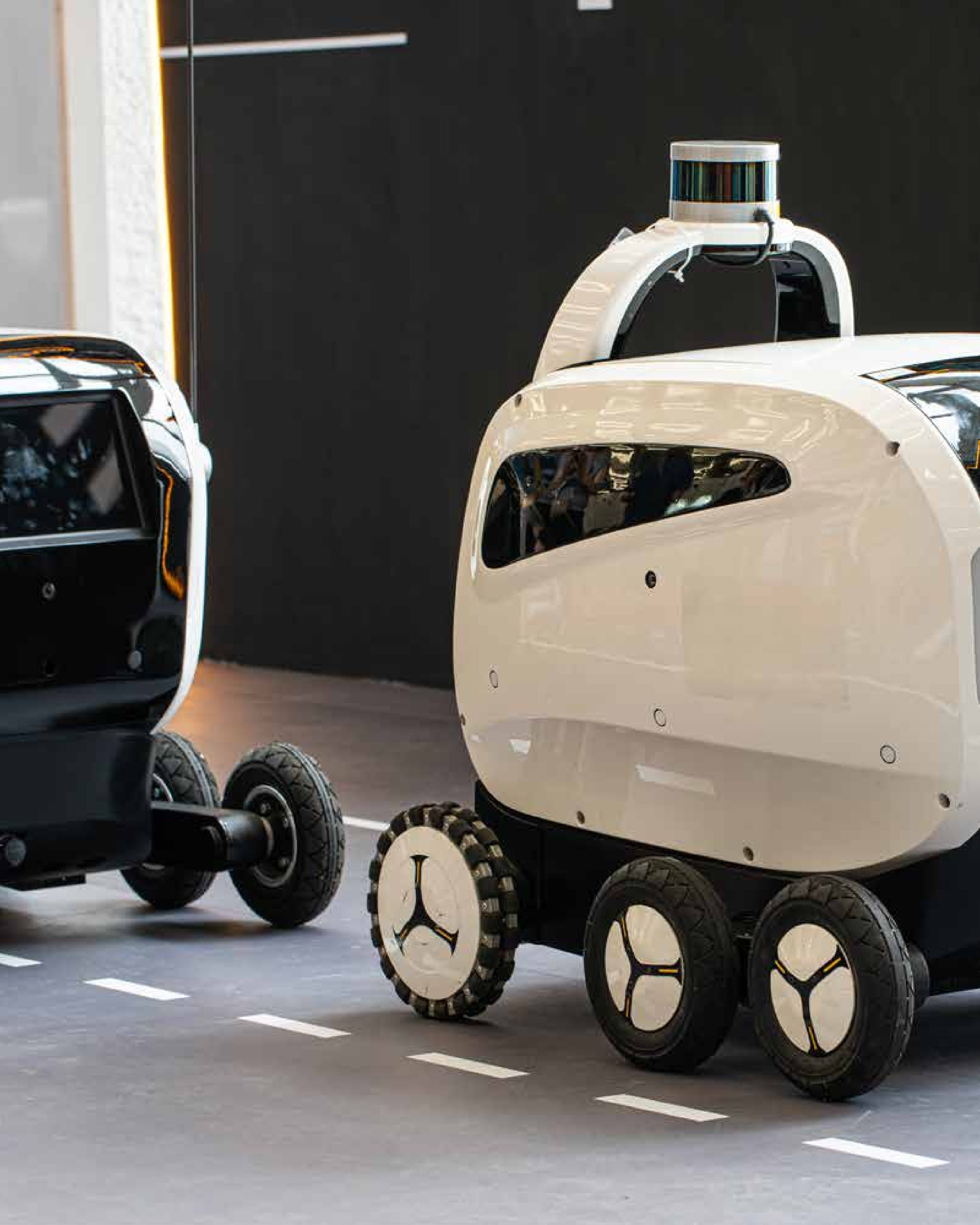
Drone tech has been fairly mature for use as a delivery mechanism for some time. However, in some major countries the regulators have taken much longer than expected to provide a workable commercial framework. This is one reason that the Goldman Sachs 2016 estimate of a $100bn market by 2020 has not come to pass.

The potential influence of Amazon is tangible across many discussions and so, if the internal business case makes sense, this has to be considered as a strong probability. For many others in the West, we question whether there would be scale without Amazon in the mix any time soon. However, given that Chinese manufacturers already command the majority of the commercial drone market in 2019, the potential for growth from China is tangible. With some more sanguine predictions being shared of a global commercial drone delivery sector worth around $20bn by 2030, analysts are attaching much of that to Asian suppliers. Firms such as DJI have, for instance, already taken a commanding majority of consumer-related drone hardware.

Progress by 2030

If drones for goods don't take off, neither will drones for people. Drones for goods will be the advance guard for implementing widespread use of drones in society, and, to some degree, laying the groundwork for air-taxis. It appears that sufficient regulations are now in place, or in progress, in enough jurisdictions that we are entering the phase of assessing commercial drone delivery at scale. By 2030 we will see greater maturity in niche areas, such as medical, and wide-ranging experimentation for other types of cargo. The 2020's will be a decade of significant investment powering exploration, with the winner use cases emerging by mid- to late-decade.





Urban Delivery

Small, slow-moving, autonomous robots offer attractive ROI and act as an accelerator of deployment. They enable safe, clean, convenient and low-cost delivery and help to raise public confidence in AV.

Context

Before we address 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 delivery vehicles operating within our towns and cities.[146]

As mentioned previously, 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 by addressing this challenge.[147] For example, DHL, the world's largest delivery company, is upgrading its fleet of 3,400 electric delivery vehicles with the latest autonomous technology. DHL says it can use its current networks to improve efficiency and enable a 24/7 service for its consumers.[148]

In the UK, the TRL-led Gateway project completed the UK's first trials of an autonomous CargoPod vehicle in Greenwich, London.[149] 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.[150] Similar products from the likes of Thyssenkrupp, Nuro, Marble, and Robby Technologies are also scaling – some in partnership with established manufacturers.[151] 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. There are several other notable consumer-facing developments:

- **Neolix**, a Chinese self-driving delivery company, expects to sell 1,000 vans by the end of 2020.[152] It is chiefly targeting markets like food delivery, mobile retail and security; over the past two years it has already sold 225 vehicles which are now deployed in 10 cities throughout China with customers such as Huawei, Alibaba, Meituan-Dianping and JD.

- **Amazon** has recently announced that EV start-up Rivian will supply them with an electric van fleet that will number 100,000 vehicles by 2030.[153] The vehicles will have extensive ADAS including automated emergency braking, front-wheel and all-wheel-drive options, lane-keep assist, a pedestrian warning system, traffic design recognition and an automatic warning system that detects and alerts distracted driver behaviour. These vehicles are expected to begin delivery in 2021, with at least 10,000 in use by 2022 and the entire fleet on the road by 2030.[154] Given that Amazon has filed multiple patents for autonomous delivery from airships and drones as well as ground vehicle robots, there are high expectations that Rivian will become a major autonomous platform[155]

- In the US **Nuro** has recently received NHTSA exemption to deploy up to 5,000 low-speed electric delivery vehicles without human controls like mirrors and steering wheels.[156] This ground-breaking approval followed three years of talks with the government and this exemption is conditional on a set of terms including mandatory reporting of information about the ADS operation as well as outreach to the communities where it will be deployed.[157] The initial rollout is taking place in Houston, with plans for it to deliver items like groceries for Walmart and pizza for Domino's Pizza.[158] The Nuro R2 is designed to make short trips and will be restricted to pre-mapped neighbourhood streets and will at all times be monitored by remote human operators who can take over driving control if needed.

- **Ford** is currently testing its self-driving delivery vehicles. Starting in 2021, Ford plans to launch a limited fleet of commercial AV delivery services in Miami, followed by Washington DC and Austin, Texas. Ford has also partnered with Agility Robotics to create a two-legged delivery robot called Digit. "This headless, two-legged robot can unfold itself from the back of an autonomous car and deliver a package straight to your door. It can carry packages that weigh up to 40 pounds, go up and down stairs, walk naturally through uneven terrain, and keep its balance if it bumps into something."[159]

Alongside these last mile delivery examples, UPS has engaged Waymo to move packages between warehouse and local delivery centres.[160] Unlike the other B2C deliveries, this is bringing in an important B2B element to the mix.

What We Heard

Many experts we consulted consider that the suburbs are *"the perfect place to develop and test AV technology, and can help to increase public awareness."* In Singapore, the aspiration for future urban delivery via *"small, clean, slow-moving, autonomous robots"* was seen as an *"accelerator of technology development/deployment,"* but not a large driver of large-scale change. One perspective in Singapore was that *"maybe urban delivery robots and drones should be considered together as two parts of the same challenge."* In Australia, while a future rise in automated food-delivery was expected, many felt that *"competing against today's white vans is a challenge – they are cheap, flexible, and dynamic."* Those in Los Angeles largely agreed and suggested for *"effective multiple delivery / drop offs in large cities you need bigger vehicles than are currently being envisaged."* The Frankfurt discussions highlighted that *"solutions need to be secure, socially acceptable and economically reasonable"* but felt that the opportunity would not be fully addressed by 2030.

In Dubai there was also mention of acceleration of automated food delivery but several highlighted that, the national airline, *"Emirates is exploring extending delivery beyond the airport."* How this plays out was uncertain but given the scale of Emirates' ambitions, this is likely to be more than just the home delivery of baggage. In a city where nearly 100% of goods are imported, parcel delivery is a significant opportunity. At the global ITS event there was also support for *"a growth in low speed urban delivery bots"* across many markets with the efficiency benefits seen as the primary driver for adoption.

"Competing against today's white vans is a challenge – they are cheap, flexible, and dynamic."

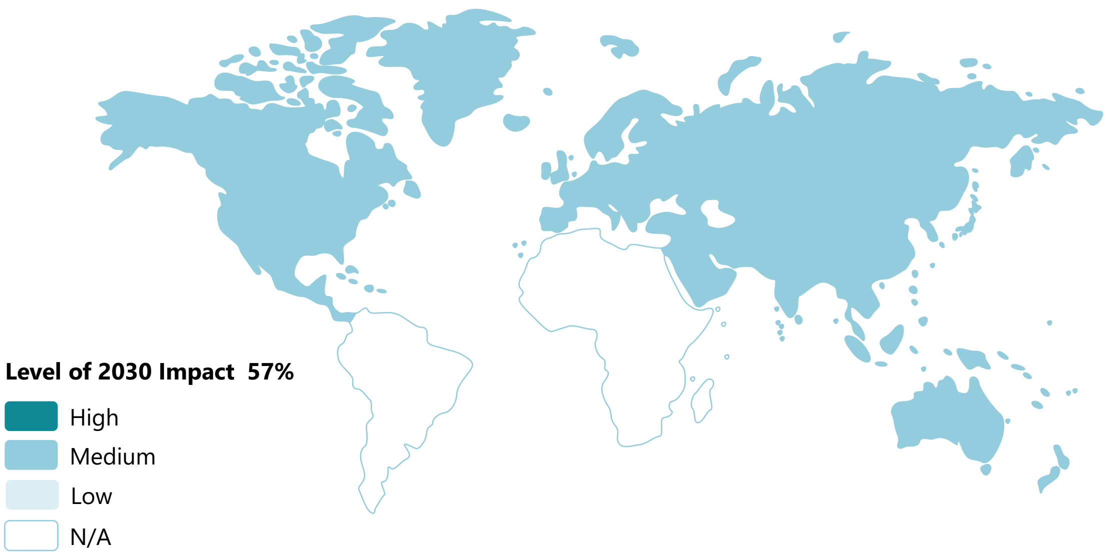
What We Think

An integrated approach to urban delivery, as mentioned in Singapore, is the likely way forward. Sophisticated delivery companies such as UPS are constantly assessing their various platforms seeking for efficiencies. Air drones, pavement vehicles, slow speed on-road vehicles add to the toolbox. New entrants such as Nuro and Udelv are currently providing a relatively simple offering, but they are ripe for acquisition as these services mature.

