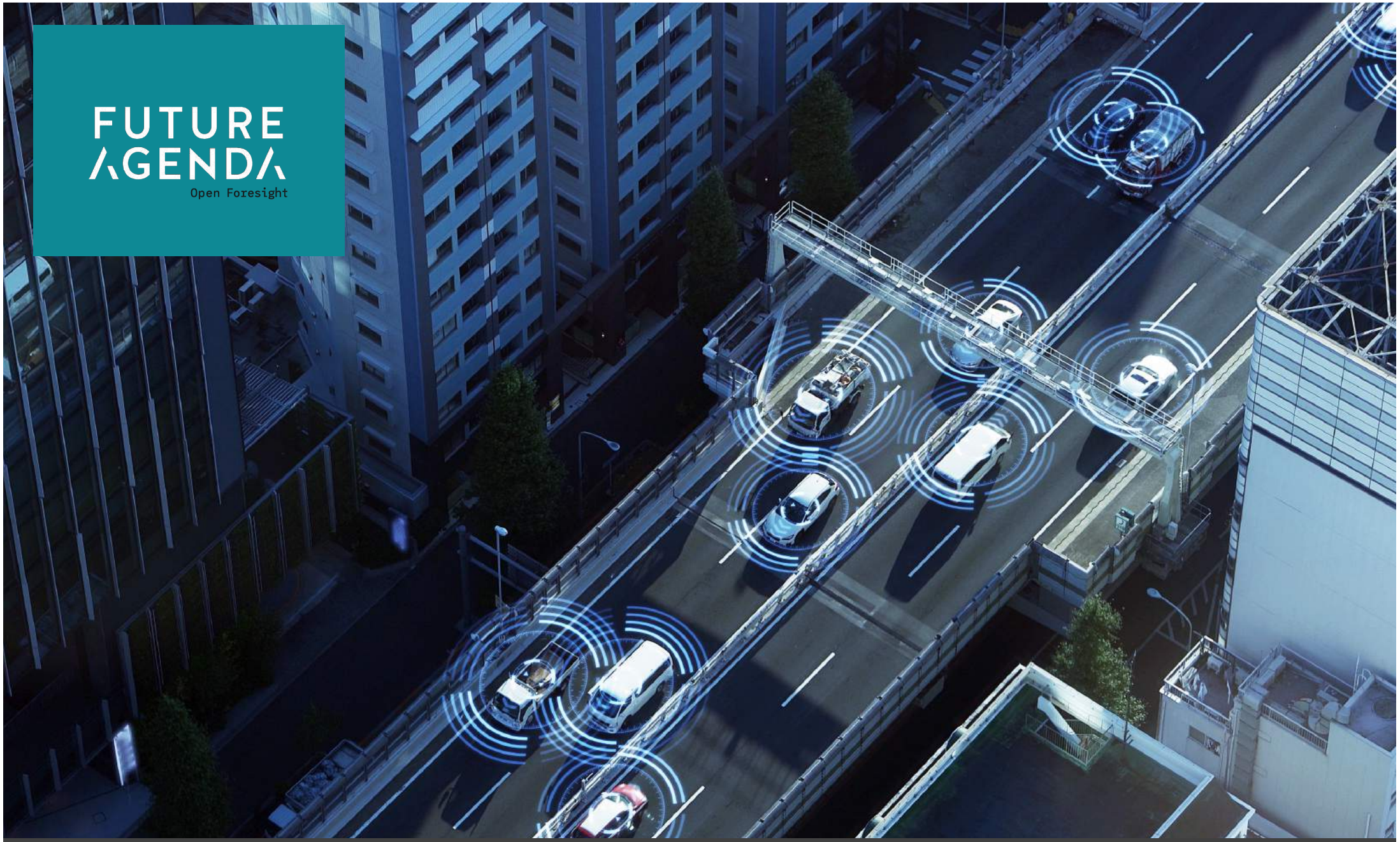
FUTURE AGENDA
Open Foresight



The Future of Autonomous Vehicles

Global Insights gained from Multiple Expert Discussions

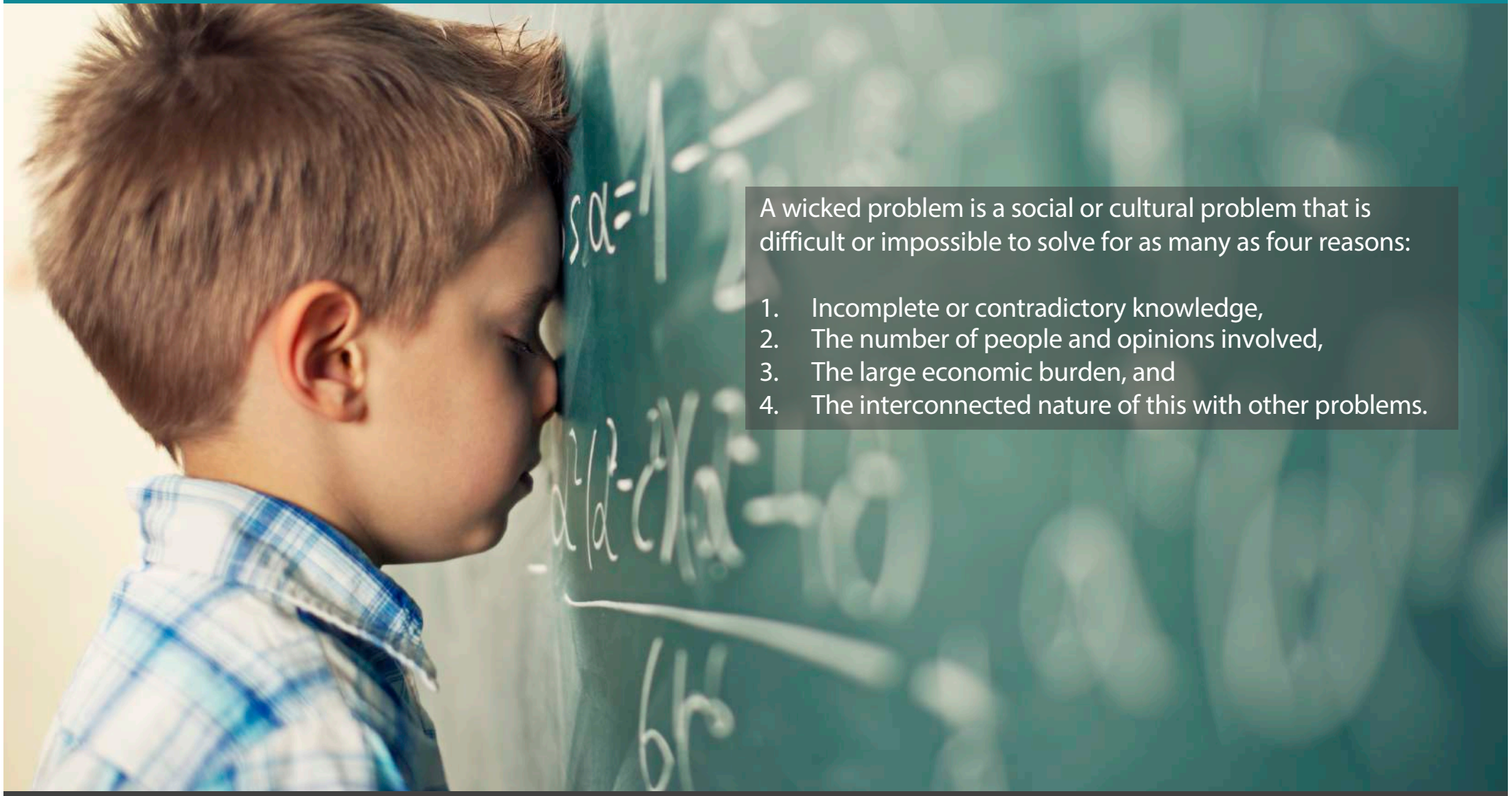
1 May 2020

- CONTEXT
- WHERE WE HAVE COME FROM
- THE WAY FORWARD
- CERTAINTIES AND UNCERTAINTIES
- RESEARCH INSIGHTS
- CONCLUSIONS
- MORE INFORMATION

Contents

This document provides an overview of the key insights on the future of AV.
Based on insight from multiple expert discussions, it shares different views and highlights the core areas of progress, and associated implications, that we can anticipate by 2030.

