International Trends in 4IR Mobility

October 2020

FUTURE CITIES SA

Funded by

UK Government

In association with

Joburg

a world class African city

pwc

FOREWORD BY FCDO

The world faces a number of linked challenges: rapid urbanisation; rising urban inequalities and poverty; climate change and natural resource depletion. Sustainable design and management of cities is vital to efficient, durable urban growth and development. Albert Einstein said: “We cannot solve our problems with the same level of thinking that created them”. So in the spirit of looking at the challenge through a different lens, the UK identified the need to support the growth of smart cities through the global Future Cities programme. It was officially launched in South Africa in February 2020, working with 3 partner cities: Cape Town, Johannesburg and eThekwini/Durban.

This programme helps deliver against the UK’s commitments to support implementation of the UN’s Sustainable Development Goals (SDG), most notably SDG 11 to “make cities and human settlements inclusive, safe, resilient, and sustainable” and SDG 9 to “Build resilient infrastructure”. And it supports further our commitment to a clean, resilient & inclusive recovery in a post-Covid world.

We are proud of the vibrancy and dynamism of UK industry and see it as a key driver for innovation. We work closely with the private sector to unlock private and public investment in energy, infrastructure and urban development in order to drive the positive change we want to see.

The Future Cities programme is about: “*An approach to planning the growth of cities that increases levels of productivity, generates sustainable wealth, helps alleviate poverty, addresses gender inequality, increases quality of life for all societal groups, allows more people to live in an existing urban area, improves resilience, minimises any negative impacts on the environment and proactively involves the city’s citizens and businesses in the process. Future cities are innovative, sustainable and utilise technology in a smart way”*.

Practically, in South Africa this means partnering with the City of Johannesburg to build capacity to assess smart technology and data to create an integrated and inclusive transportation systems. This starts by understanding how citizens’ move around the city to inform urban policy and decision-making. The Fourth Industrial Revolution offers a unique opportunity to gather and analyse huge quantities of data in order to guide that understanding, enabling policy-makers to base their decisions on what is actually happening now, rather than extrapolations of what we believed was happening historically. Getting this right will stimulate inclusive economic growth, supporting gender equality and social inclusion. In order to get it right we need to ask the right questions, gather the right data, interrogate it carefully and overlay it against other data sets e.g. geography, to ensure that the solutions we develop tactically respond to challenges borne out of specific social, cultural, technological, and environmental landscapes.

In the urban development sector, the rapid advancement in smart technologies, big data and machine learning in the past decade has generated enormous interest and investment by public and private sector to develop mobility solutions that improve access to job opportunities, recreation and housing.

This comprehensive report offers an analytical perspective on the current international trends in 4IR for the future of mobility, and aims to disseminate the lessons to government institutions, policymakers and innovators alike.

British
High Commission
Pretoria

Nick Latta
Prosperity Counsellor
British High Commission, Pretoria, South Africa

FOREWORD BY FCSA

The Fourth Industrial Revolution – driven by a range of emerging technologies, from artificial intelligence to blockchain, from the Internet of Things to robotics – is fundamentally changing life as we know it. No geography or industry has proven immune to the unique fusion of digital, physical and biological forces that characterise this era of rapid technological change. The mobility sector is no exception.

As we entered the 2020s, and even before the COVID-19 pandemic took hold globally, mobility systems were becoming increasingly tech-enabled. Automation is on the rise, with the global autonomous vehicle market expected to grow at an annual rate of almost 40% until 2026.[1] Mobility systems are becoming increasingly connected and able to communicate with one another, with over 75 billion connected devices expected worldwide by 2025, within vehicles, infrastructure and mobile devices.[2] In parallel, the global drive for sustainability is encouraging the electrification of transport, while the desire for on-demand mobility has given rise to a growing number of shared transport options, often accessed via smartphone.

The COVID-19 pandemic has not only highlighted the need for responsive, tech-enabled transport systems, but has accelerated digitisation trends and the broader uptake of 4IR technologies. Cities worldwide have extended their ride-sharing schemes; e-mobility programmes have been introduced to allow better social distancing, and a stark rise in remote working has catalysed increased use of AR and VR technologies, to connect people virtually. Now more than ever, city governments not only have an opportunity, but a responsibility, to step up their game and begin unlocking the benefits of the 4IR. The pace and scale of change we are witnessing suggests that inaction is not an option.

As Cities and regions explore the range of future technology options, it is important to understand the key emerging mobility trends worldwide, and to consider how these would play out in a local context. This report is a first step towards reimagining what Cities' mobility systems could offer, in pursuit of economic, social and environmental goals that are unique to each place. Mobility within cities is not just about getting from A-to-B. It is about granting individuals access to employment opportunities, regardless of where they live in the urban area. It is about ensuring inclusive, safe and affordable travel for the most vulnerable, despite age, race or gender. It is about sustaining a thriving and connected community without having an adverse effect on the environment.

Based on research conducted in June 2020, the international case studies identified within this report take these place-based intricacies into account and aim to reveal the art of the possible amidst the ever present 4IR. These mobility trends and examples seek to spark critical conversations among city stakeholders around what 4IR means for their cities, and encourages thinking about what the key interventions to transform mobility systems worldwide could be.

The onus is now on cities' governing bodies, and their partners, to embrace the tech-driven transformation we are witnessing and to implement technologies that will enhance service delivery for *all* users. To push the boundaries on what a safe and agile mobility system can achieve.

We hope that these trends and insights will prove to be a valuable contribution for Governments, Councils, City Mayors, as any decision makers consider the future of their own transport systems in these uncertain times.

Ben Combes
Assistant Director
PwC UK

REPORT AUTHORS

Ben Combes

Ben Combes is an Assistant Director at PwC UK and a Senior Economist in the Sustainability & Climate Change team. He is co-founder of PwC UK's Innovation & Sustainability practice, working on tech for good projects, including AI for Earth with Microsoft and 4IR for the Global Goals with the World Economic Forum. He is also an expert adviser to PwC UK's Net Zero leadership team and works with clients on climate tech and their net zero transformation strategies.

Outside PwC UK, Ben is an Advisory Board Member to the UK Parliament's All-Party Parliamentary Climate Change Group, a member of techUK's Climate Strategy and Resilience Council, and a Visiting Senior Fellow of the Grantham Research Institute on Climate Change and the Environment at the London School of Economics.

Frankie Howland

Frankie is a Senior Associate in PwC UK's Sustainability & Climate Change team, covering areas of Technology, Innovation and Urbanisation. Having worked within the firm's Disruption practice, Frankie is experienced in delivering advisory work for public and private sector clients, with a focus on helping them understand future risks and opportunities associated with advances in emerging technologies and other global megatrends. Frankie has organised and supported a number stakeholder engagement workshops, with particular expertise in the planning and facilitation of future-facing 'disruption' and place-based workshops.

Frankie is currently working with the FCDO on the Future Cities South Africa programme, exploring the potential of 4IR mobility in Johannesburg's transport system, as well as leading the Firm's collaboration with the World Economic Forum on their agenda to mobilise technology towards environmental and social good.