In all cases, regardless of how cheap “white vans” are, the labour savings from driverless vehicles is an incentive for significant deployment – but only if the overall operation is still efficient. Packages can’t move on their own and must be delivered to the final destination – unless enough users opt for unique pickup options.

Progress by 2030

Urban delivery is a Big Player game. Large and highly integrated players like UPS, DHL and Amazon have shown they are adept at evolving to meet demand. They have a history of trialling new technology to gain efficiency and will do so with driverless vehicles. Equally, Chinese firms such as Neolix may well scale up in parallel, or even quicker in their domestic market. By 2030, we can expect that in many regions low speed AVs will be deployed to serve niche needs where the vehicle capability matches up with customer experience.



Automated Freight

Driverless expressway trucks will transform long-haul journeys and the wider logistics sector. As safety goals are met and costs are reduced, regulatory support evolves with deployment.

Context

The opportunities for autonomous vehicles in large scale freight have been much discussed for the past 20 years. Indeed, until the recent acceleration of interest in the robo-taxi business model, many experts have felt that freight and logistics would be the first to deploy AV technologies at scale.

Ultimately the significant automation of highway trucks is of huge commercial interest to the freight community. The eventual aim is to enable trucks to move any load for hundreds of miles without a driver on board. This will transform long-haul journeys. For example, coast-to-coast across the US currently takes 5 days due to required driver breaks. Driverless trucks could achieve the same in 48 hours. Moreover, since the absolute trip duration is not as critical, the vehicles could run more slowly in order to hit the engine's 'sweet spot' for fuel economy of between 55 and 65 mph. The potential economic gains for haulage firms are massive.

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. Since this concept was pioneered by Otto Trucks five years ago, Waymo began a significant AV trucking development, along with start-ups including Embark Trucking and PlusAI. Truck manufacturers including Daimler, PACCAR, Traton Group and Volvo embraced this concept in recent years and have ramped up investment in product development.

China-backed TuSimple aims for their automated trucks to be able to exit the highway and manoeuvre through surface streets and traffic to arrive at the final destination, bypassing the transfer hubs. This is the ultimate goal of all the L4 truck developers, as this more fully satisfies the end user needs.

Although regulatory issues are complex, the developers see the challenges as tractable. In the US the Federal government is supportive of the concept and seven states now allow driverless vehicles of any type to operate on public roads. Australia aims to follow suit in the next few years, however Europe will lag due to the nature of the regulatory process.

Remote support, as discussed later, is likely to play an important role in making driverless trucking more resilient to unexpected issues on the roads; shippers will insist that the load keeps moving even if the ADS is encountering problems. s who can take over driving control if needed.

What We Heard

The key shifts acting as catalysts for the fuller automation of freight across different markets, include *"greater cost pressures, the wages of drivers, driver shortages in many key regions, continued growth in transportation, and rapid technology development."* In Los Angeles it was agreed that, *"the significant automation of highway trucks will transform long-haul journeys"* and across the US, many states are looking at proactive regulation to support this.

In Germany, experts see that *"by 2030, we will have level 1 and 2 autonomy realised, and will be in preparation for level 3."* While probably not at level 4 driverless operations, it was suggested that *"long haul will take the lead alongside AV in controlled environments such as ports and terminals."* Already, *"the technology is developing well, and many new players will enter the market."* However, *"with the US probably in the lead, regulation will play a pivotal role here."* One notable suggestion was that *"public funding can play a functional role in driving uptake – for example, low or no tolls on highways for AV trucks."*

In Australia, *"with the vast distances involved, the logistics sector will lend itself quicker to greater automation."* While *"there will be different levels and speed of progress in cities and regions,"* opinion was that *"by 2030, we will see fully automated trucks for long haul interstate highways, and also in some specific environments - such as smaller urban deliverers and waste collection."* In particular, as part of the change, it was suggested that *"dedicated lanes and dedicated operational time windows will play an important role as regulation gradually changes."* In the UAE, where the cost of migrant labour is low, *"potential AV efficiencies are considered to be slight,"* and so *"this is a far lesser priority than AV for people."* That said, initial government studies have now started to look at the business cases for platooning.

In Silicon Valley there was confidence that *"L4 automated trucks will be deployed by 2030: Driving 23/24 hours (including at night) will be beneficial and the demographics are pointing to fewer drivers in the future."* Moreover *"momentum is building."* For L4 driverless automation it was felt that *"they will initially be focused on favourable states – both from regulation and weather perspective."* So, as was also supported in a discussion in Austin, they said, *"Texas is an ideal example where Dallas to Houston would be a lead route – for hub to hub."* However, *"the Minimum Viable Product for investors needs to be compelling and visible."* To have impact within the decade, while *"the safety case is clear with supporting legislation in place in many locations,"* it is evident that *"the core technology has to function well – and that is not yet a given."* It was also pointed out that the transformation is *"all about the trucks not the trailers – there are too many trailers to include them."* There are clearly significant drivers of the change including *"driver shortages, the influence of unions and a better use of roads at night,"* but, on some routes across the world, there is concern that *"rail might rise up as credible competition"* plus the ever-present risk that *"government may block full automation."*

In terms of the key technologies required to bring automated freight to fruition, there was widespread agreement that these include *"HD mapping, HD radar, long range sensors, remote monitoring, camera-based localisation, advances in machine learning plus better decision-making algorithms."*

One outstanding issue to be addressed is *"when will we no longer need a driver? This is pivotal to the business case."* A follow-on question is how to determine readiness. Globally, one suggestion is *"we will need more pilots on the roads to build public trust, drive regulation, and hence public funding."* The purpose is to *"focus on building public awareness and demonstrating new use cases,"* as well as *"explore different ownership models and various vehicle configurations, in order to gain community acceptance."*

"L4 automated trucks will be deployed by 2030."

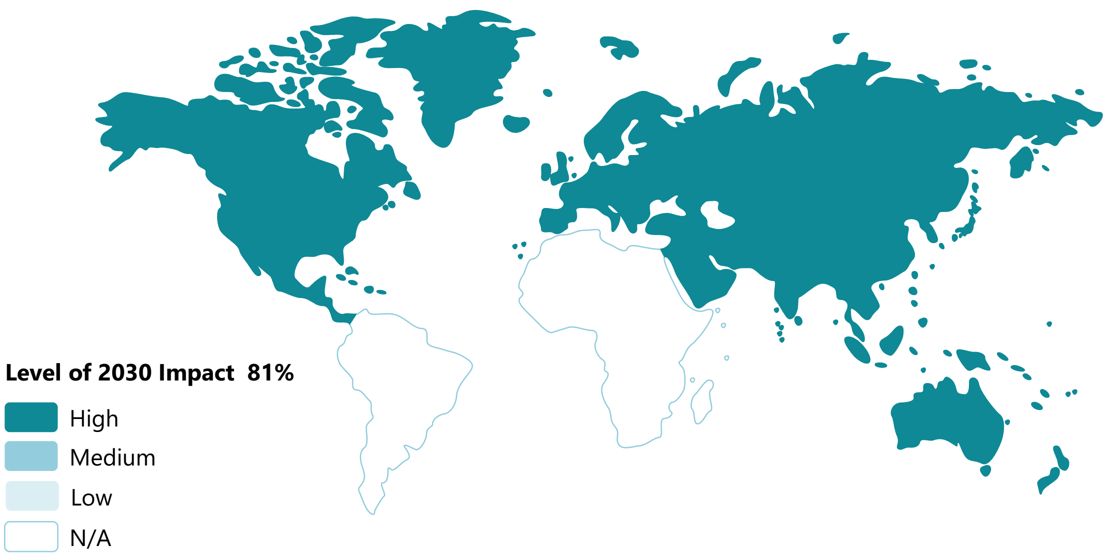
What We Think

With huge investments being made in this space, the development pace is rapid. However, the challenges to deliver an acceptable safety system are massive. Our expectation is that we will see the first true driverless freight runs in the 2021 timeframe, with initial operations in the simplest environments that offer value to shippers. This will occur in the US where full trucking automation is being strongly supported by many states as well as by the federal government. However, this could change due to shifting political winds and potential Congressional action. Barring this type of intervention, deployment may be governed by individual states which have the power to allow or block automated operations. While not an ideal situation, it is still sufficient for substantial numbers of trucks to be deployed and will likely mean that the US is one of the first adopters with Australia following soon afterwards. If this is successful, with safety goals met and freight delivered at greatly reduced costs, immense pressure will come to bear on the regulatory process elsewhere to proceed with allowance. In Europe, several companies are eager for commercial launch and as regulation is confirmed, deployment will follow. Reduced tolling for AV trucks, as was mentioned in one workshop, only makes sense if societal priorities are being fulfilled.

Progress by 2030

By 2030, driverless automated trucks will be operating broadly across (at least) the southern tier of the US, Australia and possibly the EU. We also expect to see evolution beyond hub-to-hub and transfer yards to a second-generation automated truck that can exit the highway and manoeuvre through some urban streets and traffic to arrive at the final destination. This may, however, be limited to relatively simple situations. This forecast is premised on AV behaviour in traffic and overall safety record being acceptable to regulators and the public. The perceptions and risk assessments from early deployments in the mid-2020's will be key to the industry ramping up deployment.

The freight industry itself may evolve dramatically. However automated trucks will not be ubiquitous in 2030 and there will still be substantial quantities of freight to be moved by human drivers. Outstanding questions include whether today's leading tech-savvy freight carriers will be able to maintain and operate automated trucks, or if the technology requires such sophisticated expertise that the OEMs and other ADS providers operate the trucks directly. For OEMs this would be a massive shift, since they would be competing with their former customers. Between now and 2030, the entire industry will be examining and experimenting with 'who does what' and the smaller less-sophisticated truck fleets will be most vulnerable here.




IMPROVING SAFETY
AND SAVING FUEL

Truck Platoons

As the first level of deployed automation, truck platoons help build wider momentum while delivering tangible improvements in efficiency, cost of transportation, energy use and safety.

Context

The combination of fuel and labour savings creates a powerful incentive to get platooning capability to market. Pioneered by manufacturers such as Scania, Volvo, MAN and Freightliner as well as start-up companies such as Peloton Technology, wireless links between vehicles provide 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. First generation Level 1 platooning will have drivers in both trucks and will be focused on reduced fuel costs. Second generation Level 4 driverless follower platooning will combine both labour and fuel savings.

Regulators are generally open to allowing Level 1 platooning since it offers societal 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, the majority of states now fully allow the commercial operation of platooning, comprising over 80% of annual US truck freight traffic; more are expected to follow. After 20 years of planning and technology development, 2018 saw the start of several Level 1 commercial platooning trials in Europe and the US. Level 1 platooning is now expected to be introduced commercially in the US during 2021.