CONTEXT



A wicked problem is a social or cultural problem that is difficult or impossible to solve for as many as four reasons:

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

A Wicked Problem

The future of autonomous vehicles is considered to be a complex 'wicked' problem. To address it, we need to understand and challenge many different expert perspectives.

Review existing research

Map the emerging landscape

Explore gaps via global dialogue

Identify the key priority opportunities

Prepare and share global report

Support hosts with implications

Global Insights

This project has identified where and what the key opportunities are by collectively challenging and sharing the future of AVs plus the key drivers of change across a number of pivotal locations.

Future of Autonomous Vehicles
Key Insights

FUTURE AGENDA
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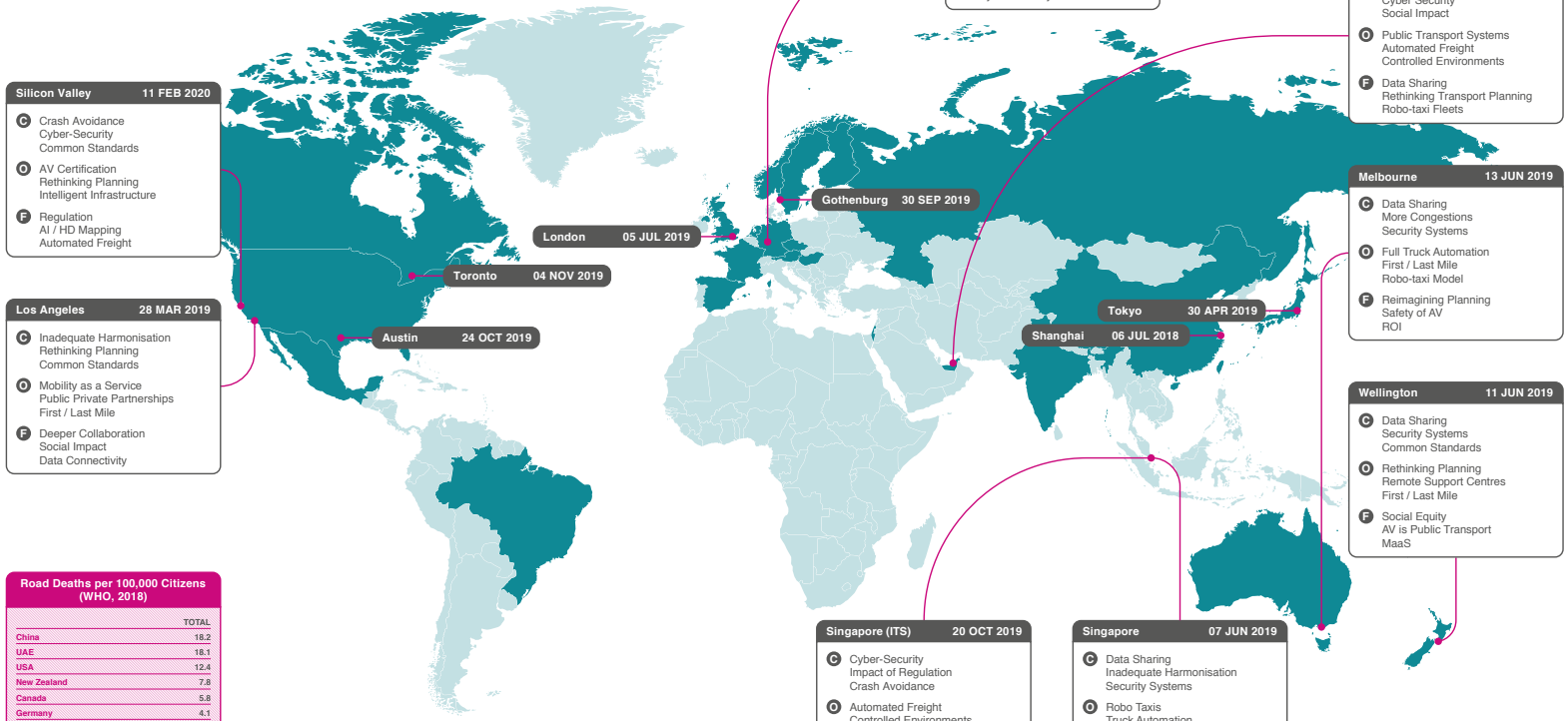


Frankfurt 22 MAY 2019
- C: Common Standards; Inadequate Harmonisation; More Congestion
- O: Truck Automation; Incentives for Collaboration; First / Last Mile
- F: Communication between Systems; Acceptance of Accidents; Cyber Security Risks

Dubai 17 OCT 2019
- C: Impact of Regulation; Cyber Security; Social Impact
- O: Public Transport Systems; Automated Freight; Controlled Environments
- F: Data Sharing; Rethinking Transport Planning; Robo-taxi Fleets

Silicon Valley 11 FEB 2020
- C: Crash Avoidance; Cyber-Security; Common Standards
- O: AV Certification; Rethinking Planning; Intelligent Infrastructure
- F: Regulation; AI / HD Mapping; Automated Freight

Gothenburg 30 SEP 2019

London 05 JUL 2019

Toronto 04 NOV 2019

Melbourne 13 JUN 2019
- C: Data Sharing; More Congestions; Security Systems
- O: Full Truck Automation; First / Last Mile; Robo-taxi Model
- F: Reimagining Planning; Safety of AV; ROI

Tokyo 30 APR 2019

Shanghai 06 JUL 2018

Los Angeles 28 MAR 2019
- C: Inadequate Harmonisation; Rethinking Planning; Common Standards
- O: Mobility as a Service; Public Private Partnerships; First / Last Mile
- F: Deeper Collaboration; Social Impact; Data Connectivity

Austin 24 OCT 2019

Wellington 11 JUN 2019
- C: Data Sharing; Security Systems; Common Standards
- O: Rethinking Planning; Remote Support Centres; First / Last Mile
- F: Social Equity; AV is Public Transport; MaaS

Singapore (ITS) 20 OCT 2019
- C: Cyber-Security; Impact of Regulation; Crash Avoidance
- O: Automated Freight; Controlled Environments; Public Transport Systems
- F: Rethinking Planning; Social Impact; Data Sharing

Singapore 07 JUN 2019
- C: Data Sharing; Inadequate Harmonisation; Security Systems
- O: Robo Taxis; Truck Automation; Urban Delivery
- F: Environmental Impact; Insurance and Liability; Less vs More Congestion

Road Deaths per 100,000 Citizens (WHO, 2018)

	TOTAL
China	18.2
UAE	18.1
USA	12.4
New Zealand	7.8
Canada	5.8
Germany	4.1
Japan	4.1
Singapore	3.6
UK	3.1
Sweden	2.8

C Top 3 Challenges O Top 3 Opportunities F Top 3 Future Issues

Top 25 AV Ready Nations
KPMG https://home.kpmg/content/dam/kpmg/nl/pdf/2019/sector/autonomous-vehicles-readiness-index-2019.pdf

Expert Dialogue

We held eight expert workshops plus six extra discussions which have identified major challenges, new opportunities and emerging issues for the next decade.