Nina Nasman

Nina is an economist and urban development consultant focused on innovation, inclusive 'smart cities' and urban digital solutions, with over eight years of technical and project management experience in international development, communications and business journalism. Nina was lead author of a report on 'Harnessing the Fourth Industrial Revolution for Sustainable Emerging Cities', in collaboration with the World Economic Forum, as well as on 'Cleantech Cities: Accelerating Climate Action Through Startups and Corporate Innovation', in collaboration with C40 Cities and the Los Angeles Cleantech Incubator.

Monica Zolczer

Monica is a management consultant focused on sustainability and innovation at PwC UK. Her focus areas are international development and transport mobility, with a strong focus on harnessing the 4IR for smart emerging cities. She has worked on a variety of Cities & Urbanisation projects, providing technical assistance to national and local governments. Highlights include the ICED Facility in which Monica co-designed the theory of change model in the China Future Cities Programme Scoping and Design report. She is currently working on Future Cities South Africa as the Programme Officer and 4IR mobility analyst. Her interest in leveraging innovation to address the global climate crisis underpins her position as the AI for Good Driver at PwC UK.

CONTRIBUTORS

Lead authors

Ben Combes (PwC UK), Frankie Howland (PwC UK), Nina Nasman (PwC UK), Monica Zolczer (PwC UK)

FCSA team

Jodi Allemeier (PwC ZA), Dom Boyle (PwC UK), Helen Chorlton (PwC ZA), Justin Coetzee (GoMetro), Mirjam van Donk (Isandla Institute), Roland Hunter (Independent), Michael Kihato (Independent), Ian Milborrow (PwC UK), Nishendra Moodley (Independent), Johan Muller (GoMetro), Kim Nair (PwC ZA), Jon Williams (PwC ZA), Wessel van Wyk (PwC ZA)

City of Johannesburg team

Daisy Dwango (CoJ), Bambhatha Hlubi (CoJ), Esther Letlhaka (CoJ), Philiswe Mbambo (CoJ), Jeff Ngcobo (CoJ)

TABLE OF CONTENTS

ACRONYMS

Acronym	Description
$	United States Dollar, unless otherwise specified
3IR	Third Industrial Revolution
4IR	Fourth Industrial Revolution
AEV	Autonomous electric vehicle
AI	Artificial intelligence
APC	Automatic passenger counting
AR	Augmented reality
AV	Autonomous vehicle
AVL	Automatic vehicle location
BRT	Bus rapid transit
C&E	Climate & environment
EU	European Union
EV	Electric vehicle
G&SI	Gender & social inclusion
GDPR	The General Data Protection Regulation 2016/679
GHG	Greenhouse gas
GPS	Global positioning systems
GTFS	General transit feed specification
ICT	Information and communication technology
IoT	Internet of Things
ISO	International Organization for Standardization
ITS	Intelligent transport system
LiDAR	Light detection and ranging

MaaS	Mobility as a service
OECD	Organisation for Economic Cooperation and Development
PPP	Public-private partnership
R&D	Research & development
RFID	Radio-frequency identification
SDG	Sustainable Development Goal
SME	Small and medium enterprises
STEAM	Science, technology, engineering, arts and mathematics
STEM	Science, technology, engineering and mathematics
UAV	Unmanned aerial vehicle, *also referred to as unmanned aircraft systems (UASs) or drones*
UN	United Nations
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
VR	Virtual reality
WEF	World Economic Forum
WHO	World Health Organization

EXECUTIVE SUMMARY

How we live, work, move and experience the world around us is rapidly changing. A range of physical, digital and biological forces are shaping the Fourth Industrial Revolution (4IR), not only characterised by global connectivity, ever present digitalisation and burgeoning data, but also an accelerated pace of change with the introduction of new technologies from artificial intelligence (AI) and blockchain to the Internet of Things (IoT).

Appropriate 4IR technologies have the potential to transform daily travel for millions of city-dwellers as well as address supply chain inefficiencies, contributing both to inclusion and productivity. As with the interconnected nature of 4IR, change is required in several spheres and across various stakeholders to overcome risks and challenges associated with new technologies – whether related to digital exclusion, privacy issues or the impact on jobs.

This report explores what 4IR means for the future of mobility and how it is shaping the business-as-usual of passenger transport, freight and other forms of mobility. Based on research conducted in June 2020, it aims to develop a shared understanding of the global 4IR mobility landscape and what this may mean for cities across the world.

Mobility is becoming more automated and autonomous, integrated and connected, electrified and shared. These broad trends interact with each other and the global megatrends, such as rapid urbanisation and recently, the COVID-19 crisis, prompting the need for new forms of governance and regulation to match the pace of technological change and manage impacts on marginalised groups, climate and environment. Emerging 4IR applications in mobility demonstrate the sector's innovation potential and we identify five high-impact areas that are set to be disrupted. These are:

1	2	3	4	5
The passenger journey: integrated ticketing, digital payments and route planning	**City planning and infrastructure:** test labs, spatial planning and predictive maintenance	**Data-driven mobility:** big data analysis, integrated and intelligent transport systems	**Safety and inclusion:** road safety, accessibility and gender inclusivity	**Delivery and distribution:** distribution and sorting centres, freight and last mile delivery

Creating a conducive enabling environment for the development and application of 4IR innovations in mobility, while managing and mitigating the risks that arise, is critical. This report also looks at four areas of implementing 4IR in mobility – namely the financing and procurement of necessary infrastructure and technology, upskilling and expansion of digital capabilities, agile governance and setting appropriate policies and regulation, and building wide-ranging partnerships. While there are few 'plug and play' options currently available, given solutions will be context-dependent, looking at the experiences of and tools used by cities around the world can help address some of the challenges of 4IR mobility implementation.

Cities play several, important roles in 4IR mobility, as regulator and policymaker, financier and investor in the ecosystem, open-access partner, stimulator of the modal shift and in some cases the user. While the pace of change and required investment may seem daunting, this report highlights three considerations, given many of the applications presented are only just reaching widespread deployment, and thinking around good practice will continue to evolve.

Context matters: Ultimately, each city needs to decide which technological innovations can enhance its overall developmental agenda and how to identify and mitigate potentially negative impacts of these innovations and platforms.

Process of change: Whichever mobility innovations are chosen for implementation, the process will require a willingness from cities to be more agile and adaptive in governance, policymaking and regulation, and accept that failures and missteps are part of testing.

Empowering transformation: Successful 4IR mobility draws on wide-ranging partnerships and creates a sense of ownership among stakeholders, while building trust and skills for 4IR readiness will help mitigate the very real risks around exclusion and the digital divide.

1. INTRODUCTION

We are surrounded by an ever-growing number of creative innovations in mobility, enabled by the Fourth Industrial Revolution (4IR). The 4IR is allowing people and goods to move, or indeed be moved, within and between spaces with greater choice and ease than ever before. Yet the success of such innovations will depend on the careful and considered integration of these 'new mobilities' into the existing landscape of urban mobility and change, both locally and globally. This section sets out the purpose and structure of this report, and gives an introduction to 4IR technologies and the wider context of global megatrends.