What We Heard

Most agree that *"there is no real opposition to level 1 truck automation, and regulators are supportive of platooning, since it offers societal as well as business benefits."* In Melbourne, one view was that by 2030, *"Level 1 AV will be in place - but will have low impact on productivity."* The big prizes for freight may come later. Platooning, for instance, can evolve into higher levels of automation, such as driverless followers.[161]

In the US, platooning has been in testing for several years and now and looks set for further scaling in this decade. But *"taking the driver out of the follower vehicle will be key to ROI."* In terms of financial impact, some highlighted that with a (5 to 8% fuel saving) CO2 benefit will be useful. In comparison to full L4 automation of individual driverless trucks discussed in the previous section, one benefit of platooning is that it *"can also potentially operate in poor weather states"* since there is a human driver in the lead vehicle. The trials underway by Forest Product Innovations supporting the Canadian timber industry are seen as an interesting proof of concept – on private land with snow / ice half the year.[162]

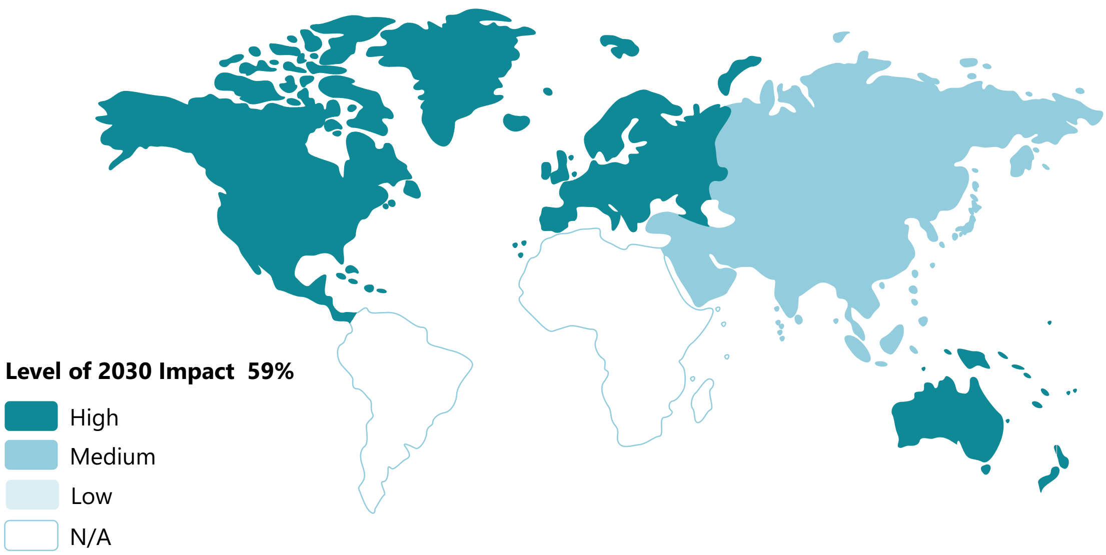
"There is no real opposition to level 1 truck automation."

What We Think

First generation platooning, which provides substantial fuel-savings, is of considerable interest to large fleets in the US and Australia with commercial availability expected in 2021. It appears that Europe and those in other markets are largely waiting for the second-generation driverless follower system providing both savings on both fuel and labour: the 'AutoFollow' technology. With intense development now underway by OEMs and start-ups alike, AutoFollow will be a powerful new tool for freight carriers. First deployments will be in the US with a human driver in the lead, but AutoFollow platoons will be able to operate broadly across the entire country. By contrast, stand-alone driverless trucks will initially ramp up more slowly as they will be limited to areas with favourable weather conditions. We expect driverless follower platooning to come to market within 2-3 years.

Progress by 2030

With first generation platooning launching soon this will be a common sight on highways in the US and Australia by 2030. To some degree the rate of scaling up will track with fuel prices. AutoFollow platooning will initially be adopted by fleets already running first generation platoons, thus scaling up quickly. This will be the case with platooning in Europe, since lower fuel consumption translates to reduced emissions – a key priority here but not yet elsewhere.



Controlled Environments

Automation within controlled environments continues to expand steadily. AVs within airports, port terminals and logistics facilities start to venture onto the open road.

Context

Within any discussion of autonomous vehicle use, distinction has to be made between those required to function on the open road, and those that are operating within controlled environments. Significant use of automation is already in place in mines, port terminals, airports and industrial sites.

Mining companies have been some of the first to embrace automation. Whether through self-driving versions of conventional trucks in Norway or the huge autonomous vehicles found in open cast mines in Australia and Chile, automation in this sector has had significant and rapid payback. Having first launched in 2015, many of the large mining vehicles in Australia are now self-driving.[163,164] In 2019 Rio Tinto brought an autonomous mining truck fleet from Caterpillar.[165] In 2018 Volvo, for example, announced the commercial use of self-driving trucks in the limestone mine of Brønnøy Kalk AS on a 5km route, 80% of which is through tunnels.[166] Other companies have quickly followed suit and several are now planning for fully autonomous mines within the next year or so:[167] Scania has announced a cab-less model.[168]

Vast **port terminals** have also adopted automation early on. Over 80% of global trade by volume and more than 70% of its value is carried on board ships and handled by seaports worldwide so the potential impact of large-scale roll-out could be significant. Some time ago Rotterdam set the pace with the introduction of unmanned cranes, automated guided vehicles and a fully automated terminal.[169] DP World, one of the largest owners of ports globally with over 50 sites across six continents, including Rotterdam, is seeking to scale automation worldwide with AVs part of the strategy.[170] Allied to this there is also increasing seaborne AV development. Here, 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. Rolls-Royce is one of several companies leading the development of fully autonomous ocean-going cargo ships and it expects to launch the first one in 2035.[171] An EU project, led by the Fraunhofer Centre for Maritime Logistics, is also assessing the economic, legal, insurance and technical feasibility of operating unmanned merchant vessels in the open seas.[172] In China an alliance including Rolls-Royce, ABS and Wartsila plans to deliver an unmanned cargo ship in 2021.[173] The Maritime and Port Authority in Singapore has kicked off research with Nanyang Technological University; and in Japan the government is supporting an R&D project with Mitsui aiming to have autonomous ships operational by 2025.[174] The ambition is to move containers seamlessly across the seas, into port and then onto into the hinterland for delivery.

Many also see **airports** as an ideal testbed for AV technologies. Self-driving pods are already in use at various airports including London's Heathrow, with other autonomous vehicles also planned for Gatwick, Paris' CDG and Tokyo's Haneda. In 2018 the main airline industry body, IATA, proposed over 40 further use cases for AVs at airports including, for example, baggage handling.[175] Indeed, in late 2019, in partnership with Charlatte Manutention and NAVYA, Air France and Toulouse-Blagnac airport brought into service an autonomous tractor for transporting baggage between the baggage sorting area and aircraft.[176]

There is also significant use of automated vehicles within industrial sites focused on indoor operations. For many it is Amazon that may have the greatest impact here. The company's robots are already widely used across its huge warehouses around the world.[177] Since its acquisition of Kiva, Amazon has scaled up its automation capability reaching over 200,000 warehouse robots by 2019 – double the number in 2017.[178,179] Other companies are also making impact. In the UK Ocado, an online-only supermarket, has made the news with its highly automated warehouses and technology that is now being licensed globally.[180] In Germany, DHL is just one of several companies bringing AVs into warehouse operations at scale with self-driving swarming vehicles handling pallets, loading and unloading trucks.[181] Outdoor operations are the new AV frontier in these settings. In the US, start-up Outrider recently raised funding to deploy driverless yard trucks to logistics / freight yards.[182] Pilots are underway with several major shippers including Georgia-Pacific and four Fortune 200 companies.

However, while these achievements are all to be acclaimed for the leading-edge automation, it is important to note that these 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 AV, there are more complex challenges to be addressed on the open road. It is at the interaction between controlled and uncontrolled environments where we may see most innovation in the next decade.

What We Heard

As was agreed in most locations *"controlled environments are good test-beds for technology to be introduced into the real world."* In the first workshop in LA the question was asked, *"how can AVs within ports move outside the boundaries and mix with the wider infrastructure?"* The opinion shared was that, within the decade, containers that are automatically unloaded from ships should be able to flow directly to their destination without the need to change carrier vehicle at the port exit. In Dubai where the Jebel Ali port is currently a 50/50 mix of automation and traditional drivers, it was considered that *"reaching full automation would make life easier."* But being able to have *"AVs move outside the port border and interact with normal traffic on the roads"* is considered to be a major technological hurdle. In the US the suggestion was that *"a Wal-Mart car park is maybe the most complex environment for AVs."* In Germany it was thought to be roundabouts with elderly motorists. Mixing AVs with normal traffic is inherently complex – even within a controlled environment.

In Australia the development of automation in mining has benefited from a fully contained environment through which to refine the technology. Although adding 25% to the price of each vehicle in the early days, costs have dropped significantly – *"the price difference between an automated and normal truck was initially $1m ($4m vs $3m) – but as the tech developed this dropped significantly."*

In addition to ports and mines, a common area of controlled environment debate was that of airports. This was discussed in Shanghai, London, Los Angeles, Singapore, and Dubai. For China, with so many new airports under construction, embedded automation is seen as *"a core component for frictionless trade,"* while in London, Heathrow was highlighted as regionally *"being at the fore in AV testing."* In Singapore where Changi is frequently rated the world's best airport, the design of the new Terminal 5 is *"embracing far wider automation than others."* For example, *"robots will process cargo, autonomous aerobridges will align to aircraft doors, AVs will unload baggage and robo-taxis will pick up passengers after processing through automated security."*

In LA, where several airport operations professionals were part of the group, the opinion was that *"by 2030 we see robo-taxis being integrated at airports with ease."* Although currently having no AV use planned at LAX, there was expectation that *"we could overcome silos and can start bringing everything together."* With appropriate regulatory support and proof of consumer acceptance there was also confidence that *"automation could extend further into operations."*

In a detailed airport discussion in Dubai, distinction was drawn between automation airside and landside. *"Airside (away from view) we can achieve a lot (e.g. baggage handling and moving passengers from terminals to planes). Landside the issue is how to integrate with other modes as airport-based AV moves out further into the city."* The different use cases for 'below wing' (aircraft towing, baggage handling, ground power / air-start / refuelling, water and lavatory services) and 'above wing' (passenger escort, meet and greet) were also noted. Citing *"the uniqueness of ownership of assets (by individuals and organisations) as giving DAA more control"* than many of its peers around the world, expectations for automation for progress are very high. *"By 2030 50% to 75% of passengers and baggage / cargo movements could be autonomous at UAE airports."*

For passenger movement, the key developments will include: *"driverless (assisted) coaches for remote arrivals and departures, automated push-back from terminal for aircraft and movement of passengers in terminals and between gates."* For baggage and cargo, the corresponding opportunities are *"AVs in baggage sortation, movement of baggage / cargo containers between safe areas as well as safe, autonomous movement of vehicles around aircraft."* Of concern here is the potential risk from AV collision with stationary aircraft and the suggestion that *"in an automated airside environment the cost of insurance may well increase."* Questions were also raised on whether *"AV capability can be retrofitted to existing infrastructure and what the lifecycle of airside AVs will be".* Ultimately, given that labour is cheap in Dubai, *"whether, if it is not about cost-savings, can AVs improve service standards?"*