ADVI Australia & New Zealand Driverless Vehicle Initiative

HOCHSCHULE FRESENIUS UNIVERSITY OF APPLIED SCIENCES

NZ TRANSPORT AGENCY WAKA KOTAHI

DB

LKY Lee Kuan Yew School of Public Policy National University of Singapore

SIEMENS

DRIVE SWEDEN

Metro

Transurban

Heredore Consulting

UWE BRISTOL University of the West of England

FRANKFURT HOLM HOUSE OF LOGISTICS AND MOBILITY

MOTT MACDONALD

wsp

Our Hosts and Partners

Leading organisations involved in the hosting of events included a broad mix of transport agencies, universities, consultancies, trade bodies and logistics companies

DB

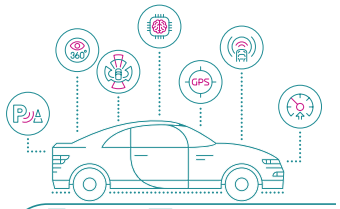
WHERE WE HAVE COME FROM

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
- 2000 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
- 2010 TUB self-driving vehicles demo in Germany
- 2010 Uber founded
- 2011 Nevada authorises AV testing
- 2012 Florida authorises AV testing
- 2012 Peloton truck AV company founded
- 2013 FlixMobility founded in Germany
- 2013 Amazon acquires Kiva Systems for $775m
- 2013 Lyft founded as Zimride
- 2013 Google completes 300,000 automated driving miles
- 2014 Google completes 500,000 miles of autonomous driving
- 2014 Caterpillar starts robotics trail
- 2014 NuTonomy spun out of MIT
- 2014 Port of Rotterdam launches automated guided vehicles
- 2014 Oxbotica spun out of Oxford University
- 2014 UK Government allows AV testing
- 2014 Amazon predicts drone deliveries within 5 years
- 2014 Tesla announces Autopilot
- 2015 Mercedes S Class includes semi-automated features
- 2015 Google fully automated prototype tested
- 2015 NIO founded in Shanghai
- 2015 Apple launches project Titan
- 2015 Uber recruits key talent from CMU robotics centre
- 2015 Tesla Autopilot capability introduced
- 2016 Audi, BMW and Daimler acquire HERE for $3bn from Nokia
- 2016 Volvo launches Drive Me project in Sweden
- 2016 Volvo pledges that by 2020 no one will be killed in a Volvo
- 2016 GM invests $500m in Lyft autonomous vehicle partnership
- 2016 GM acquires Cruise Automation for $1bn
- 2016 Apple invests $1bn in Chinese ride share Didi Chuxing
- 2016 Ford and VC firms invest in NuTonomy
- 2016 Qualcomm acquires NXP for $39bn
- 2016 Toyota and Uber announce partnership
- 2016 Uber completes 2m miles in automated testing
- 2016 Lyft announces partnership with NuTonomy
- 2016 Peugeot-PSA announces partnership with NuTonomy
- 2016 Bosch and Nvidia announce AI partnership
- 2016 Intel acquires Mobileye for $15bn
- 2016 Apple starts testing autonomous vehicles
- 2016 Ford invests $1bn in Argo AI
- 2016 Audi and Nvidia announce AI partnership
- 2016 Daimler and Nvidia announce AI partnership
- 2017 Intel invests in HERE
- 2017 Waymo spun off as separate company from Google
- 2017 Amazon drone testing in Cambridge, UK
- 2017 Tesla Autopilot completes 300m miles of operation
- 2017 US Federal AV policy agreed
- 2017 Pony.ai founded
- 2017 Samsung acquires Harman Industries for $8bn
- 2017 Uber AV prototypes in San Francisco and Pittsburgh
- 2017 Drive.ai spun out of Stanford University
- 2017 Uber acquires Otto truck start-up
- 2018 Starsky Robotics truck technology unveiled
- 2018 Baidu announces Apollo AV platform and fund
- 2018 US Federal AV policy 2.0 agreed
- 2018 Ford Lyft partnership announced
- 2018 Lyft partners with drive.ai
- 2018 Waymo testing without a safety driver
- 2018 NuTonomy acquired by Aptiv for $400m
- 2018 Tesla semi-truck announced
- 2018 Beijing permits AV testing on public roads
- 2018 US Federal AV policy 3.0 agreed
- 2018 Waymo semi truck announced
- 2018 Self-driving Uber car kills pedestrian
- 2018 Baidu completes 140,000 km of self-driving in a year in Beijing
- 2018 Volvo launches Vera autonomous platform
- 2018 Lyft completes 5,000 self-driving car rides in Las Vegas
- 2018 China permits city governments to issue AV road licences
- 2018 Baidu begins mass production of Apollo self-driving bus
- 2018 Uber shuts down AV truck project
- 2018 Waymo completes 5m miles of testing

Google | Baidu | Tesla | Lyft | Uber | Volvo



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

AV Development Timeline

The possibility of developing an autonomous vehicle has been explored for many years. Since 1939, projects have been building momentum towards today's intensive activity.

THE WAY FORWARD

Realistic Expectations

After a reset in 2019, more realistic ambitions for autonomy are providing greater focus for OEMs and big tech as well as guiding investor expectations on timelines and impact.

CERTAINTIES AND UNCERTAINTIES

1 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.

2 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.

3 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.

4 Monitoring is Assumed:

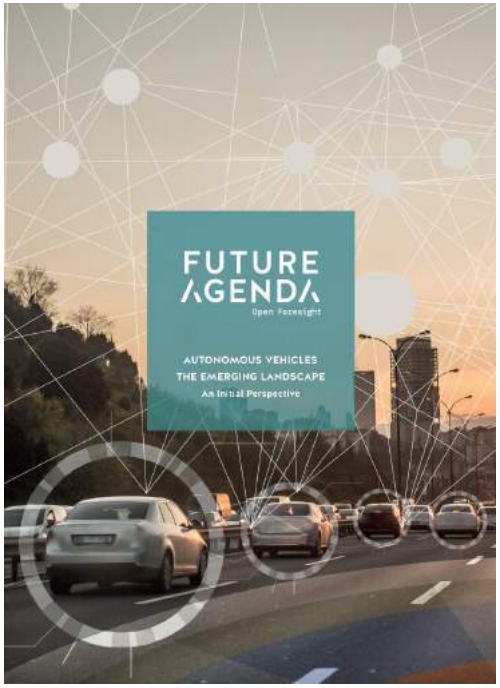
While highly automated and able to eventually operate autonomously, all AVs will be monitored by both people and machines. Human supervision, either in the vehicle or remotely, will be required by regulators and expected by users in the early years and, over time, as trust builds some of this will be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

5 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 cars will be designed for multiple person shared occupancy. Prototypes such as Volvo Truck's Vera and Cruise's Origin are good examples. For privately-owned passenger cars, coming in significant volumes after 2030, interiors are also likely to evolve substantially.