1.1 Purpose and structure of report

This report explores what 4IR means for the future of urban mobility and how it is shaping business-as-usual. Through investigating a range of key 4IR trends, international applications and lessons on implementation, **this report aims to develop a shared understanding of the global 4IR mobility landscape** and what this may mean for cities across the world. Importantly, the report will not only consider innovations that may be within reach in the coming years, but also look ambitiously at what may be possible in the future.

Of course, context is crucial, and while this report seeks to showcase examples from both the developed and the developing world, there are no 'plug-and-play' solutions that will directly be replicable in any given city. Moreover, the global COVID-19 pandemic has largely been an accelerant of many 4IR trends, which are continuing to alter patterns of mobility, and will be touched upon in this report, alongside potential impacts on and links to gender and social inclusion (G&SI) and climate and environment (C&E).

The report is structured as follows:

Section 2 looks at **international trends** at the intersection of 4IR and mobility, focusing on five thematic trends: (1) The rise of automation; (2) Intelligent and connected systems; (3) Electrification for greener transport; (4) The sharing economy; and (5) A responsive and evolving enabling environment.

Section 3 presents specific **innovation case studies** where 4IR mobility is changing how cities' transport systems operate, uncovering their potential. These are grouped under five application areas: (1) The passenger journey; (2) City planning and infrastructure; (3) Data-driven mobility; (4) Safety and inclusion; and (5) Distribution and delivery.

Section 4 explores the practicalities and intricacies of how cities create an enabling environment for innovation and facilitate **the implementation of 4IR mobility**, including financing, upskilling, adaptive governance and partnering.

Section 5 summarises the report's **key messages and learnings** for how cities can move towards harnessing similar innovations.

1.2 Introduction to 4IR

What is meant by 4IR?

Life as we know it is continuously and rapidly changing, with no geography or industry immune to the unique fusion of digital, physical and biological forces that comprise the 4IR. Coined by the *World Economic Forum* (*WEF*) in 2015, the 4IR builds on the 3IR digital revolution of the late-1990s and early-2000s. This current revolution is not only characterised by global connectivity, ever present digitalisation and data, but an **accelerated pace of change**. The speed of 4IR break-throughs has no historical precedent in previous revolutions, evolving at an exponential rather than a linear pace.[3] Across almost every industry, every country, this rapid change is heralding the transformation of entire production, management and governance systems. With 4IR technologies able to deliver complex outputs faster and with fewer inputs than before, they are shaping how we live, work and experience the world. Inaction to this wave of change is simply not an option.

Megatrends

The 4IR is driven by a coalescence of interconnected and interdependent global megatrends: a number of global shifts which are not only reshaping the world we live in, but demanding that we respond to them with pace, innovation and rigour.

Owing to **rapid urbanisation**, a high proportion of global population growth is now taking place in cities. The UN projects that urban areas will be home to 60% of the world's population by 2030, and that the developing world will account for up to 95% of this urban expansion in the coming decades.[4] In established cities, infrastructure will be strained to its limits – and beyond – as populations expand, while developing economies will need to factor burgeoning urban populations into city planning from the outset. This will demand careful consideration of how existing infrastructure is developed, adapted and retrofitted to suit the needs of a growing population.

This population growth is by no means consistent or uniform across the globe, with different geographies experiencing varying forms of **demographic and social change**, from large youth to increasingly ageing populations. We are also seeing a rise of social upheavals across cities. These changes will affect the size of workforces, introduce new consumer markets, and reshape demand for housing, transport, education and other services. Again, infrastructure change will be required to meet evolving capacity and service needs.

Given the net population growth globally, the world is now in the midst of a new era where human beings are the primary agent of global change – the Anthropocene. This age is characterised by **climate change and resource scarcity**, introducing challenges such as shifting weather patterns, rising sea levels, depleting water resources and energy shortages – as well as making pandemics, like the COVID-19 crisis, more probable. These characteristics are fundamentally transforming business-as-usual across the globe, with a heightened focus on the 'clean' and 'green' aspects of production, consumption, development and growth.

Tying the above together is the proliferation of **technological breakthroughs**, which both enable and accelerate change. Yet access to (affordable) data and technology is still highly unequal and exclusionary, risking to leave populations behind that are unable to keep up with this exponential pace of technological change. Below, we explore specific technologies leading this charge.

Given broader **shifts in economic and political power** from Western nations, emerging markets such as the 'BRICS' (Brazil, Russia, India, China and South Africa) may also be some of the firstmovers in applying new 4IR innovations. If developing nations are able to establish the necessary regulations and business infrastructure, progress the upskilling agenda and harness the right investments, they position themselves well to follow these emerging markets to 'leapfrog' developed markets in leveraging 4IR technologies.[5]

Emerging 4IR technologies

A suite of digital, physical and biological innovations are shaping the 4IR response to challenges posed by these megatrends; many already show promise at reshaping urban transport networks, and change will only accelerate over the coming years. Ranging from Artificial Intelligence (AI) to Robotics, Virtual Reality to Drones, technologies of the 4IR are complementary and even interdependent – definitions are provided in Figure 1 below for innovations related to the disruption of urban mobility. How these technologies interact with one another in the mobility sphere, as well as with other trends, will be explored in the next section.

Figure 1: Emerging 4IR technologies relevant to the mobility sector[6]

Artificial Intelligence (AI)

Software algorithms that are capable of performing tasks that normally require human intelligence, e.g. visual perception, speech recognition and decision-making.

Augmented & Virtual Reality (AR & VR)

Computer-generated simulation of a three-dimensional image overlaid to the physical world (AR) or a complete environment (VR).

3D Printing

Additive manufacturing techniques used to create three-dimensional objects based on 'printing' successive layers of materials.

Blockchain

Distributed electronic ledger that uses software algorithms to record and confirm transactions with reliability and anonymity.

Autonomous Vehicles (AVs) & Drones

Enabled by robots these are vehicles that can operate and navigate with little or no human control. Drones fly or move without a pilot and can also operate autonomously.

Internet of Things (IoT)

Network of objects embedded with sensors, software, network connectivity and computer capability, that can collect and exchange data over the internet and enable smart solutions.

Energy Capture & Storage

Ranging from advanced battery technologies through to intelligent virtual grids, organic solar cells, spray-on solar, liquid biofuels for electricity generation and transport, and nuclear fusion.

Computing Technologies

Technologies such as quantum computing can be combined with big data, cloud services, IoT and sensors, to perform large-scale computation at greater speed and complexity than traditional computing approaches.

Robotics

Electro-mechanical machines or virtual agents that automate, augment, or assist human activities, autonomously or according to set instructions.

Advanced Materials

Science technologies, which produce materials with new and improved functionality, in terms of strength, weight, conductivity and electrical storage ability.

2. INTERNATIONAL TRENDS IN 4IR MOBILITY

Innovations of the 4IR are set to revolutionise how people travel and goods are transported around the world, or eliminate the need entirely.[7] Promising both disruption and opportunity, '4IR mobility' refers both to how mobility systems can respond and adapt to the 4IR trends shaping them. This term also covers how 4IR technologies can optimise and enhance new and existing mobility networks at the city, national and international levels, helping them become more efficient and sustainable. This section introduces 4IR in mobility and explores five key trends shaping it today.