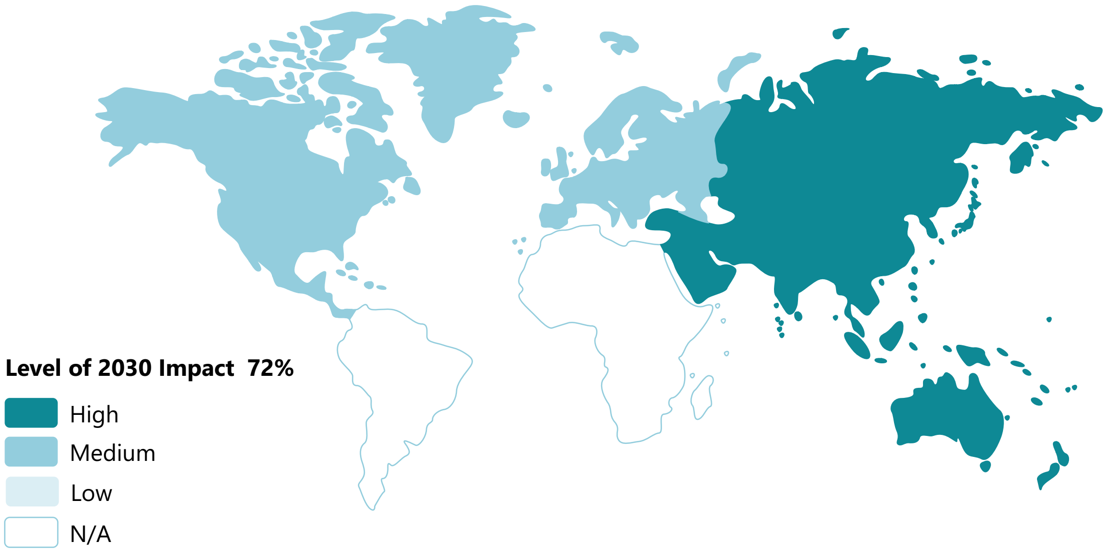
In Singapore, workshop participants were encouraged to think about controlled environments through a different lens, as they can *"include dedicated lanes in cities – so don't just think of this as terminals and other closed areas."* In the global ITS event, the key issue for *"wider AV deployment in and beyond controlled environments"* was considered to be geo-fencing and the ability to digitally determine where the vehicles can operate – and where they cannot go. Whether large vehicles in ports and airports, cars in dedicated lanes on the highway or robots trundling down the pavement *"successful geo-fencing will be critical – with supervision capabilities pivotal."*

What We Think

Automation across multiple controlled environments is clearly making strong headway, with benefit coming in new areas such as with automated baggage carts at airports. At a larger vehicle level, although moving beyond some of these controlled environments onto the open road is seen as a major technological hurdle, the strong business cases for being able to transfer ‘outside the gate’ will propel this forward. Depending on use, we will see these L4 trucks moving out of ports and airports to local short runs in relatively simple but uncontrolled environments. We do not expect road operators to dedicate lanes specially for AV trucks, except in isolated cases. Similarly trucks initially operating only on major roads will gradually expand capability to be able to exit the highway and deliver loads to warehouses that are close to the expressway.

Progress by 2030

Thus, by 2030 we will see a pincer movement taking automation to the streets – the most challenging environment of all. Relatively basic controlled environment vehicles will gradually become more capable and venture out from geo-fenced sites at the same time as sophisticated highway trucks learning to move from the highways to streets. Niches will combine and connect such that we will be encountering points of automation on a regular basis.



Part Four: Data and Security

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Data Sharing

Better, deeper and more secure, data sharing is pivotal to enabling the full AV ambition. Mobility brands agree protocols for V2X interaction and support the use of shared data sets.

Context

Over the past decade many in and around the transport sector have become embroiled in the need for greater data sharing. Some of this has been focused on the ability to improve efficiency, some on the role data can play in ensuring better safety and some on the prospect of potential value that may lie in the data itself. This combination of needs vs. wants is confusing. As regulators and manufacturers seek to agree what is essential for AV operation navigating through the noise and seeing the wood as well as the trees is a necessary but tricky requirement.

Opinions around the value of data for automation abound. Cisco suggested that a connected cars data will be worth $1500 a year by 2030 but McKinsey's perspective was that may it is around $500. Several academics now suggest that in fact it has no intrinsic economic value. Amongst all this automotive companies have sought to develop business cases that make the most of the opportunity. *"Questions on title, control and usage of data lead to many sectors taking different views."*[183] What is clear is that many in transport and beyond have now started to be clearer about what data is proprietary, what may need to be shared between two parties and what should ideally be open data available to all. Economic value may lie in the proprietary datasets, but more systemic or societal value may lie in the shared data. A challenge here is whether open data should be shared publicly, similar to the way that data is made available by public transport networks already, or if it should only be shared with 'trusted' parties within the sector.

AVs will rely on some degree of connectivity for monitoring and support within the provider's eco-system. Generally, this will be accomplished through commercial mobile connections. But there is debate about the value of data being exchanged between vehicles (V2V), with an intelligent infrastructure (V2I) or everything (V2X) in real-time.

While regulators are yet to detail much more than basic sharing of information about safety-related incidents, within the automated driving community, some initial data sharing is already underway. For example, VW now equips all of its new Golf cars with V2X, generating basic safety messages ten times per second in accordance with existing standards, but no personal or business relevant information is transmitted. Cadillac has done the same for several years and GM is also expanding this across their model range.[184] Moreover, Ford and Waymo both recently publicly shared data sets to help researchers innovate. The initial steps have been taken but many expect that there are more to come.

What We Heard

Data sharing was a top 3 issue globally, consistently ranking high for future impact. The need for more and better data exchange between key parties in the AV ecosystem was highlighted in many discussions. In Los Angeles, this, *"and deeper collaboration on protocols,"* was seen as essential to enable full AV impact. In Frankfurt, there was a call for more *"sharing options between manufacturers and public authorities,"* while in Singapore, there was a request that *"we must set clear standards for key devices – including both the data needed and the access systems."*

However, there seems to be a problem as currently, only a few of the key private players are willing to share limited amounts beyond the minimum information defined by regulation. In Germany, car companies revealed that *"we don't have clarity on how all the required information will be available to the vehicles."* In addition, some felt that "*currently, there are too many data protocols out there – so VWs don't talk to BMWs: companies are not sharing information because of competition."*

Some sort of open data system within trusted parties was consistently called for - but without much detail on what, how and with whom. It clearly needs to encompass V2X modes but having agreement on what is shared is a key gap to be filled; a process underway within international standards bodies. In New Zealand, there was recognition that for areas like high definition mapping, *"we should not be betting on one type of coordination,"* but rather seek to have multiple options available. Maybe, as suggested in Singapore, *"building the ecosystem through partnerships with academia, will be pivotal."*

A concern in the UAE, where the RTA is not currently releasing its data, was that *"today the ecosystem is highly fragmented with organisations seeking to retain not share data – 'knowledge is power' is a core belief: There is a fear of giving away data."* Changing this will require proactive policy making. It was considered that a positive ('fit for purpose') society-driven pathway will *"use data to inform new regulations and guidelines and regulations including AI and machine learning."* However, a more negative cost driven future sees *"a more market driven solution, growing power of GAFA (Google, Amazon, Facebook and Apple) and other non-accountable tech firms."* Underpinning, connecting and influencing both of these are growing concerns over cyber-security and privacy as well as the embedded perspective is *"not to share data if it can be sold – profit is the priority over the common good."*

What We Think

It is clear from the many vigorous discussions on this topic that the generic term 'data sharing' meant vastly different things to different people. Thus, some definition is needed. Initially AVs deployed by specific fleet operators will operate independently of one another, so Waymo and Cruise robo-taxis will, for example, not be connected with each other. Whether they will eventually share data depends on the evaluations of system performance gains that this can deliver; this is currently unclear.

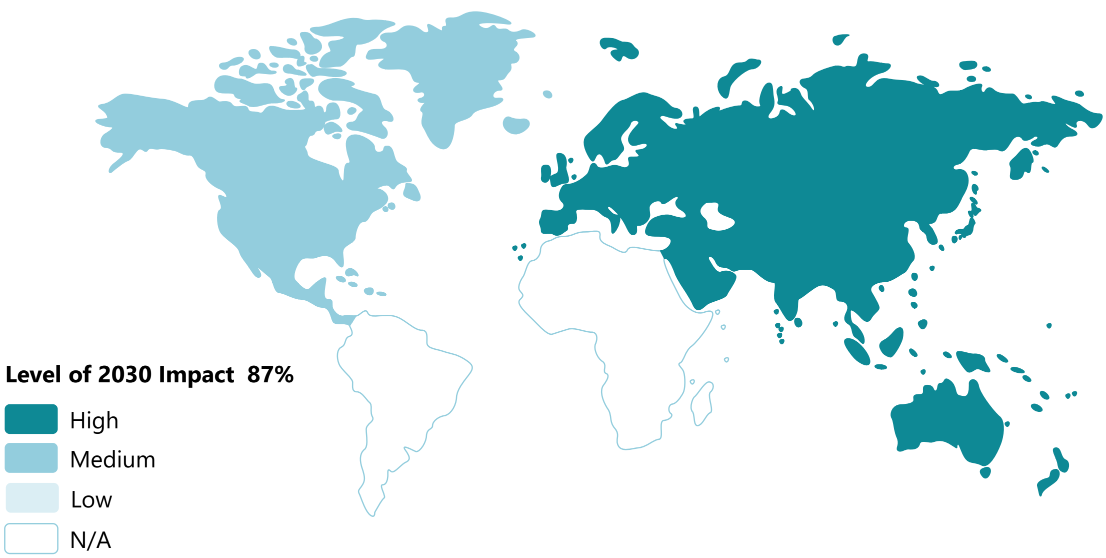
The 'data has value' issue has been around since telematics systems became common in cars. It clearly causes confusion and may continue to do so. Developments here depend primarily on market forces but emerging regulations such as Australia's Automated Driving System Entity concept could include at least some degree of reporting of safety performance data.[185]

The system operating effectively with directly sharing data between vehicles refers to the moment-to-moment interactions between vehicles, which in turn can improve safety and especially traffic flow. In the past this has been thought of as open sharing, but with the rise of TNC's which have extensive numbers of their vehicles in a particular region, we see initial gains will be from data sharing across many vehicles with the data kept within specific TNCs.

Progress by 2030

Discussions in 2010 focused on the value of data for enterprises. Over the last ten years businesses found ways to share data and better collaborate - between automakers and insurance, for instance. Now with AVs, data sharing for safety is being discussed, even though many current designs cannot depend on external data for safety – mainly because it may not always be there.

We do not consider data sharing as a linchpin for the deployment of AVs. Rather we see it as an enhancement as deployment of AVs scales. In the last decade data sharing discussions focused on privately-owned vehicles, but in the coming decade AVs will predominantly be fleet vehicles which motivates more of a B2B activity. We therefore see no reason government should require real-time sharing of large data sets. Instead reporting requirements should be agreed and implemented based on legitimate regulatory needs to assess safety.



Cyber Security

With a rising threat of hacks, denial of service, vandalism and theft of data, organisations seek to protect AV through building common approaches for broader, closed but collaborative systems.

Context

While automation and the advent of the IoT is providing great opportunity, there is also concern about the increased risk of hacking from varied bad actors.[186] At the wider city infrastructure level, Johannesburg is the latest and biggest city to have been victim of a ransomware attack.[187] A whole industry of companies such as Darktrace have emerged in an attempt to thwart attacks.

Within the automotive sector, although many are confident that security levels are high there is concern about the general vulnerability of the system. Because of the interconnected nature of AV all actors involved have to be secure from cyber-attack. This is a huge challenge.