What We Know

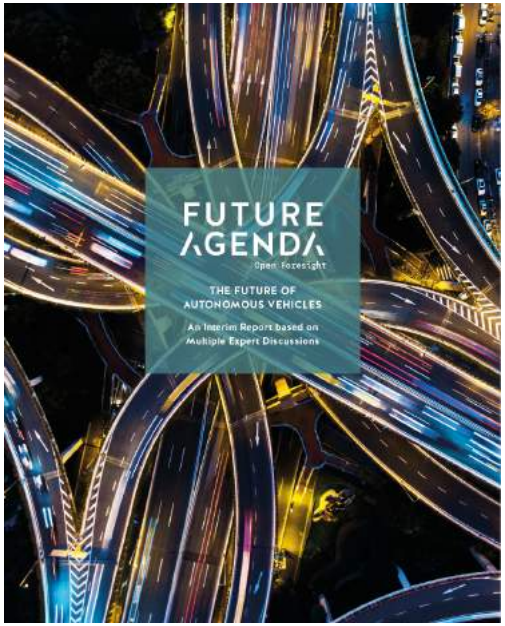
While there are multiple debates, we see five main issues on which many agree. These are close to 'certainties' upon which assumptions and scenarios can be based.



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

Initial Questions

An initial perspective mapped the autonomous vehicle landscape and identified twelve key questions to explore via the research project.



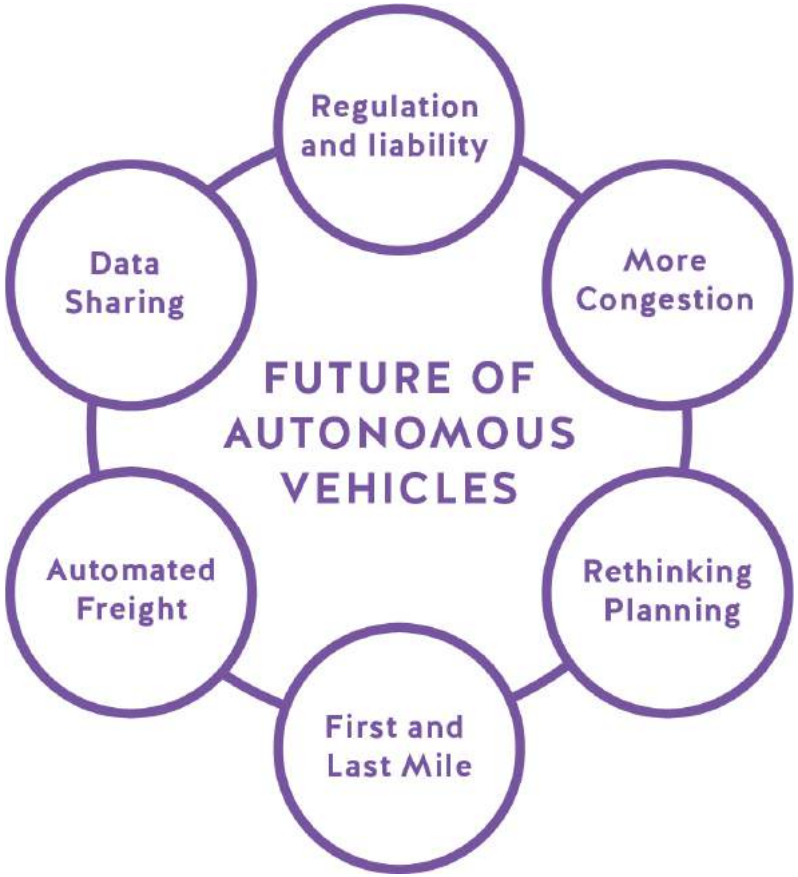
1. What lessons can be learned from other sectors – for example, mobile and healthcare?
2. How much will AVs be tied to EVs, and therefore intertwined with charging infrastructure roll-out etc.?
3. Will air-taxis have impact beyond a few niche locations?
4. How will drones used for parcel delivery integrate 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?

Further Exploration

In the interim report we identified an additional 12 questions from the first tranche of workshops that we then sought to addresses in the second half of the project.