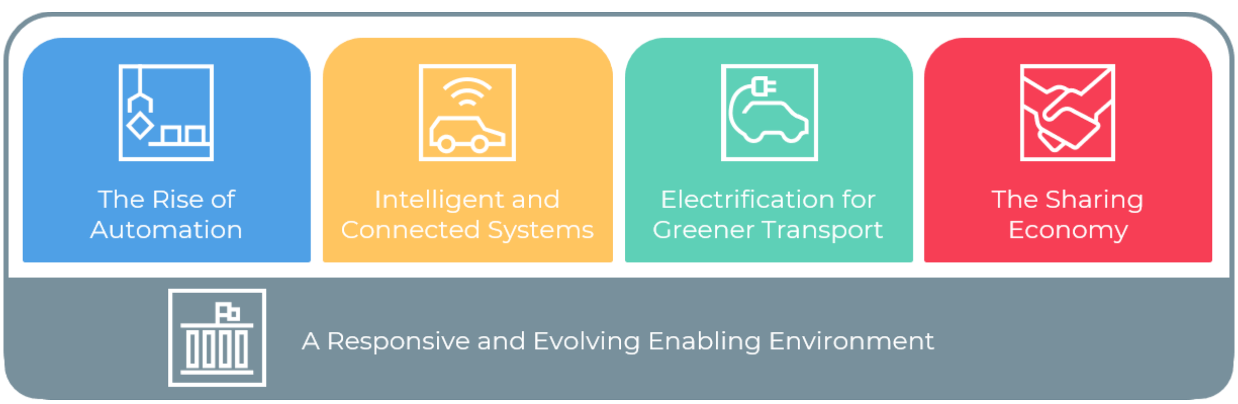
2.1 Bringing 4IR into mobility

Emerging 4IR applications in mobility demonstrate the sector's innovation potential. Examples include the rising number of mobile-based travel apps, leveraging AI and blockchain to allow consumers access to unified payment systems, and interfaces for booking different modes of transport. The deployment of autonomous and unmanned vehicles, including drones, to distribute freight and assist in last-mile deliveries has the potential to speed up distribution processes whilst reducing road traffic and resultant pollution. Meanwhile, combinations of AI, IoT and smart sensors are being rolled out across various urban transport systems to collect real-time congestion data, update traffic signals, and regulate traffic flows. These data-informed, automated decisions have the ability to reduce passenger delay rates, increase public transport use and reduce congestion.

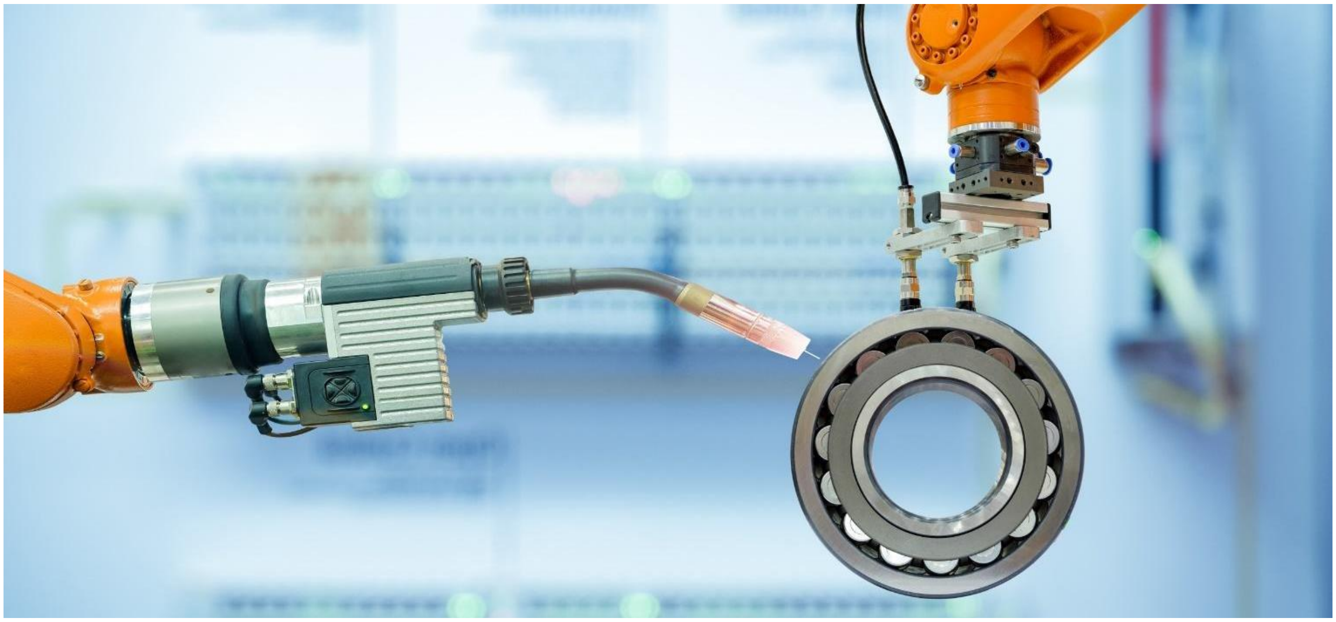
Global trends and local factors set the context for 4IR mobility considerations. Mounting pressures on transport infrastructure cannot necessarily be solved by simply extending existing networks or increasing fleet frequency. New, innovative approaches are needed to address challenges such as travel demand management, inequalities in access and higher variations in peak travel times. The incorporation of climate change considerations into mobility planning is also urgently needed; transport represents over 20% of global CO_2 emissions, a figure projected to rise significantly by 2050.[8] Transitioning existing transport modes to renewable energy or optimising platforms for shared mobility to reduce private vehicle use are just some of the options.

This section provides an overview of five key trends that have dominated the international mobility sector in recent years, based on our desk-based review. These trends, presented in Figure 2, are inextricably linked and need to be considered in parallel. Each subsection opens with a 'what if?' vision statement to help readers envisage mobility in the future and turn hypothetical scenarios into realistic concepts, followed by an explanation and discussion of the trend and its impact.

Figure 2: Five interlinked global trends in 4IR mobility



2.2 The rise of automation



What if?

Imagine a world where you could enter the destination of your journey into a vehicle's satellite navigation system and then sit back, close your eyes and sleep until the car alerted you of your arrival. If no parking spaces are available, the car drives itself back to your driveway, or any other location, and returns to collect you at the end of the day. On your trip home, you decide to order dinner for the family which will be dropped off in front of your door by drone.

What does this mean?

'Autonomy' is the capability to operate without direct human control. When applying this innovation to mobility specifically, 'autonomous' vehicles (AVs) refer to ones that are **intelligent and self-driving**. Features enabling driverless mobility include video cameras, radar sensors, laser scanners, ultrasonic sensors, mapping, infrared cameras, Light Detection and Ranging (LiDAR)[9] and differential GPS. Using deep learning techniques, terrestrial autonomous vehicles (AVs) are taught, amongst other things, to abide by the highway code, demonstrate lane discipline and maintain control during emergencies.