In an integrated, interconnected and digitally dependent AV transport system there are three major areas of concern that are discussed:

- System wide denial of service where a whole network is closed down by either foreign government agencies or sophisticated bad actors as part of a wider cover cyber-warfare campaign
- Vehicle level hi-jacking where an individual AV is hacked for fun as the latest sophisticated teenager challenge; and
- The stealing or infection of personal and corporate data either for ransom or for reselling on the dark web as is the norm for individuals' financial and medical data

All three are variously seen as credible threats and so are the focus of significant corporate and consulting activity. Addressing these in a coherent manner that gives users confidence, regulators assurance and manufacturers a minimal, and ideally zero, risk of liability is an important step on the critical path to AV adoption.

What We Heard

Linked to more open data sharing and access to systems, is the associated security risk. *"System and infrastructure security"* were key concerns in Frankfurt, and they advocated some sort of closed system to address provide more protection. The priority, they argued is on preventing *"hacking, denial of service, theft of customer data, vandalism of sensors, trolls taking over robo-taxis, and using cars as weapons,"* as well as other cyber security threats, but also not constraining the collaboration that is needed. As with all IoT systems, there is a balance between connectivity and risk, and for high speed AVs, this is a major challenge to address. In New Zealand, some questioned *"what happens if the whole system collapses? Will anyone be able to drive a vehicle? How will we move? Do we go back decades?"* Is anyone planning for disaster recovery scenarios when a hack or an error takes down the whole network? Others elsewhere felt that this extreme scenario would be an unlikely occurrence, as there are numerous overlapping safety systems likely to be in place.

A deeper exploration in Germany concluded that, if we can get this right, then *"success for 2030 is that nothing will happen. Everything will work smoothly. There will not be major hacks of AVs or the infrastructure, people won't be injured, and the system will be secure."* It was proposed that *"if AVs are closed systems, then the vehicles can be in control of what data is used and shared: verifiable information should only be used, and so all data has to be verified."* What is needed, it was suggested, are closed, but collaborative systems, with *"protocols that highlight which information is delivered to what vehicle in which way via what channels,"* and that within Europe, *"Germany can take a lead and set the standards for the rest to follow."*

One growing, tangible risk area highlighted in the US was that of hijacking of unmanned autonomous trucks. Although a low probability in some eyes, when *"oxycontin is worth more that gold"* the risk of hacking / hijacking the vehicles transporting this and other products may be attractive for some. In Silicon Valley the concluding view that *"addressing cyber security is essential for success: we have got to get this right."*

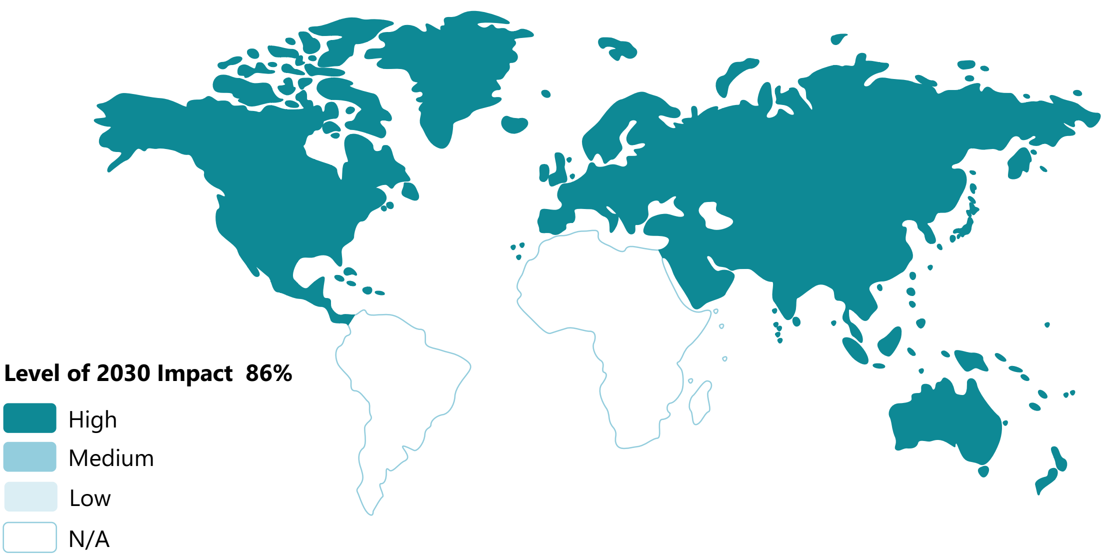
"As with all IoT systems, there is a balance between connectivity and risk."

What We Think

We are confident that most questions regarding cyber-risk raised in the workshops are being worked on intensively by ADS developers - as well as thousands more. Given the potential liabilities of getting it wrong, this is an ongoing priority issue for many across the whole AV supply chain. ADS cybersecurity builds on extensive work already undertaken in this area for non-automated vehicles sold today plus new innovations in adjacent fields. Although understandably consistency rated as a high impact issue in the workshops, we believe that the key players are implementing effective approaches based on sophisticated best practices.

Progress by 2030

We can claim substantial progress by 2030 if, as was suggested in Frankfurt, 'nothing happens' in terms of safety critical cyber-breaches. Equally the idea of 'closed but collaborative' systems is an excellent way to frame progress going forward. Initial]systems will be fully closed but based on market dynamics plus regulatory pressure in some regions, new offerings will start moving along the continuum toward more collaboration as the decade rolls out.



Remote Support Centres

Manned support centres initially provide oversight, support and emergency response for all AVs. In the absence of drivers, most public transport vehicles require remote human supervision.

Context

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 pioneered a 'Seamless Autonomous Mobility' concept in which a remote human mobility operator is able to view the situation through the vehicle's sensors, understand the situation, and plot a new path.[188] The vehicle then uses its autonomous capability to move or 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.

Now the view of remote support to an ADS is evolving, gaining more support as approaches are being championed by Aurora, Waymo and Enride:

- To facilitate deployments in new operational domains while maintaining high reliability, **Aurora** is investing in tele-assist.[189] This set of technologies allows trained specialists to monitor vehicles and provide high-level guidance when needed. This increases availability -the amount of time that vehicles are capable of fulfilling their mission. Greater availability means more rides, faster delivery, more satisfied passengers, and a better return on investment. Although designed to respond appropriately in all circumstances, there is still the possibility that this caution could cause it to get stuck in uncommon or complex scenarios. For example, say it perceives a traffic guard waving a vehicle toward an obscure or unexpected detour. A human driver would see the gesture, watch other vehicles move toward the detour, and intuitively understand what they should do. In its early days, a remote support system could lack this type of contextual understanding and would therefore choose to come to a safe stop to await further instruction.
- **Waymo** uses Remote Assist to support its vehicles when needed.[190] Waymo frames this as similar to "air traffic control for our self-driving cars." If a road were to suddenly be closed due to construction, then the vehicle would likely pull over and request a second set of eyes from fleet response specialists who can then confirm the road closure so the Waymo Driver can plan an alternate route.
- **Einride** is also showcasing its one operator to multiple vehicle capability in action at a customer site.[191] This technology enables one remote operator to take responsibility for several self-driving Einride Pods, monitoring them when in autonomous mode and taking active control of a vehicle for unforeseen or more complicated

manoeuvres, such as parking at a loading dock. As the Pod and similar vehicles are introduced into a freight network, transport managers will, it is argued, be able to employ operators who will monitor and control fleets of driverless vehicles from a remote drive station, eventually expanding up to as many as ten per operator. This has the potential to increase the average workday for a fleet of vehicles from 8 to 24 hours with optimised charging, loading, and unloading schedules, increasing productivity up to 200 percent while reducing the hourly cost of transport by 30 percent.

Collectively, these and similar developments from Designated Driver, Ottopia, and Pylot aim to provide the user reassurance and regulatory compliance for supervision by humans as needed. While not the 50-year solution, many consider that this is the way to go for the next decade or so.

What We Heard

While many aspire to a fully automated experience, where machines and systems can manage independently, the need for human input, at least for a transitionary period, was highlighted in several discussions. Most significantly, and as detailed in Frankfurt, there is an operational support requirement for AV. For instance, *"autonomous public transport vehicles will not replace all of the functions currently undertaken by a bus driver: driving the bus, monitoring passengers, validating tickets, ensuring full functioning of the vehicle, and being the point of help in the event of passenger need."* New Zealand addressed similar points.

The German view was that, and as some OEMs have already proposed, *"there needs to be some sort of central management."* The common notion of this is a remote support centre able to take over control, override machine decisions, and interact with passengers from afar – not too dissimilar from how drones are 'flown' by the military, or how autonomous ships may operate in the next few years. *"By 2030, we can envisage fully connected manned control centres providing oversight, support, and emergency response for all AVs. Humans will have supervisory and, if needed, active control of AVs."*

In Silicon Valley, with some key advocates of remote support in the room, views included opinion that *"every system has some level of human oversight"* and *"so are our exceptions on AI and ML too high? - AI needs human supervision."* Consensus was that for the first decade at least, AVs will need human oversight and this *"supervision will be like air traffic control - one human overseeing many AVs"* so potentially the FAA approach is a good model. But there are key questions such as the ratio of human supervisors to vehicles. A typical air traffic controller looks after up to 10 planes at a time but *"in US cities there is 1 supervisor for every 4 bus drivers."* Although *"public transport expects more supervisors than private,"* this ratio will be significant for some business cases: A solution where we have *"robo-taxis with a human on board will be a farce."*

"For the first decade at least, AVs will need human oversight."

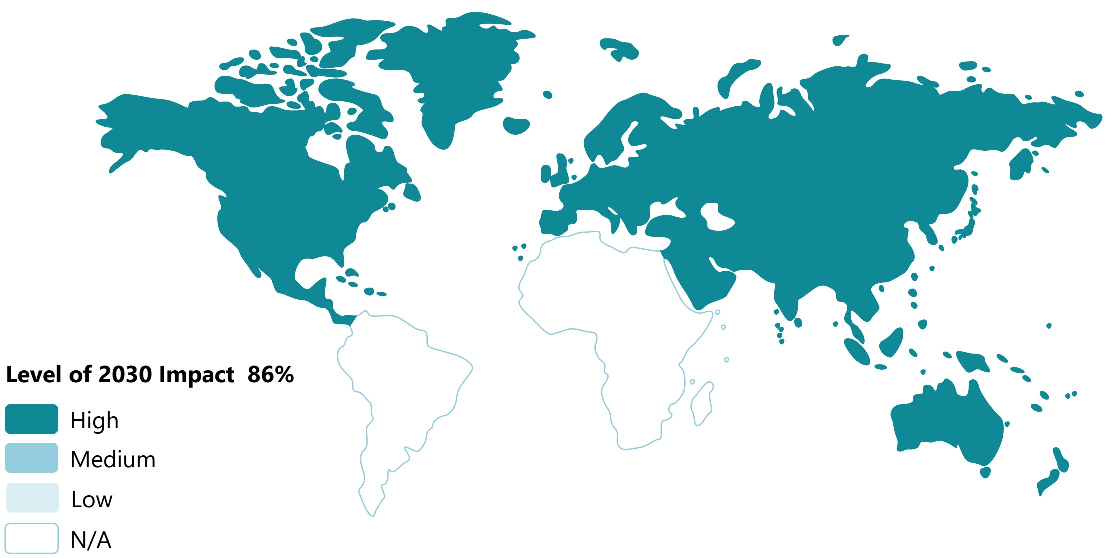
What We Think

Remote support was widely embraced as having some role in AV deployment and we agree. Backing for direct remote driving in regular traffic is generally not supported due to the potential for data delays in the communications system; instead the idea is that the vehicle always does the driving, fulfilling the safety case with on-board systems, while the remote human provides permissions and advice as needed. At the same time, there are some situations in which remote driving can make technical and business sense; for instance, when operating at very low speeds in highly local or semi-controlled environments, such as the Einride deployments.