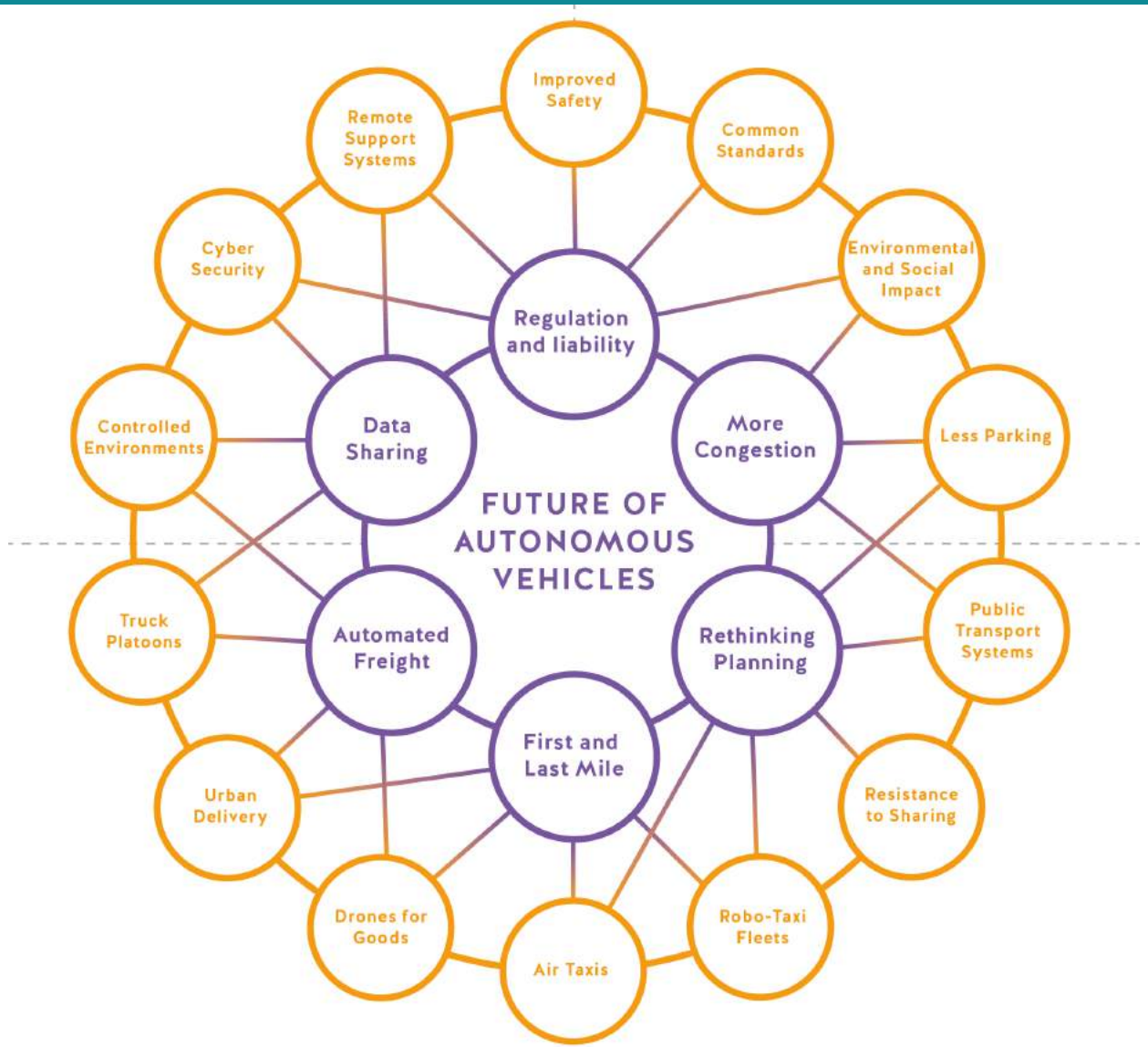
FUTURE AGENDA

RESEARCH INSIGHTS



Six Macro Themes

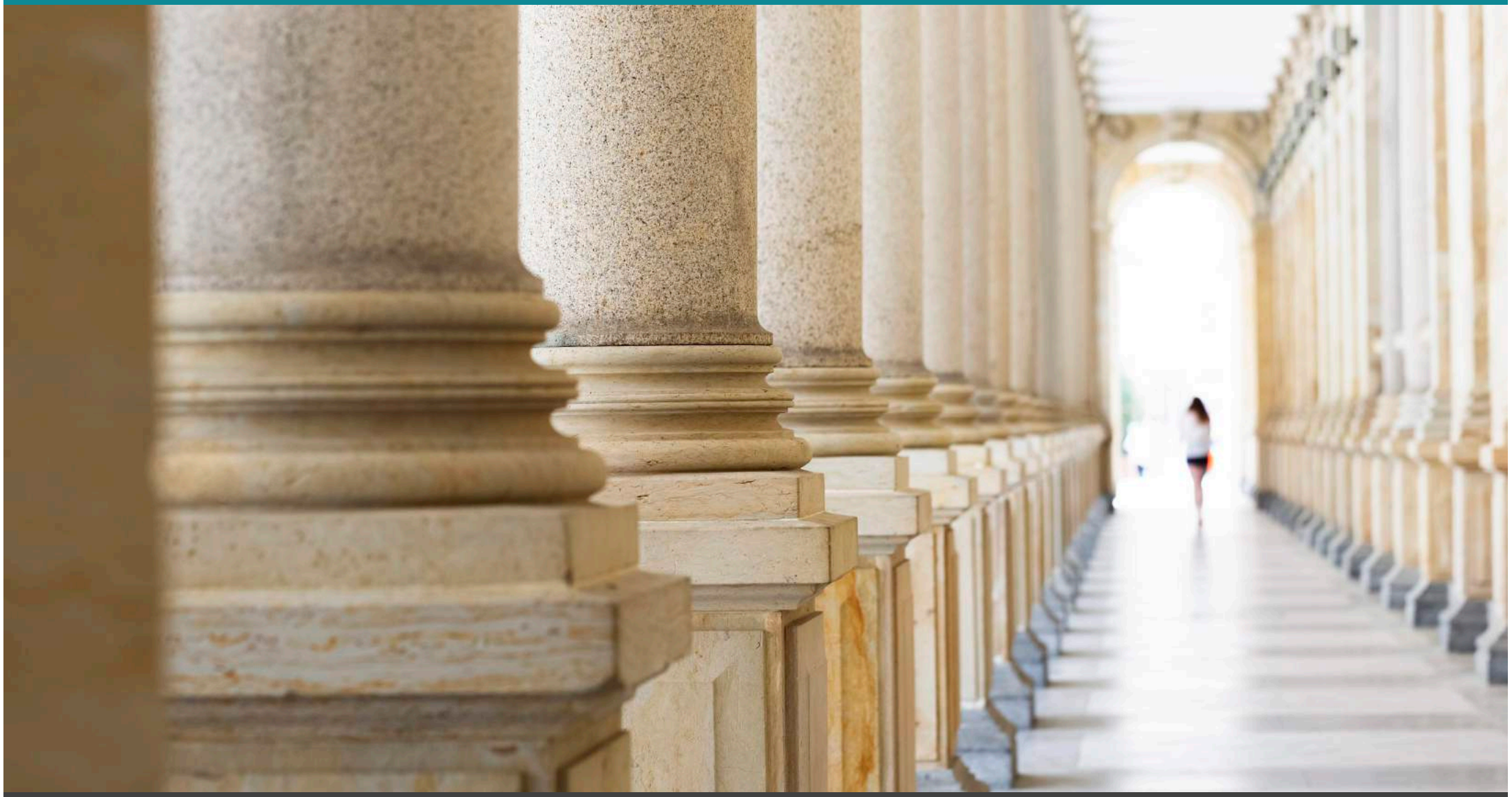
From the discussions, a number of key issues were prioritised, debated and explored in depth Within these, there are six pivotal high-level macro drivers of change are focus of greatest debate.



Priority Areas for Focus

Underlying and connected to these six, there are another additional fourteen priority topics of focus. Together these 20 areas can all be considered pivotal for the future of AVs.