The level of automation for AVs varies between no, partial and full automation.[10] By definition, drones are not yet fully autonomous as they still require an operator to supervise their flight paths, and are therefore described as 'automated'.

Opportunities	Challenges
Terrestrial AVs	
• Optimisation of traffic flows, thereby reducing congestion and saving fuel; • Safer and more efficient transport; • Convenience for drivers; • Improved accessibility for vulnerable groups and those unable to drive; • Less land required for car parks, which could be repurposed; • Unlocks commuter time.	• High cost of AV technology; • Possibility of increased congestion, longer travel durations and GHG emissions; • Liability, insurance and regulation issues; • Impact on employment in mobility services and automotive manufacturing; • Customisation to local conditions; • Relies upon positive public perception and trust in AI.[11]
Unmanned Aerial Vehicles	
• Cost effectiveness;[12] • Less congestion on roadways, improving air quality and reducing stress on roads; • High speeds (benefit for emergency response and disaster relief teams); • Ability to reach remote or post-disaster districts.	• Requires regulation around airspace, insurance and privacy; • Necessity of drone landing mats or pads, akin to helipads; • Costs associated with drone delivery stations, computers and monitoring software, and engineers for maintenance and upgrades.

What are the current trends?

AVs are largely still in the trial phase, but some early pilots have been deployed across the globe. From October 2017 to November 2019, *Bloomberg Philanthropies* catalogued 136 cities worldwide piloting and developing policy for the transition towards AVs.[13] One estimate claims that 18 million new AVs (24% of global car sales in 2019)[14] will enter the global automotive industry by 2030 bringing with them unprecedented change to personal and public mobility.[15] The **uptake of AVs is predicted to occur incrementally**, with cars of levels 1-3 autonomy appearing on roads and highways in the near future, while vehicles with levels 4-5 autonomy will likely emerge in the latter half of the decade, due to higher technological costs and regulatory issues.[16] Once these barriers to entry are overcome, up to 15% of new cars sold in 2030 could be fully autonomous.[17]

This movement toward AV uptake is also reflected across **train- and bus-based forms of transport**, with their respective global autonomous markets expected to grow by 13%[18] and 30%[19] year-on-year. In fact, *NAVYA* autonomous shuttle buses have been operating in Japan since 2018,[20] while Dubai recently announced its plan to implement self-driving sky pods across 50km of the city's busiest districts.[21] A number of important challenges must be considered alongside the integration of automated and autonomous technologies, including the risk of job losses, increased demand for upskilling, and the potential for exclusion if access is not equitable for all citizens.

2.3 Intelligent and connected systems

What if?

Imagine your car, bicycle or scooter was conscious of all road closures and traffic jams on your usual morning commute. When congestion is high, your vehicle suggests an alternative, faster route and presents options for public transportation by projecting ‘5th screen’[22] content on the windscreen using AR. The voice-enabled virtual personal assistant integrated in your vehicle allows you to verbally select your route of choice, without taking your hands off the wheel. Your journey is free of delays as all vehicles and road users' smartphones communicate with one other, preventing traffic accidents and congestion.

What does this mean?

‘Intelligent and connected’ refers to the ability to **communicate and share data with other systems** – over 75 billion connected devices worldwide are expected by 2025.[23] In the mobility sphere, intelligence and connectedness includes networking with other vehicles (V2V), the transport infrastructure (V2I), such as traffic lights, or other road users (V2X), such as pedestrians and cyclists. For example, V2V communications would warn a vehicle of another one suddenly braking, while a V2X application might detect a cyclist in the driver’s blind spot. Intelligent transport systems (ITS), which leverage V2I networking, are seen as crucial for efficient AVs and city management of mobility to reduce congestion on roadways by limiting stationary vehicles and stop-start driving. Additionally, as fast-moving vehicles produce less pollution than slow-moving ones, efficient traffic management can reduce air pollution in cities through reduced congestion.

Intelligent and connected vehicles

Opportunities

- Predictive navigation can optimise traffic flows, reducing congestion, air pollution and travel times;
- Improved quality of life as mobility becomes less stressful;
- Real-time reporting on maintenance needs for road and infrastructure; and
- Fewer road accidents.

Challenges

- Little potential for suppliers to make revenue directly;
- Limited 4G and 5G coverage on roads;
- Investment in infrastructure to enable V2I communication; and
- Regulation requirements, such as geo-data privacy.

What are the current trends?

The spread of 5G will encourage sales of connected cars, at an earlier stage and greater pace when compared to AVs; this figure is expected to reach 16 million in the EU, USA and China by 2030. As technology continues to shift towards **5G readiness and adoption**, it is estimated that around 70% of new cars will be 5G-connected in the USA by 2030.[24] Vehicular connected services will include in-vehicle voice assistants to improve user experience and commerce platforms to provide revenue for merchants, advertisers and local businesses. Meanwhile, network operators and urban planners will collaborate to **retrofit existing road infrastructure** and deploy new connected technology, such as smart lampposts.[25] Technological readiness drives customer demand, but technology alone cannot guarantee penetration in the automotive market – regulation, including of 5G, will play a key role in defining which technological component, or trend, reaches uptake first.

2.4 Electrification for greener transport

What if?

Imagine a life where the concept of a petrol station was obsolete, replaced by busy charging stations and on-street residential charging points for all-electric vehicles. In this vision, all modes of transport – including trams, trucks, cars, trains, container barges, and airplanes – are powered by self-contained energy storage devices such as lithium-ion batteries. Global greenhouse gas (GHG) emissions in the mobility sector have reached a historical low, while concerns of air pollution and smog in urban areas are a distant memory.

What does this mean?

An electric vehicle (EV) is powered by one or more electric motors, using **energy from rechargeable batteries, solar panels, or electric generators to convert fuel to electricity**. The term 'EV' is often used to refer to plug-in electric cars, such as *Tesla*'s automobiles, but the term also includes electric trucks, maglev trains, electric aircrafts and trams, as well as e-bikes and e-scooters. By definition, all-electric drive vehicles do not consume petrol or diesel fuel. The GHG emissions of EVs are, instead, related to the power generation source of electricity which could be renewable, such as wind and solar, or fossil fuel-based, such as coal and gas.

All-electric vehicles in sustainable emerging cities

Opportunities	Challenges
• Reduction of transport emissions and associated improved air quality; • Renewable energy sources can enable	• Cost of and sparse charging infrastructure; • Capability of national grid networks to meet electricity demand;

the sector to achieve net zero emissions;
- Less noise pollution;
- Fuelling and maintenance will likely cost less over the course of ownership;[26]
- EVs could be used as decentralised energy resources;[27]
- Reduced reliance on oil reserve purchases in a foreign currency, and;
- Applicable to freight, public transport and personal mobility.

- Convention of petrol stations;
- Political concerns around facilitating decline of fossil fuels;
- Requires regulation and subsidies to encourage the purchase of EVs, and;
- Cost of buying and running an EV largely depends on local context e.g. government grants, duty exemptions, public charge points.