Discussions about the widespread approach for air traffic control certification being a good model are appropriate, but we did not get the sense from any participants that the government-run aspects of remote support should be employed. We are persuaded that the fleet operators want to have full control over the supervisions of their operations, whether developed in-house or outsourced.

Progress by 2030

As L4 fleet services deploy in the first half of the decade, we expect to see remote support used extensively to reduce risk and enhance service quality. With ADS software increasingly becoming smarter, then the role of remote support will be reduced. With remote support initially a significant cost component for L4 fleet services, the aim will be to eliminate it over time if high standards of safety and service quality can be reliably delivered. We do not however expect to be at this point by 2030 but anticipate that system capability will have proceeded significantly in this direction. Therefore, the number of vehicles handled per remote operator will steadily increase.



Questions and Answers

Our Initial Questions

As mentioned earlier, from the initial perspective, we highlighted 12 pivotal questions to be addressed in this series of expert workshops. These were:

13. Where will be the key hotspots for AV development and deployment?
14. Which socio-political forces may accelerate the adoption of full Level 4/5 automation?
15. Where is advanced regulation most likely to act as a catalyst for AV deployment?
16. What level of safety (crashes) is acceptable for the full launch of AV in the next decade?
17. Will AV increase or decrease total traffic flow and congestion?
18. Will automated mobility services replace, reduce, or extend the reach of public transport?
19. Of all the technologies in the mix, which ones are in greatest need of further development before the benefits of AV can be realised?
20. What are the distinct benefits from AV that are not already coming from current and future connected ADAS?
21. How important will international standards and commonly shared technologies be for AV adoption - or will it be more regional?
22. Which will be the pivotal organisations, cities, and governments that control adoption rates?
23. Who will lead on integrating all the various systems needed to enable AV to operate?
24. Who will customers trust more to deliver a safe, reliable, and comfortable AV experience?

Our Initial Questions

At the halfway stage, we had gained good opinions on most of these and so added a further 12 questions to be explored in phase 2. These were:

13. What lessons can be learned from other sectors?
14. How much will AVs be tied to EVs, and therefore intertwined with charging infrastructure roll-out?
15. Will air-taxis have impact beyond a few niche locations?
16. How will drones used for parcel delivery integrate with drones for other purposes?
17. How will planning evolve to become a public/private partnership?
18. Will private companies contribute to the cost of the infrastructure, and will public sector agencies allow for this?
19. Will the growth of AVs mean more open/liveable/walkable urban public spaces?
20. How will cities adapt today's public transport systems in an era in which automated MaaS overlaps their mission?
21. How will designers overcome resistance to sharing rides with strangers?
22. For what types of routes and freight will Level 4 truck automation happen first?
23. How will supply chain approaches be transformed by Level 4 truck automation?
24. What effect will growth in AV urban/suburban parcel/grocery/food delivery have on other road users?

Our many discussions have added more context; some have addressed the issues locally, some globally, and others have raised additional issues still open for further debate. In addition, several discussions have highlighted that the answers for some areas of AV for people and goods are different. Below are the consolidated answers for these 24 key questions:

Where will be the key hotspots for AV Level 4 development and deployment?

Although there are overlaps, it is evident that development and deployment should be considered independently.

Development of AV includes a wide range of issues such as software development, simulation, and track testing. For both people and goods, on-road testing with safety drivers is vital to stress the software on the way to achieving systems which operate safely in all situations.

- For people AV, the US is clearly the focus of much attention, with Silicon Valley, Detroit, Pittsburgh, and Boston all at the fore. However, across Asia (China, Japan, and Korea), there is major activity, while in Europe, Germany, Sweden, and the UK are the primary hotspots. Start-ups in Israel are making substantial technology contributions.
- For goods AV, the US tech development focus is very much in California. In Europe, alongside Germany and the UK, Sweden is a major centre, while in Asia, China is moving ahead of others.

Deployment aims to offer full driverless commercial utilization, which will occur where extensive testing has been conducted and where local regulations allow driverless operations.

- For people AV deployment in the US, with its favourable regulations, Arizona is a notable centre, alongside Las Vegas, San Francisco, and Pittsburgh. Elsewhere Singapore, China, and the UK are the top locations.
- For goods AV deployment, the focus is very much in regulatorily-proactive US states such as Arizona and, Texas, and to a lesser extent in Australia and, again, Singapore. Movement of goods in controlled environments not involving public roads can occur anywhere.

Which socio-political forces may accelerate the adoption of full Level 4/5 automation?

With people AV, demographic needs are playing an influential role. So, providing access for the significant and growing elderly population is important in locations such as Japan, and has become a focus for some government mandates. Globally, and already evident in multiple regions, the younger generation is seeking a more sustainable option for mobility in cities, and the alignment with urban electrification strategies is supporting rising synergy with AV technical requirements. In addition, the jobs created vs. jobs lost debate is significant in many locations.

For goods AV, the primary issues focus on drivers and freight volumes for long haul trucking, but with different emphasis in various regions. So, the lack of, and hence high cost, of drivers is particularly important in countries like Germany and Australia and the US, more than in India, the UAE and China. The public discourse regarding AV replacing drivers has moderated somewhat in the last year but remains an issue in countries where unions are dominant. Many see that market forces supporting driverless operations will, however, win the day. For residential delivery, the continued global growth of e-commerce and complex routing presents a different technical challenge so this will scale more slowly.

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

As we have seen, the regulatory environment is a primary reason for companies to locate activities in one country or city over another.

- In Asia, China has issued national standards for AV testing and multiple cities have approved initial deployment on public roads. As such Baidu and its peers are busy scaling up activities across the country. Regionally, however, some claim that Singapore is furthest ahead with supportive legislation in Japan and Korea also now having growing impact.
- In the US, a hands-off approach at Federal level is resulting in individual states being more proactive to attract deployment, while north of the border in Canada, Toronto and wider Ontario are seen as the leaders in establishing the best conditions with testing also underway in Vancouver.
- Australia is devising a detailed regulatory framework, starting initially with passenger vehicles. This is likely to be rolled out in the next couple of years with New Zealand also being proactive.
- In Europe, the EU regulatory approval approach is slow by design, with commercial trials being done via regulatory exemptions. Full deployment here may therefore well lag behind some other regions although Sweden is being progressive with its sandbox approach and so accelerating activity locally.
- In the Middle East, the UAE can be flexible and that is encouraging Dubai to be pre-emptive in some key areas such as air-taxis.

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

There is general agreement that AVs will need to be safer than human-driven vehicles, with lower crash rates and the data to prove it. Even though it is an expectation driven by media hype, most now also recognise that 'zero crashes' is a very high target that is unlikely to be met. For the current testing phase, with safety drivers in the mix, it is seen as critical that the tech developers meet the highest standards of training and monitoring of their safety drivers, to avoid mishaps due to human lapses. Some have raised the possibility that early deployment could see crashes with AVs caused by human drivers in other cars more frequently than the other way around. This is however more of a reflection of early generation AVs under test than the final products which aim to perform in a human-like way and integrate seamlessly into the wider transport ecosystem.

Will AV increase or decrease total traffic flow and congestion?

This is a question with very different views around the world. In general, a core assumption being made is that the growth in human driven TNC vehicles reflect customer demand and have already increased congestion in some city centres. As they are introduced, robo-taxis will replace these to some degree, but also increase demand due to lower pricing. Moreover, if there are more robo-taxis in the mix, then there will be system compensations – such as less personal car travel and less use of public transport. So, one strong opinion here is that there will be no net change in the volume of vehicles, but the expectation that more efficiency may increase the average speed of travel. Eventually, therefore, we would see a decrease in congestion but not within the next decade.

Some are being bolder in aiming for quicker reductions in congestion. Singapore has the most ambitious targets and has a decrease in congestion as a core part of its new masterplan strategy, with MaaS adoption also enabling the reclaiming of space currently used for parking as part of making more liveable cities.

Additional, but as yet uncertain, factors that could help to improve traffic flow include:

- High levels of adoption of ridesharing meaning fewer robo-taxis deployed,
- Incentives/penalties to limit robo-taxis roaming around empty until a rider is assigned,
- More night-time running of trucks reducing congestion during the day, and
- Improved V2X connectivity and data sharing that can help smooth traffic flows.

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

The integration of MaaS and public transport within the overall transport system is evidently influenced by the pre-existing norms that vary from city to city. Some locations already have extensive public transport networks, while others are more limited. Rail-based mass transit systems are seen as less likely to be impacted by AV than road-based buses and smaller campus shuttles. The general view is that, if mobility needs are met via robo-taxis in areas where public transport is presently uneconomical, then this is all the better for transit agencies which are subsidised by public funds. In order to support this, there are more collaborations underway between transit agencies and the TNC, with paratransit special transportation services (for people with disabilities) in the US being taken over by TNCs in some cities.

Moreover, in some locations with high risk neighbourhoods, where human drivers are reluctant to go, some see that automated vehicles may well improve access. In terms of design options, several are confident that a wider range of vehicle sizes and layouts that may be available, could provide more flexibility than existing timetables. So, in locations where current services are provided by one of two sizes of bus, in the future there could be a wider range of, for example, 2, 4, 8, 12, 20 and 40 person AVs - so seating capacities adapt to market demand and provide improved access and reach. Personal security for riders is however a primary challenge which must be addressed to overcome the last person on the bus problem.

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

With the momentum behind AV growing, extensive tech development is underway across all major technology categories (HD Maps, lidar, radar, computer vision, AI, V2X and INS (inertial navigation systems)). Associated funding is at vast levels across all fields. As such, while some speculate that one company presently has better technology for a specific task than another, given the scale of the opportunity, most would agree that, if there is indeed market demand for L4 services, then venture funding will appear to fund technology development and address any gaps. Private sector forces have already created eco-systems to serve current needs, and extensive evolution can be expected in the years ahead. So, if there is need for more focus in one area than another, the natural flow of innovation and funding will ensure that is met. As with traditional transport systems, a full portfolio of technologies helps to build and progress the balance, but without one universal common solution - and this is likely to continue. While LIDAR, INS, or HD Mapping may have short-term focus in certain cases, the proliferation of tech companies and the low probability of major convergence of customer requirements will mean a continued multi-technology, multi-tier ecosystem of technology for multiple future AV systems.

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

It is evident that with ADAS adoption growing, the crash rates for human-driven vehicles will begin dropping for both cars and trucks alike. This will happen without AV. However, AV can deliver a next level of safety benefits and help reduce road deaths and injuries now caused by distraction, drunk driving, and fatigue. Regarding the congestion challenge, only connected autonomous vehicles have the potential for a step change: Fleet-based AVs will employ the right level of connectivity to improve traffic flow once their scale is sufficient to make a difference.

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

Standards are a means to an end, not an end in themselves. In these discussions, it is essential to distinguish between technical standards (implementation focused) and safety standards (behaviour focused). Moreover, in many fields, for disparate markets, there may be no strong economic reason to standardise on technical factors. For safety standards, China will have different standards to the US and Europe, with other locations where domestic market size is significant, such as Japan and India, also having alternative approaches. The commercial providers can adapt to these disparities just as they have for fuel economy and emissions standards. Although Europe is busy setting safety standards which will lead to regulations, several consider that they are behind the curve and will lag behind other locations. While there is more likelihood of regional rather than global safety standards in the first AV wave, the European process that incorporates ISO standardisation will, however, subsequently ripple across many markets globally.