Systemic Considerations

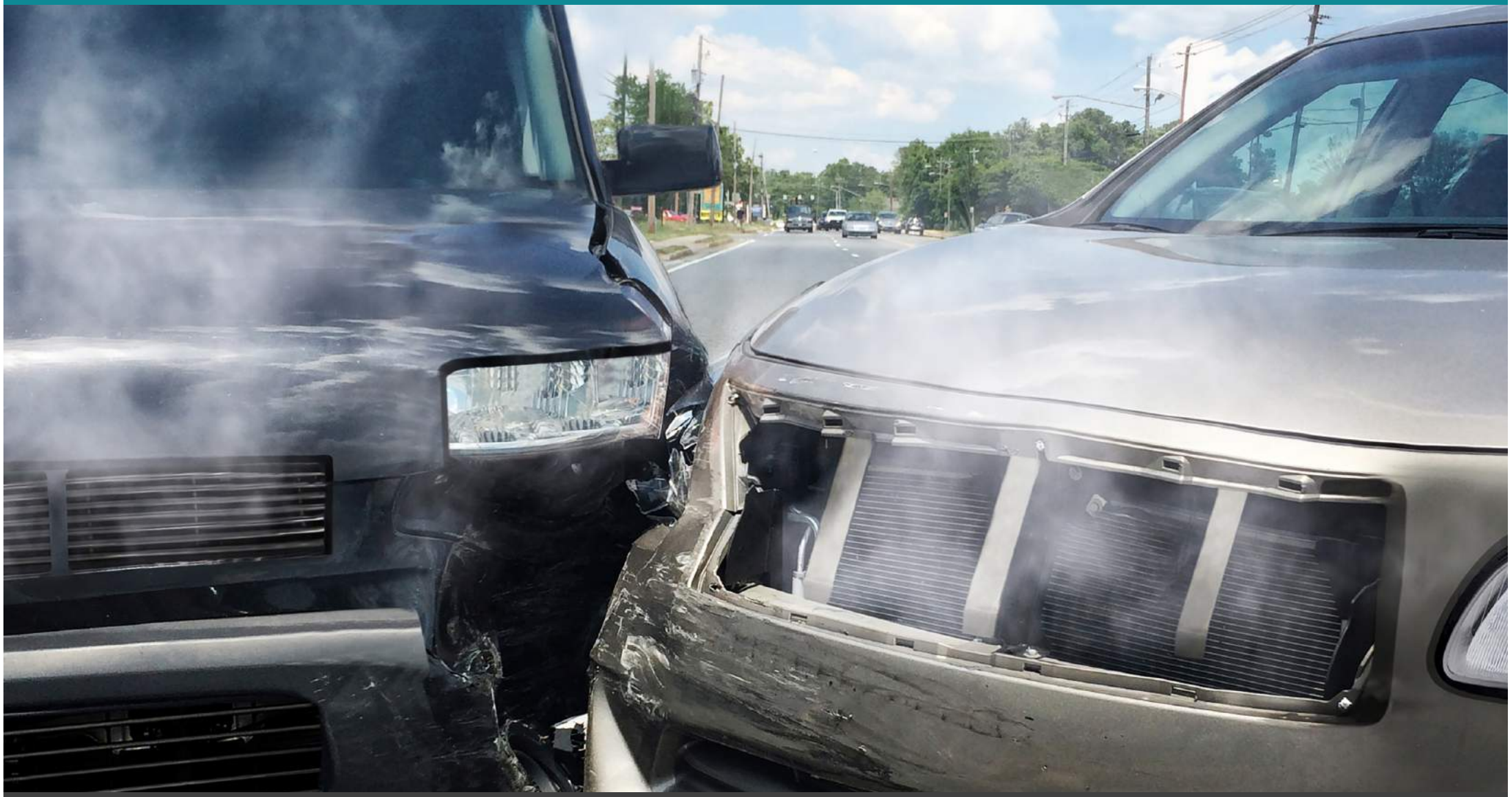


Regulation and Liability

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.

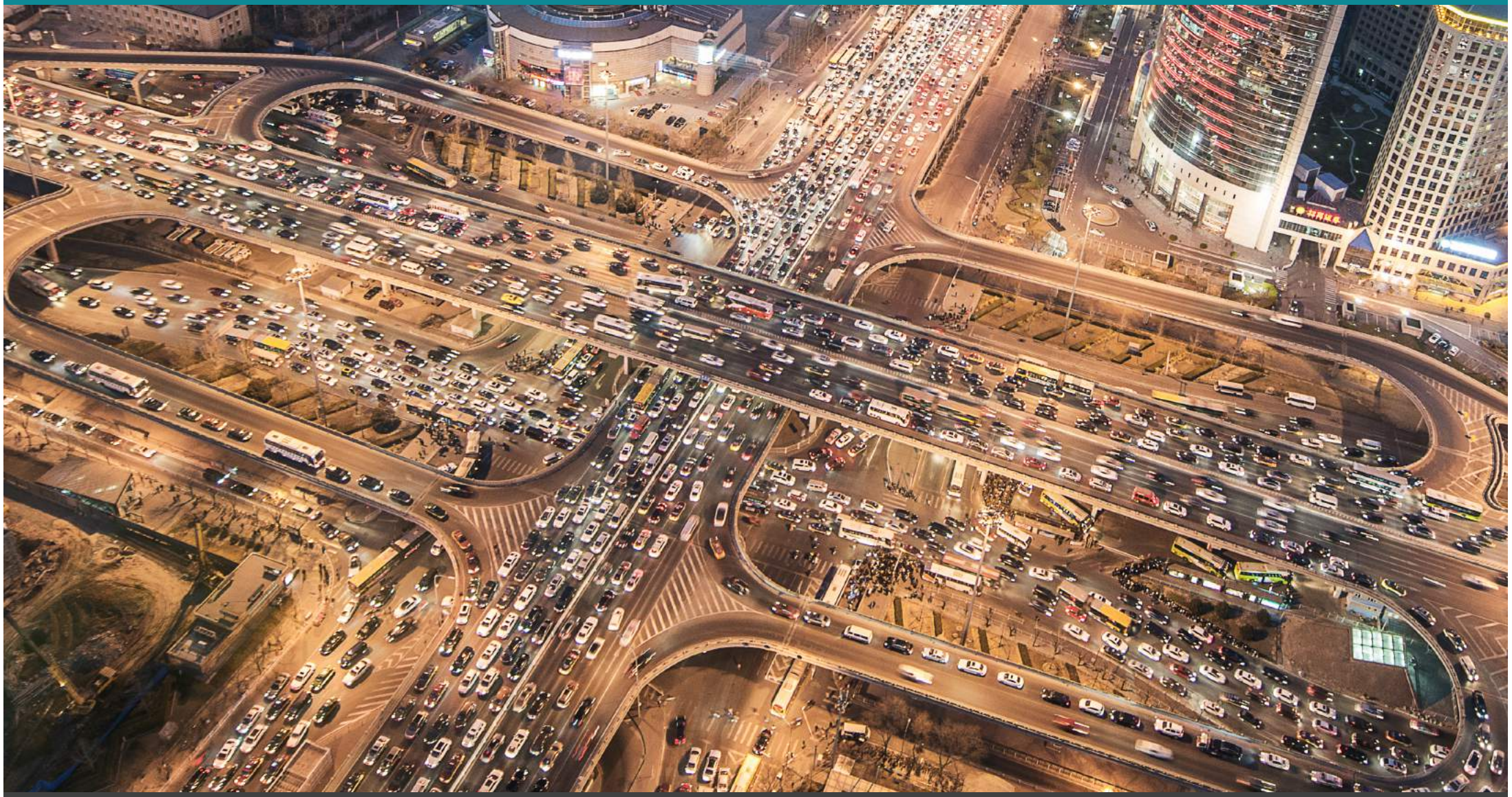


Improved Safety

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 .