What are the current trends?

EV sales are being boosted by a confluence of factors including: advancements in battery technology; improved charging infrastructure; consumer preference for sustainability, and; a strong legislative push internationally to improve air quality in cities. Estimates claim that around 40% of new car registrations will be electric in the EU, and 46% in China, by 2030.[28] Increased **government incentives** for plug-in EVs to address affordability concerns could inflate these figures further. In Japan, the subsidy for purchasing an EV, without scrapping a used car, is 100,000 yen (~$950) for a standard or small car.[29] **Electric buses, trains and trucks** are similarly on the rise as a smart, sustainable option for public transport and freight. Companies such as *Local Motors* are piloting autonomous electric shuttles in neighbourhoods, campuses and city centres,[30] whilst zero-emissions maglev trains in East Asia are revolutionising the speed of intercity travel.[31]

Insufficient domestic, commercial and public **charging infrastructure** is the largest barrier to uptake. Automotive manufacturers are addressing this issue by installing charging infrastructure on well-travelled routes. Currently, *Tesla* has installed 1,870 Supercharger Stations with 16,585 Superchargers in North America, Europe, Asia and the Middle East,[32] while *BMW* has rolled out its *ChargeNow* EV charging infrastructure in countries such as South Africa, Botswana and Namibia.[33] Centralised regulation to promote flexible charging could also help 60% more EVs to be charged.[34]

C&E focus: EVs can reduce outdoor air pollution and improve public health

Ambient air pollution is a major environmental risk to health. In 2016, around 91% of the world's population was living in areas where the *World Health Organization* (*WHO*) air quality guideline levels were not met.[35] Policies and investments supporting cleaner transport would address a key source of outdoor air pollution and improve cardiovascular and respiratory health. The UN Clean Air Initiative, announced in 2019, calls on national and regional governments to commit to achieving air quality that is safe for citizens and to align a related policy response by 2030.[36] Through reduced air pollution alone, regulation could contribute to SDG 3 on good health and wellbeing, target 11.2 for access to sustainable transport, target 11.6 for air quality in cities, and SDG 13 on climate change. EVs could play a huge part in achieving these goals and improving the health of populations internationally.

2.5 The sharing economy

What if?

Imagine a world where ownership of personal vehicles is unnecessary. All your mobility needs can be accessed via your personal account, following the same logic that it is more cost-effective to subscribe to a gym membership rather than purchase each fitness machine yourself. Cars are available to rent on-demand, with no minimum rental period or designated drop-off location. The vehicle choice can and will vary each time, depending on your daily need: the people-carrier, for example, can be downsized to an e-scooter after the children have been dropped off at school.

What does this mean?

Shared mobility is an umbrella term referring to **shared transport options** that allow users to access services on an **as-needed basis**, such as car-sharing clubs, peer-to-peer ride-sharing, on-demand taxi services, bike-sharing, and microtransit. The increasing reliability, variety and ubiquity of shared mobility is shifting typical ownership structures, as the need for personal vehicles is reduced. As this trend is driven mainly by consumer demand, it encourages new, emerging business models based on Mobility-as-a-Service (MaaS) for first- and last-mile mobility.

Shared vehicles in the MaaS business model

Opportunities

- Reduced street congestion and associated GHG emissions;
- Increased implementation of non-motorised transport;
- Reduced need for car parks, offering new spatial opportunities for real estate;
- Over 20% cheaper than private vehicle ownership;[37]
- Shift towards selling to mobility providers, rather than consumers, and;
- Facilitated physical distancing during the COVID-19 pandemic.

Challenges

- Relies upon consumer behaviour to upturn conventional ownership models;
- Requires regulation to ensure good driver behaviour and passenger safety;
- MaaS services which use a smartphone app pose accessibility issues;
- Insurance/ liability issues of multiple vehicle users, and;
- Requires private-sector partnerships to integrate shared mobility with public transport e.g. payments, alternative route options.

What are the current trends?

Arguably, the rise of the sharing economy is the most tangible and widespread international trend in 4IR mobility. The ubiquity and reliability of ride-sharing, e-hailing, bike-sharing, car-sharing clubs, and microtransit startups such as *Uber*, *Lime*, *Flinkster*, *DriveNow*, *Mobike* and *Bird* have disrupted traditional transport services in an unprecedented way.[38] The **increasing responsiveness and reliability of shared mobility** is shifting typical ownership models, with the need for personal vehicles diminishing. Private cars and other vehicles may no longer be purchased for compulsory transportation, but solely for pleasure.[39] Early signs of this **consumer shift** is evident in North America and Germany as the number of car-sharing members grew over 30% annually between 2010 and 2015.[40] Looking forward, it is estimated that more than 45% of all personal mileage in 2030 will be covered using shared vehicles.[41] Research supports this prediction as over 50% of consumers would be willing to pay up to $250 for a monthly subscription of unlimited rides within town, while 47% would give up their car in favour of autonomous 'robotaxis'.[42]

COVID-19 focus: The pandemic has spurred the deployment of shared micromobility options

Around the world, from Dublin to Sydney, cities have extended ride-sharing schemes, announced ambitious cycling infrastructure plans, and pedestrianised city centres to facilitate urban mobility while respecting social distancing guidelines. As cities relax lockdown restrictions, local governments are leveraging e-mobility as a means to reduce stress on public transport and minimise the risk of infection, while supporting the wellbeing of their citizens. For instance, shared mobility provider *Via* partnered with multiple cities including Abu Dhabi to provide transport to healthcare workers during off-peak hours.[43] Similarly, the *Smart Ways to Antwerp* programme has enhanced its web-based journey planner to include shared mobility options and integrate a new cycling route planner to support sustainable mobility during the pandemic.[44]

2.6 A responsive and evolving enabling environment

What if?

Imagine a world where students were as inspired to become drone operators, robotics engineers or AV designers, as they are to become astronauts, ballerinas or doctors. Higher education institutions offering 4IR-related qualifications are hotbeds of innovation as academia receives dedicated funding for advancements in emerging technologies. Partnerships between government, industry and academia (triple-helix) encourage knowledge sharing, best practice and universal training opportunities for upskilling in 4IR-related topics.[45] Financial incentives are offered to startups to experiment, pilot and launch frontier technology solutions to the 17 SDGs. Similarly, governmental regulation and policies encourage a behavioural shift away from familiar conventions and toward the future of society. This vision is only possible due to interoperability, the open sharing of data across all public- and private-sector platforms, and the highest standards of data security.

What does this mean?

An enabling environment refers to a broad range of important facilitators: triple-helix **partnerships** across academia, government and industry; **regulation** which promotes the disruption necessary to unlock the potential of the 4IR; **incentives**, such as subsidies or tax abates, to change consumer preferences; **access to education and training** opportunities to upskill the future workforce; and **interoperability**, with strong data security policies (more detail in section 4).