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

For now, the focus is very much on regulation as being at the fore for encouraging deployment. However, while some are being highly proactive, there are concerns that they could veer towards becoming too heavy-handed. But adoption rates are not going to all be about national regulation – there are several other key factors at play that also vary from city to city. These include the access and quality of EV charging and regional energy storage, the quality of current public transport systems, and the implementation of rider-per-mile taxation, which makes sense from a public sector viewpoint in many cases. Also important is the initial testing locations for the organisations directly offering automated mobility services, which will comprise a growing mix, such as Ford, Toyota, GM Cruise, Waymo, Uber, Lyft, Grab, WeRide, Didi, and Baidu. The candidate lead locations globally could include several US cities (San Francisco, Phoenix, Pittsburgh) as well as others such as Singapore, Shanghai, Shenzhen, and London.

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

It is clear that, while some level of independent approaches will be taken, the need for collaboration in AV deployment is vital, and so integration and partnerships are indeed going to be critical. While media focus is mostly on OEM collaborators, including the likes of GM, Ford, VW, BMW, and Toyota, other key integrators will be the more vertically integrated firms like Waymo and Uber, that are already selecting their lead manufacturing partners: Hyundai, Jaguar and Volvo are, for instance, targeting large future sales of robo-taxi vehicles via the TNCs. Other existing mobility providers, such as Avis and Hertz, will also seek to have a major say.

Alongside these, several tier 1 automotive suppliers are making acquisitions and building reach – ZF, Bosch, and Delphi spin-off, Aptiv, are some of the most prominent. Beyond such private companies, some see that major public transport authorities will also play an integrating role – either directly in London, Shanghai, and Singapore, or indirectly when operations are outsourced to private transport operators like Transdev and Keolis, in which private sector incentives motivate PTOs to implement AV.

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

Although initial research some years ago suggested that the established OEM brands would be trusted more than the tech firms, over the past year or so, confidence in TNCs and others has been growing. Waymo, Lyft, and Baidu are now considered to be just as trustworthy as Ford, GM and Toyota. Moreover, with all the integration, partnerships, and acquisitions underway, the emerging view seems to be that, as long as the whole system works, most consumers will be increasingly agnostic. Mobility services will be multi-platform and multi-brand, with regional as well as global players, that are all equally trusted to provide safe and reliable transport by their respective customers.

What lessons can be learned from other sectors?

While the coherent rollout of 4G for mobile is hailed as an example of international cooperation and coordination, the rifts around 5G and the pushback by some against the leading role of Huawei raises questions about this sector as a role model. In addition, the early years of cellular GSM and CDMA technologies were highly competitive and driving different technical communications standards.

In healthcare there are very good examples of coordination in some regions but not others. In countries with joined-up, and often mostly public, healthcare systems such as Singapore, much of Europe and, today, increasingly China, there are high levels of coordination, sharing and standardisation across key areas such as patient data and electronic healthcare records. These are driving faster, better roll-out of new technologies and are also enabling greater levels of transparency. However, in other, often mainly private and highly fragmented systems, such collaboration and cooperation are, as yet, not on the horizon. From the healthcare examples that are progressive, key issues that have been at the fore have been ensuring high levels of interoperability, good shared access to data, overcoming privacy concerns through ethical partnerships and cooperation on global approaches through bodies such as the WHO.

Telecom is a world where extensive inter-operability is required for scale. Healthcare costs and effectiveness count on frictionless data exchange. But companies bringing AV to people and freight do not rely on inter-operability or data sharing. If they see the need for either, which may come about as the sector scales up, they will establish alliances to make it happen. One other sector for potential insights in terms of human interaction and getting strangers to be in shared spaces for some time may well be the airlines. That said, post pandemic behaviours may differ.

How much will AVs be tied to EVs, and therefore intertwined with charging infrastructure roll-out etc.?

It is clear that for some forms of transport AV and EV have become linked – but this is not universal. In the next decade, as investment in EV infrastructure gathers pace, we can expect short trip urban delivery vehicles, robo-taxis and many public transport shuttles to align for combined AV and EV deployment. This is especially the case in China and may well also be a pre-requisite in European cities as part of driving environmental benefits.

However, there are many areas where EV may lag AV – long distance trips, trucks and near constant use scenarios as well as countries and states that are yet to introduce electrification regulations and also many rural locations where distances are significant and the EV charging infrastructure is yet to scale. In such situations, the question of whether there are two systemic changes – first to AV and then later to EV is a core question. Equally there are other scenarios being explored where alternative fuel systems such as hydrogen cells decouple the assumed AV / EV interaction and so enable autonomy and a change of energy system to occur independently.

Will air-taxis have impact beyond a few niche locations?

While there are evident locations, such as Dubai, where air-taxis are very much at the fore of the AV vision, in most they are a subset of the mix or largely absent. While Uber testing is taking place in Dubai, Dallas, LA and Melbourne, it is notable that there is pushback for major use in Melbourne and little confidence of 2030 of significant impact in LA. Equally, although much Alphabet Wing testing has been taking place in New Zealand, 2030 impact of air-taxis there is considered likely to be relatively minor. The debate of whether air-taxis are electric helicopters or people-carrying drones may appear semantic, but it highlights the underlying assumptions behind niche vs mass use – and certainly most experts seem to think niche will be the focus for this decade. However, there is an important link to the wider issue of electric aviation and climate change. If, as many expect, regulation against internal combustion engine on land is matched by a push for aviation to go cleaner quicker and deeper than the current 2050 industry targets, then some see that the incentives for wider innovation may support broader scaling. With energy density, battery life and weight the three priorities for many in electric aviation, if these are solved for the target short-haul flights, then the impact for air-taxis could be significant.[192] As yet, however, most credible ambitions for electric aviation shifts are focused more on 2040 than 2030 and so, for now, the next decade for air-taxis looks like being a formative period with significant investment, with deployments serving niche freight and passenger trips at a price premium.

How will drones used for parcel delivery integrate with drones for other purposes?

The highly sophisticated parcel delivery companies will remain dominant as the portfolio of alternative systems evolves. Their experience and expertise will be applied to drone deliveries, and as their voice across government and industry stakeholders is strong, they, rather than new start-ups will set the pace.

How will planning evolve to become a public/private partnership?

There are a few nations with the right structures for creating and implementing innovative transport plans, plus an effective working relationship with local corporate stakeholders. Good examples here include New Zealand and Australia. Other regions such as UAE, Singapore and China are more top-down and can dictate the way forward. Elsewhere large corporations serving the public infrastructure and mobility agencies will become thought leaders, taking best practices from one city to another.

Will private companies contribute to the cost of the infrastructure, and will public sector agencies allow for this?

This is unlikely in most markets but may be possible in some as part of a wider push back against digital organisations. For example, in Europe where digital taxation in the form of a 3% revenue tax is at the fore of many plans, this could equally apply to Uber as much as to Facebook. The question is however whether this is a rather simplistic endpoint or a steppingstone to a more sophisticated approach. The idea of a curb tax for pick-ups and drop-offs has been increasingly mentioned for robo-taxis and a similar pavement tax for urban delivery vehicles is being considered by some. Given the high investment costs for a more intelligent infrastructure, public agencies at both city and state level are clearly looking for additional sources of funding. As such, the curb tax or similar could well become part of a 'social license to operate' for companies in several locations like San Francisco and Singapore which will add to fares for users. Elsewhere it is more likely that co-investment by the corporate sector is possible in specific situations, such as with privately-owned motorways and streetscapes interacting with local planners.

Will the growth of AVs mean more open/ liveable/walkable urban public spaces?

Urban planners globally are keen that AV should be a catalyst for wider transformation of cities – less car parks, narrower roads and less congestion are all top of many wish-lists. However, if seems that these are largely 20- or 30-year possibilities and, other than for a few locations, AVs will more likely add to congestion in their first decade or so of use. The coupling of AVs to EVs has clear implications in terms of a reduction in noise and air pollution and so may well be part of EV only zones in many European and some Asian cities within the decade – but these are unlikely to be AV specific.

How will cities adapt today's public transport systems in an era in which automated MaaS overlaps their mission?

Cities must find new models for planning their road-focused public transport systems, ones which are more adaptable to change. Shifts in mobility patterns have been underway now for some time due to TNCs, city-bikes and scooters, so automated driving brings an additional element that acts as an accelerator of transformation. Public transport exists due to city priorities for transportation equity and managing congestion, but automation can serve as an enabler towards these aims whether it is run by private or public entities. This will be an area of much innovation and experimentation.

How will designers overcome resistance to sharing rides with strangers?

Vehicle manufacturers recognise that tomorrow's AVs will not be the same as today's cars, but also see that a need for familiarity may mean that there are common features. The 'not sharing with a stranger' challenge is perhaps one of the most significant unknowns and so multiple companies will be seeking to launch the best solutions. There will be much design experimentation, with leading students and companies applying their expertise to optimise the rider experience, ensure profitable operations and be an asset to their host cities.

For what types of routes and freight will Level 4 driverless truck automation happen first?

Long haul trucking routes are the low-hanging fruit for Level 4 truck automation. The operating regions initially will be those of low complexity to the self-driving system, free of extreme weather, topography and traffic. As the technology evolves, the core competitive discriminator for the tech companies and OEMs will be in expanding the Operational Design Domain to cover ever-more complex geography all year-round.

How will supply chain approaches be transformed by Level 4 truck automation?

Supply chain dynamics for on-road freight are currently tightly intertwined with the limitations on truck driver hours of service. Moving a load in fully automated fashion will mean shorter trips such that, for example, in the US it will take 2 not 5 days to cross the country, allowing fruits and vegetables to ripen a little more before harvesting so they arrive at the grocery store in perfect condition. Equally, refrigeration equipment on trailers will run vastly fewer hours, saving fuel and reducing emissions. Globally the broad deployment of automated trucking will drive significant redesign of many supply chains.

What effect will growth in AV urban/suburban parcel/grocery/food delivery have on other road users?

The public's appetite for direct delivery has not yet peaked so this question will continue to be a key focus for transportation researchers in the coming decade. Only with larger more comprehensive datasets taking into account myriad factors such as comparing reduced individual trips to stores with greater delivery vehicle miles, can we start to assess these effects.

Final Conclusions

It is clear that, across the various markets, there are areas of alignment on some issues - but also notable nuances in approach to AVs that are different, country to country. Beyond validating the five ‘certainties’ identified earlier, from all our discussions, we can see nine key issues emerging as significant - all of which are intricately inter-connected and collectively do indeed amount to a highly ‘wicked’ problem:

1. **Fleets are now driving progress:** In terms of the dominant business models, momentum is clearly behind both robo-taxis and truck fleets.
2. **Automated trucks are coming:** Freight has much to gain in terms of efficiency; this has regulatory momentum and wide industry support.
3. **Safety is a pre-requisite:** Expectations are high, but as many advances are already in process, improvements look likely.
4. **Congestion is a conundrum:** While the aim is for less congestion and the role of connectivity is pivotal, user behaviour and Transportation Network Company (TNC) strategies could initially mean more congestion.
5. **Multiple options for the last mile:** There are many alternatives in the mix, all bridging different needs and location gaps.
6. **First vs widespread deployment:** Where and why we see initial AV services may not necessarily align with where mass impact will occur.
7. **Deeper collaboration will be needed:** Moving from partnerships to long-term multi-party collaboration is seen as a critical enabler.
8. **Technical standards may not be pivotal:** Although comprehensive technical standards are advocated, they are not essential for AV; in some regions, safety standards will support regulation.
9. **Regulators are influencing deployment:** Proactive regulation is attracting companies, but the balance of light vs. heavy regulatory approaches may impact this.