Moving People

Public Transport Systems

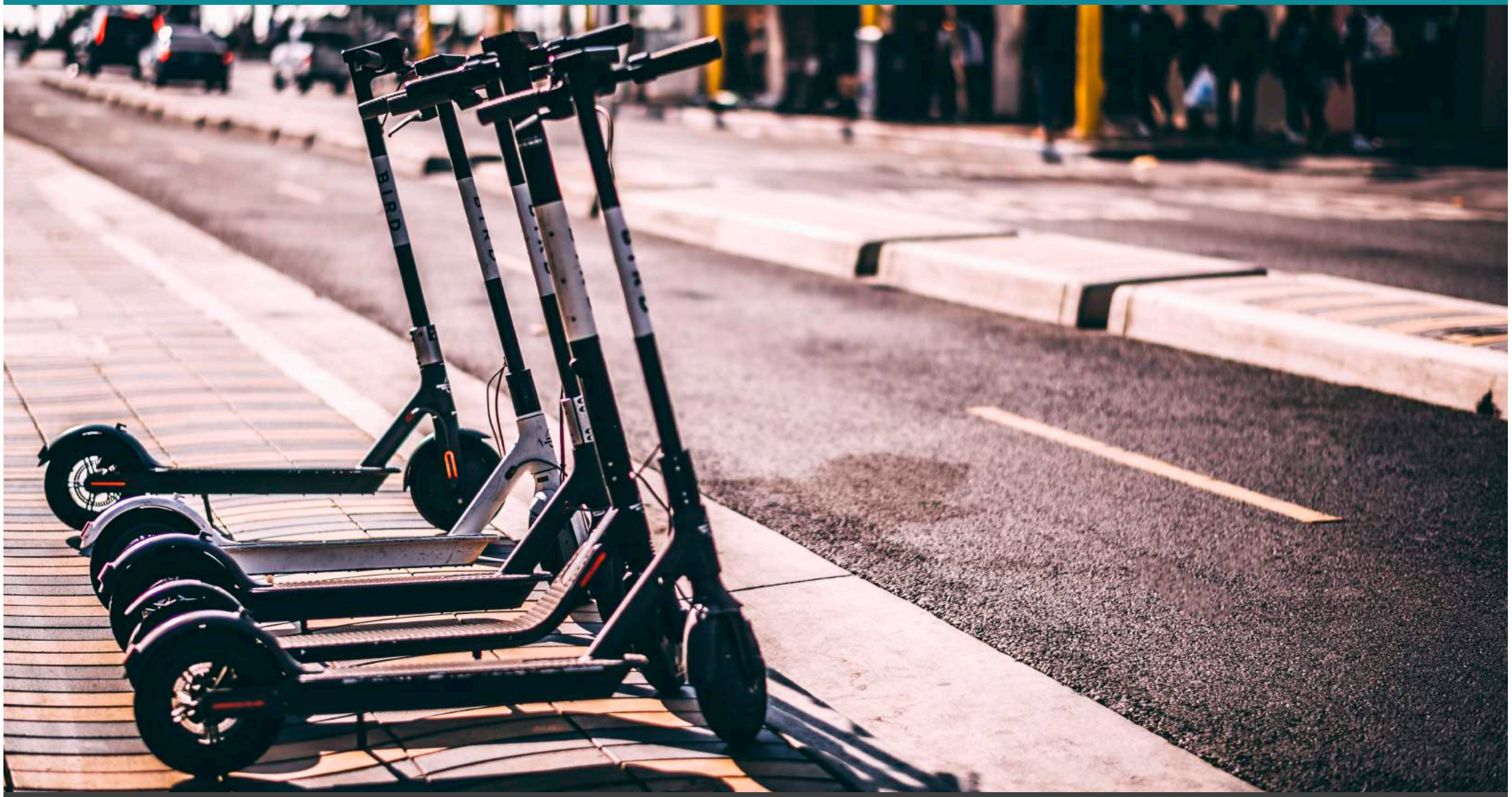
Autonomous buses, shuttles and new mobility solutions to fill transport gaps are introduced. Security, flexibility, reach, interconnectivity and funding are the primary issues for many cities.

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.

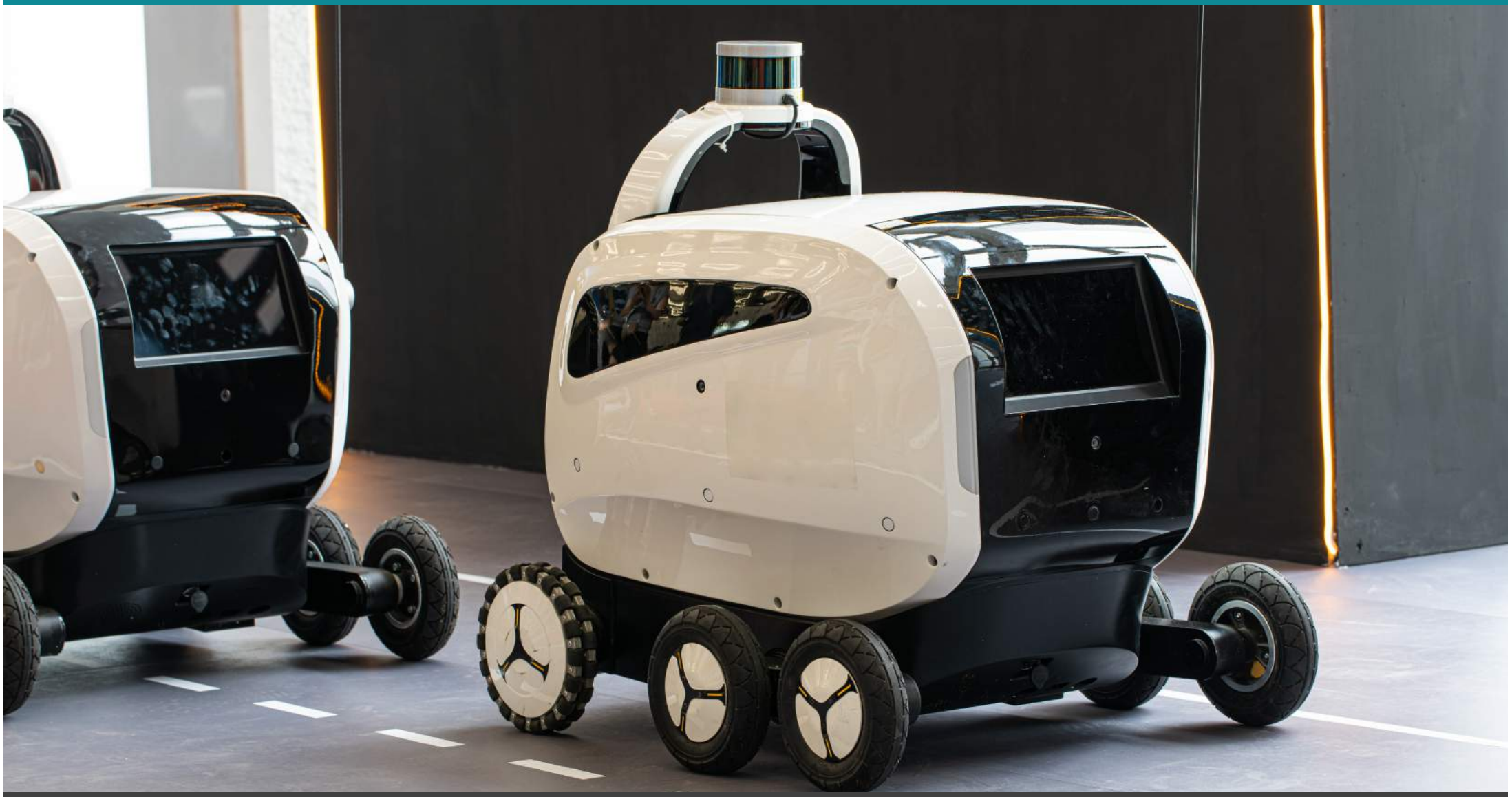
Air Taxis

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.