A responsive and evolving ecosystem responds to, and promotes, the development and application of 4IR technologies in the mobility sphere. Both parts are equally important since 'enabling' proactively encourages innovation, whether from a financial or practical perspective, while the 'responsive' and 'evolving' components recognise the fast pace of technological progress and the necessity for adaptability. Disruptors like *Uber* or *Lime*, by definition, upturn conventional business models and encourage **behavioural change**, so can be a key driving force for new regulation. It is important to note that these policies must consider **affordability and inclusion**, such as public subsidies, to allow lower income groups to benefit from these mobility options. As such, innovation and the external environment continually shape one another and must have complementary goals to successfully leverage the 4IR in an inclusive fashion.

What are the current trends?

Components of a 4IR mobility enabling environment can be identified in some areas of the world today. Australia is an example of an innovative ecosystem that promotes frontier technologies. Specifically, Australia is ranked highly on regulations supportive of the adoption of AVs, boosted by the *National Transport Commission*'s (*NTC*) *Automated Vehicle Program*.[46] The *NTC* works with stakeholders in government, industry and the community to remove over 700 legal roadblocks that inhibit the deployment of AVs, including governmental access to data generated by AVs.

Smart Dubai is another example of an enabling environment that has evolved to **align policy, partnerships and society** in leveraging 4IR innovation. Through initiatives such as *Paperless*, *AI Lab*, *Startup Support* and *Dubai Blockchain Strategy*, the *Smart Dubai* government office embodies a collaborative and agile approach to facilitate city-wide smart transformation.[47] Despite the ambition to make Dubai 'the happiest city on earth', this strong focus on digitalising all aspects of society – healthcare, education, culture, housing, entertainment, teleworking and mobility – could cause 'creative destruction', deepening pre-existing exclusion barriers or causing job losses.[48]

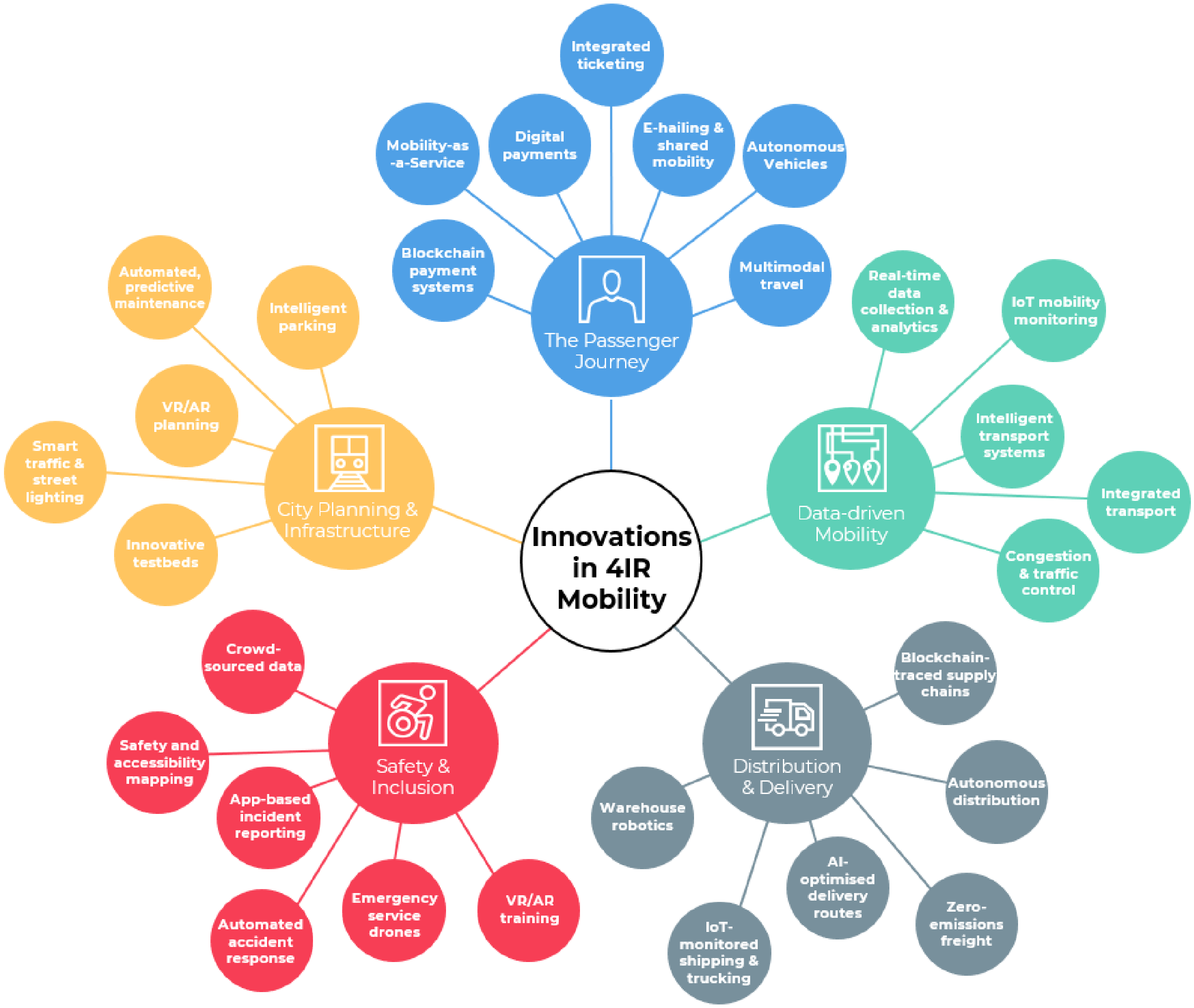
Environments can also **evolve gradually** in response to frontier technologies, as incumbents react to the rise of new mobility options. Electric scooters, though present on UK streets for a few years, are only being legalised under a 2020 *UK Department for Transport* proposal.[49] The **slow churn of policy**, however, must be careful not to delay or stifle the evolution of mobility, while balancing societal and environmental concerns.

3. FIVE APPLICATION AREAS FOR 4IR MOBILITY

This section explores innovative 4IR applications in the mobility sector, across a range of geographies and scale of ambition. While this section presents a range of potential opportunities that 4IR technologies can unlock both in the short- and long-term as a result of the international 4IR mobility trends discussed in section 3, the practicalities and challenges of deploying these applications will be explored in more detail in section 4.

The 4IR mobility use cases covered here are grouped into five overarching areas. These have been selected through desk-based research as themes that have emerged as key mobility constraints in international cities. The five application areas and the specific use cases this section will cover are presented in Figure 3 below.

Figure 3: Network diagram showing 4IR innovations under the five thematic areas of mobility



Each subsection will first provide an overview of the challenges currently faced in the mobility application area and how 4IR innovations have been leveraged to address these issues. The broad narrative of international applications is accompanied by deep-dive case studies, selected by the success of implementation and applicability to alleviate the identified challenge. The specific examples showcased in this report are based on a review of hundreds of case studies covering different geographies, modes of transport and application areas. Given that context is important, the emphasis is on outcomes, lessons learnt and identifying the factors that make innovations successful or not, rather than the technical detail of each technology.