Reviewing each of these in more detail:

Fleets are now driving progress: Across the discussions there was strong agreement that for the short and medium-term, the action lies in fleets, rather than with privately-owned vehicles. As well as being the focus for the TNCs, robo-taxis will provide new revenues to passenger car OEMs, while technical learning occurs which can then be transferred to mass-market vehicles. Automation will be implemented forcefully for fleets moving goods as well. This simplifies the insurance picture, as fleet operators will work with insurers to price risk and devise appropriate coverage. Some well-capitalised companies, such as Waymo and Uber, are likely to self-insure their assets, and may extend this to liability as well. Resolving issues for the more complex world of personal auto insurance comes much later.

Automated trucks are coming: Experts are generally convinced that automated trucking and truck platooning are coming in the near future. Economically, full driverless freight operations are the Holy Grail, with platooning acting as a major stepping-stone. Although increasingly supported by regulation in a growing number of locations, level 1 platooning is not seen as having a broad societal effect other than in reduced energy consumption and associated emissions; however, it will deliver significant business benefits. As driverless truck developments progress, supply chain operations will begin to change in multi-faceted ways – many of which are yet to be elaborated. What, for example, are the effects on fresh produce grown in the western US and shipped to Chicago in winter? Energy costs of climate control for loads are reduced and the tomatoes can be picked ripe rather than green.

Safety is a pre-requisite: While safety has been one of the main discussion topics, participants acknowledge that overall system safety is improving steadily, as more ADAS-equipped vehicles are purchased and operated. As such, the additional contribution of autonomous vehicles in reducing today's human-caused crashes will be marginal. The AV safety conversation is more about ensuring these vehicles do not pose a new threat to today's road users. On a physical level, they will ideally operate more safely than humans – and opinions on this are evidently setting high expectations. However, cybersecurity also fits into this picture as another risk factor. Participants in Frankfurt acknowledged the high cybersecurity rigour with which the auto-industry already designs vehicles and manages the system - but of course there is always room for greater robustness. Overall, a clear viewpoint emerged that safety validation processes for AVs, as are being implemented by tech developers and carmakers, are very sophisticated. Nevertheless, pressure must continue to be applied, to get it right. Failing to meet the safety anticipations would be a major setback for AV deployment.

Congestion is a conundrum: Congestion remains a problem that autonomous vehicles cannot solve on their own – even though some expect them to do so. While in several cases, the arrival of TNCs like Uber has added traffic in cities, tomorrow's robo-taxis should not necessarily represent an additional increase over the current numbers of MaaS vehicles. In general, rising traffic volumes and a slowing of average speeds are age-old concerns, and will continue to be a primary focus for both advocates and critics. Here, the needs of society, cities, and tech firms will reinforce one another, so that moment-to-moment data sharing – which is likely to be via some combination of V2X and cloud - should improve traffic flow when sufficient scale is reached. Mobility service providers can deploy V2X on their vehicles, both to be a good citizen and achieve shorter trip times – an issue that is especially important in energy management for EVs. Another component which could potentially ease congestion is the willingness of robo-taxi customers to rideshare with strangers, and this will be central to the outcomes of MaaS. Pricing levers can only go so far – at some point, this is about user behaviour. So, what, for instance, will be the effect of a per-mile tax on robo-taxis, based on factors including occupancy? This and other unknowns create a conundrum for transportation planners who hope for less congestion in the end but recognise that there could be more in the medium term.

Multiple options for the last mile: For both people and goods, the first/last mile is a hotbed of activity. In terms of public transit, alongside electric scooters, bikes, and other traditional options, the integration of TNC operations with public transport systems is a dynamic area with the promise of a win-win if and when priorities are aligned. However, right now it is too early to draw conclusions on which combinations will gain priority, as the outcomes may vary dramatically from city to city. For goods, the growth of urban delivery will be interesting to watch, as a broad portfolio of services can potentially be more agile than those serving people. As for drones, they are seen as part of a 'means to an end' for the last mile - more probable for goods than people in most scenarios - but not yet a priority in this discussion.

First vs widespread deployment: It is important to avoid conflating the 'first' deployments of AVs with later 'widespread' deployment. Taking just passenger vehicles as an example, while initial robo-taxi services may be operating as early as 2020, city-changing levels of deployment will occur for only a few individual cities over the next decade. In many locations, widespread deployment will largely only start to play a role after 2030. Therefore, while regulators need to act to enable first deployment, planners also have to accelerate their time-horizons.

In China however, the narrative may differ. 2019 McKinsey analysis proposed that we are less than 10 years away from 90% of passenger-kms travelled in China being handled by automated vehicles: the prediction is for 2025-27 to be the inflection point.[193] While there is visible impetus and other advocates for fast roll-out, others consider that it may take a little longer. During this project WeRide announced a partnership with a very large local taxi group in Guangzhou for the rollout of their robo-taxi services.[194] Equally, Baidu is ramping up activity and Didi Chuxing's autonomous driving unit is now an independent company and attracting more investment.[195] China will, however, clearly not be alone in launching robo-taxi services in the next decade; growth is likely to be robust elsewhere as well.

From our discussions, for private, commercially driven models, "we will see many trials ahead, of pilot deployment in niche markets, and then scale up and optimisation." For public city-driven scenarios, "the priority will be developing and agreeing frameworks and roads, including road use pricing." What needs to be overcome is the "tension between public and private sector ROI."

Deeper collaboration will be needed: Across all areas and all locations, there were extensive discussions of concepts around collaboration. Generally, these were in the context of government-industry collaboration (e.g. data sharing for safety validation) and sometimes referred to industry-industry collaboration (e.g. data sharing for development purposes). While in some workshops, debates turned somewhat towards collaboration as an end in itself, rather than a means to an end, it is clear that many expect a step change from current levels.

In reality, tech developers will assess what they want to keep under their total control, versus working multi-laterally. For instance, remote support is likely to be defined and implemented by the tech developers working on their own, and/or with private sector partners. How, therefore, can the public sector engage and be engaged? So far, the view is probably via more government-government and government-industry dialogue and establishing associated consortia.

Balancing simplicity and complexity will be crucial here. Government-industry and government-government dialogue through existing channels has, for instance, been occurring since the start of the AV era. A unilateral approach is employed by several in the AV ecosystem, and is driven by the desire for simplicity. In June 2019, Uber released extensive info on its 'Safety Case' approach for digestion by regulators and others.[196] While this is not 'collaboration' per se, it serves to enhance their dialogue with governments, while informing the broader community.

More formal consortia can be challenging and time-consuming to implement, yet several key players have joined industry collaborations such as Partners for Automated Vehicle Education, the Safe Driving Coalition for Safer Streets and similar groups. Collaboration across the OEM technology development world is highly active, including the Ford/VW alliance for automated and electric vehicles, and Honda partnering with GM to bring Cruise robo-taxi services to market.[197,198] Additionally, the move towards industry verticalization is accelerating - for example, Ford adding Quantum Signal AI to their stable of acquisitions, joining Argo AI and others.[199] Tech industry collaborations are a given; the challenges now and in the future will be in crafting effective government-industry interactions. One view is that new industry-government structures for managing AV integration into society could come in the longer term, but this may slow things down in the short term. A deeper dive into the various forms of collaboration in our future workshops will be valuable.

Technical standards may not be pivotal: Standards are a form of collaboration in which industry, and sometimes governments, have much at stake, particularly safety standards. However, if we look at today's ride-hailing services, it is clear they have not been hampered by a lack of safety standards since humans were in the driver's seat. In workshops to date, the need for standards has been advocated by many – but without clarity on whether they were calling for technical standards, safety standards, or both. Looking at three areas of importance:

- Technical standards are not necessarily required, particularly when data sharing is done through the cloud, allowing software to translate different data formats.
- They are generally driven by economics, for instance to achieve economies of scale, a process which happens well downstream of initial system introduction.
- Standards to support inter-operability can be enablers to growing a nascent market.

However, many countries establish their safety regulations based upon safety standards created by global organisations such as the ISO and the UN. Safety standards can indeed be pivotal for allowing initial deployment.

Regulators are influencing deployment: Regulations form the intersection between geography and AV technology, and the regulators are seeking to build clarity and level playing fields. This can provide more certainty, which in turn drives deployment, but not always. Companies deploying automated mobility services are all seeking to maximise ROI, and they have a widening choice as to where to deploy. Multiple cities and countries are competing to be welcoming; but other jurisdictions feel a need to add stringent conditions - as has been done in some places with human-driven TNCs.

Singapore already has extensive requirements on AV provider testing, which is likely to continue for deployment. It is currently 'hot' for deployment plans because of its enabling approaches, but will this remain the case if regulations ask too much from AV providers who can turn their deployment planning elsewhere? Too heavy a hand from government may delay deployment, yet there is clearly a case for protecting the public good for safety and efficiency. For instance, one Melbourne participant raised the possibility of a 'national diverse mobility authority' having wide oversight. In the workshops, we have seen the tensions between heavy-handed but enabling regulations, versus more hands-off 'wild west' environments such as the USA. The right approach for widespread deployment is yet to be determined.

Many are enthused by a 2030 vision shared in the Silicon Valley workshop that "AV will have become a watershed event like the launch of smartphones 13 years ago." The multiple discussions around the world have evidently highlighted a number of important issues – some of which certainly require further debate. Future workshops in 2021 will continue to explore both niches and commonalities but, in the meantime, we hope these insights are useful, provocative and help to steer additional thinking and dialogue.

More Information

If you would like additional details on the Future of Autonomous Vehicles project, how it was undertaken or any of the insights shared in this report, please contact either of the authors - both of whom have led multiple projects exploring the future of transportation, technology and societal adoption of change.

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Future Agenda is an open source think tank and advisory firm. It runs the world's leading open foresight programme, helping organisations to identify emerging opportunities and make more informed decisions. Future Agenda also supports prominent organisations on strategy, growth and innovation.

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The Future of Autonomous Vehicles

The dream of self-driving vehicles has been a long time coming. It is however now within reach and the pressure is on the deliver on the vision. With sustained technology development, increased investment and raising public awareness, there is enormous interest in the imminent mainstream use of autonomous vehicles on the streets.

The Future of Autonomous Vehicles project was undertaken to canvas the views of a wide range of experts from around the world in order to create a clearer, informed global perspective of how autonomy will evolve over the next decade. Beginning with a discussion with government officials just outside Shanghai in July 2018 and ending with leaders from across the US autonomous vehicle community in the hills above Silicon Valley in February of 2020, this project has covered a lot of ground. In all, eight workshops and six additional discussions have engaged with hundreds of different opinions, shared perspectives and built considered future pathways.

This report is a synthesis of many voices and opinions on the likely future of autonomous vehicles. We have done our best to accurately reflect the views we heard and the context in which they were expressed.

Full details are on www.futureautonomous.org

About Future Agenda

Future Agenda is an open source think tank and advisory firm. We help organisations, large and small, to explore emerging opportunities, identify new growth platforms and develop game-changing innovations. Founded in 2010, Future Agenda has pioneered an open foresight approach that brings together senior leaders across business, academia, NFP and government. The aim is to connect the informed and influential, to challenge assumptions and build a more comprehensive view about the future that will help deliver positive, lasting impact.

For more information and to have access to all our insights please visit
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