Goods Transport

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 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 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

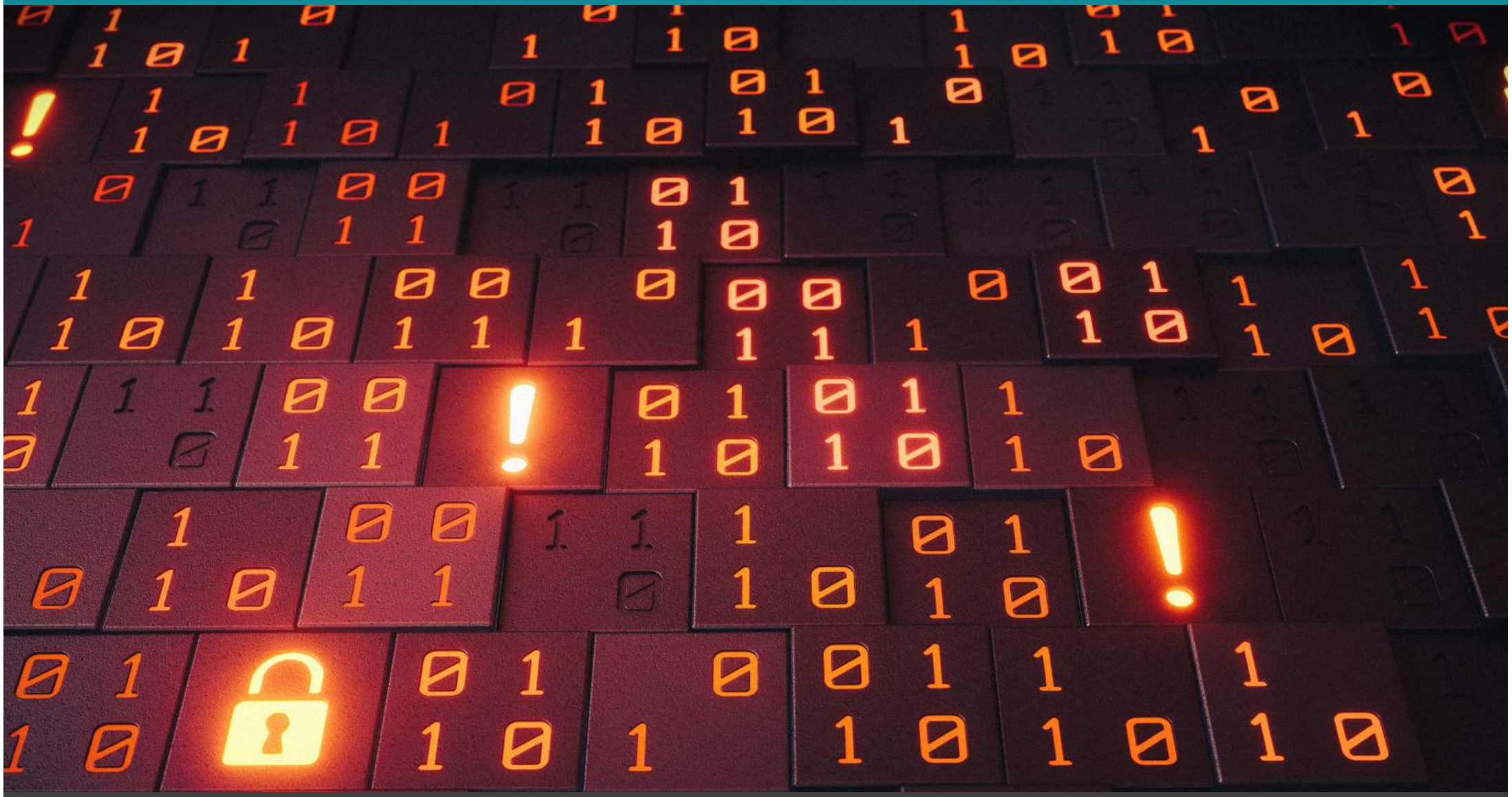
Automation within controlled environments continues to expand steadily.
AVs within airports, port terminals and logistics facilities start to venture onto the open road.

FUTURE AGENDA

Data and Security

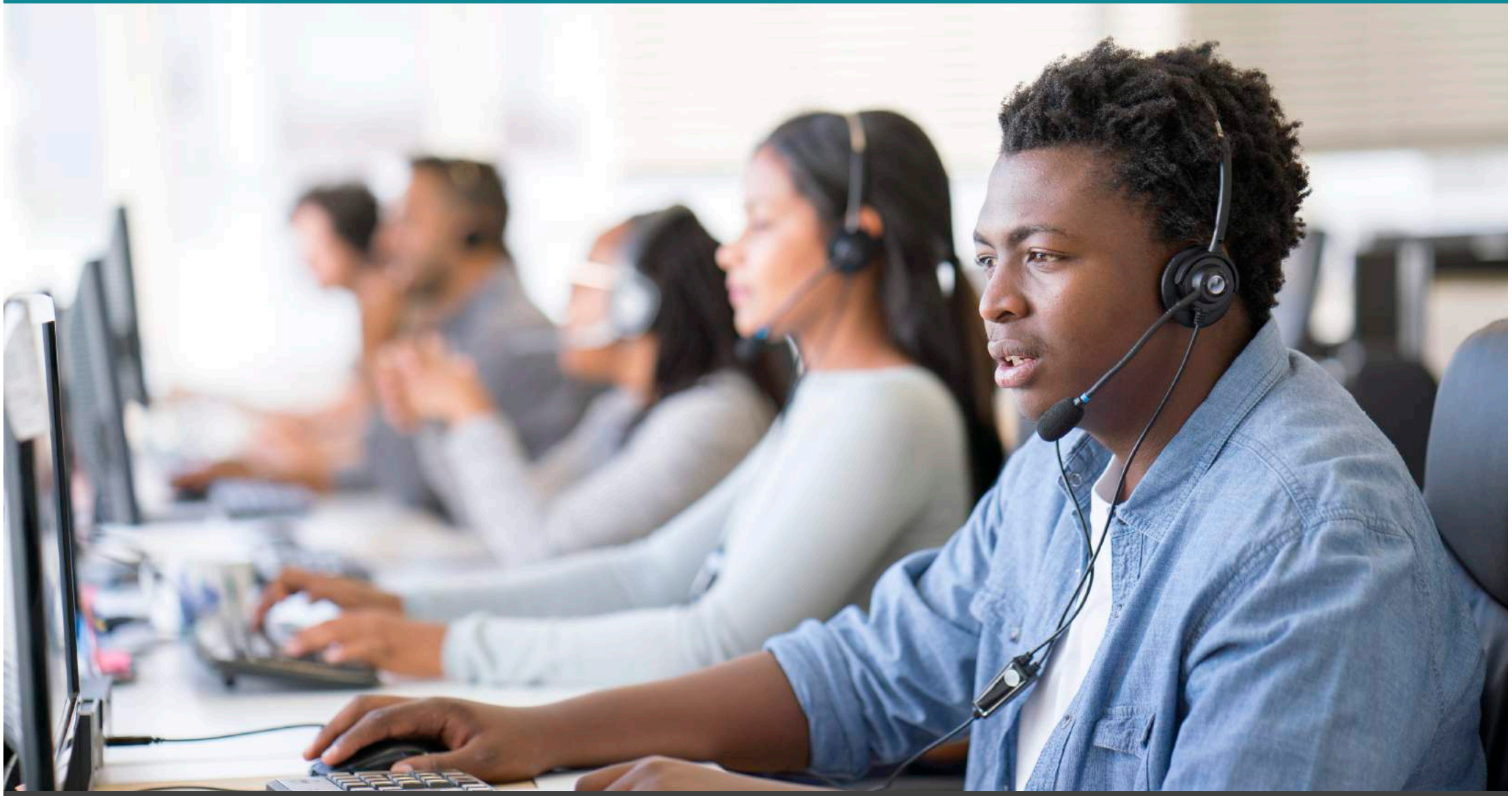
Data Sharing

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.

CONCLUSIONS

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.

Nine Thoughts

We can see nine core issues as significant for the next decade. All are intricately inter-connected but collectively define the highly 'wicked' problem to address.

MORE INFORMATION

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More Information

If you would like additional details on this project, how it was undertaken or any of the insights shared in this report, please contact either of the authors.

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