3.1 The passenger journey

The 4IR has the potential to transform the journey experience for millions of passengers, whether travelling for work or leisure. Rapid urbanisation is contributing to growing urban transport needs,[50] yet many cities worldwide have failed to adapt to this increased demand with scale and speed, and are struggling to provide safe, affordable and reliable transportation for their citizens. Future mobility will have to be seamless, more flexible and better cater to users' needs.

We are already seeing innovative action across the globe. **Integrated ticketing** is being rolled out to increase convenience for users, allowing them to purchase a single ticket for travel across multiple modes of transport, provided by a number of different operators.[51] A stark rise in **digital payments** accepted by various transport modes and bodies – increasing convenience e.g. through contactless technologies, monthly billing and online wallets – is unsurprising given 27% of consumers say they would use more public transport if it was easier to pay.[52] Digital payments can also be linked with mobile apps focused on improved and simplified **route planning**, providing incentives for public transport use by allowing customers to plan their journeys, identify delays and discover alternative routes. Half of consumers surveyed in a 2019 global Visa survey would use more public transport if there was a consolidated app that enables both trip planning and payment.[53]

These innovations deploy a combination of technologies to deliver services to their consumers, using **smart sensors** and **IoT** to gather data on the transport systems, **AI** and **computing technologies** to analyse this data and identify necessary information, and payment and mobile technologies to deliver this information to the user.

COVID-19 focus: Remote ways of working reduce the need to commute

The coronavirus pandemic is forcing companies to rethink how they operate, one major aspect of this being where their employees are based. Ultimately, the pandemic has accelerated the trend of working from home, which has the **potential to lessen demand for commuter-based transit** in the longer term.[54] It must, however, be recognised that not all are granted the luxury of being able to telecommute, dependent not only on their line of work, but their access to the necessary technological equipment. New analysis from the *Royal Society of Arts* in the UK also cautions that the workers least able to work from home are often the lowest paid – including road transport drivers.[55] This indicates an **economic disparity** between those who are able to work from home and shield from the virus, and those who have little choice but to put themselves at greater risk by physically travelling to and from work every day.

Simultaneously, this rise in remote working **opens up space for the use of AR and VR technologies**, facilitating continued employee and client engagement. One example is how Taiwanese smartphone maker *HTC* has introduced a virtual reality meeting service, where users create an avatar, don a headset and find themselves in a virtual room with colleagues.[56] *Microsoft* has also been developing virtual collaboration tools, where users can exchange, annotate and edit virtual documents in real-time.[57] With the current circumstances giving these technologies space to grow and take hold, could we see VR/ AR uptake and decreased travel demand continue beyond the life of the pandemic?

Holistic travel planning

The majority of passenger journey-related innovations collectively come together to form **Mobility-as-a-Service (MaaS)**. MaaS empowers the individual to travel on-demand, introducing the luxury of convenience into the transport market. Many MaaS operators integrate the end-to-end transport journey in a smartphone app for seamless travel: route planning, payments and alternative journey options. These apps use computing technologies, such as AI, to analyse travel demand information and congestion patterns to improve **journey planning** for users, including real-time information on traffic and the most suitable driving routes. The introduction of integrated ticketing and payment systems increased ridership on public transport by 12% in Italy.[58] This uptake could increase the loading of public transport, reduce the number of private vehicles on the road and reduce congestion as a result. Yet work needs to be done to ensure accessibility of these 4IR innovations for users without smartphones, whether on affordability grounds or readiness to use.

> *Lara.ng* is a Lagos-based chatbot that uses AI to offer conversational directions and fare estimates for public transportation.[59] Startup challenges have included finding skilled hires and working with the government to form PPPs.[60]

> Transport for London's *Oyster Card* can be used on various travel modes across London, including underground tubelines, overground trains, buses, trams, and selected riverboat services.[61] The *Oyster Card* can be 'topped up' with cash, debit card or online payment options, as well as offering the choice between pay-as-you-go or season ticket options.

Helsinki's *Whim*, a MaaS app, offers bundles for subscribers across a range of transport modes. Not only can customers plan, book and pay for all their mobility needs through the app, their model rewards customer loyalty with discounts on travel when they pay a subscription fee upfront.[62]

The rise of digital payments

While many integrated travel planning systems employ physical cards, there is a rapid increase in **digital and app-based payment solutions**. Digital transport tickets and cards offer greater reach, improve customer experience, boost loyalty among regular users, and simplify local travel for occasional visitors and tourists. Meanwhile, ticket operators enjoy simplified distribution and reduced operating costs as a result – a Visa study found that ticket management in a public transit system costs 14.5 cents for every physical dollar it collects in fares, compared to only 4.2 cents for every digital dollar.[63] The use of **blockchain for unified payment systems** is steadily rising and enhances the security of payments for both commuters and transport operators, as well as provides increased accountability through the traceability of providers. Exclusion remains a risk.

Alipay's QR code-based payment system has been rolled out on bus and subway systems of over 50 Chinese cities. The user simply scans a QR code on their phone against a kiosk as they board the transport; the technology processes payments in 0.3 seconds without need for internet connectivity on either device – ideally suited where signal can be unreliable.[64]

In Madrid, Santander bank and Vottun blockchain startup are developing an application that commuters can use to centrally access and pay for all different modes of urban public mobility. This partnership is part of the Municipal Transport Company of Madrid's *Madrid in Motion* initiative, encouraging innovation across the Spanish capital's mobility network.[65]

The City of Fortzaleza, Brazil, has declared that they will soon be upgrading their public transport payment systems to accept cryptocurrencies through a QR code-based app.[66]

From private to public vehicle ownership

The sharing economy has given rise to an array of **ride-hailing services**, the most notable of which is *Uber*, operating in over 900 cities worldwide.[67] Such services dramatically increase the convenience and responsiveness of transport options to the user, essentially granting access to on-demand travel. Again, the inherent attributes of blockchain technology could enable a **decentralised peer-to-peer community** where drivers can set their own fares and transact directly with customers on a platform that manages ID verification, journey validation and fund transfer.[68]

Singapore-based blockchain firm MVL has raised $5 million in Series A funding to support TADA, a blockchain-based ride-hailing service. This zero-commission ride-hailing app is hosted on MVL's blockchain and, by continuously tracking the vehicle history, is able to incentivise and reward drivers for good service.

SafeBoda offers a similar service for motorcycles in Uganda, with all riders trained in road safety, first aid and customer care – see case study in section 3.4.

PlentyWaka in Nigeria lets users book and schedule bus trips via their mobile app.

Building on this trend of shared, on-demand transport, we are witnessing the rise of **autonomous electric vehicles (AEVs)** operating as personal taxis, picking up and dropping off users when requested. The continued uptake of AEVs could ultimately lead to better traffic management, routing and reduced need for vehicle ownership, as well as welcoming an age of cleaner transport.

A pilot by *ZMP Inc* in Japan saw a **self-driving taxi** service fitted with an array of sensors and cameras to successfully drive passengers through central Tokyo.[69]

Autonomous rail is also being developed, such as *Hyperloop*; a vacuum-based, emission-free transport system with potential to move people and cargo between cities in one-fifth of current journey times.[70] Yet high construction costs are likely beyond most cities' reach.

Having taken its maiden flight in Germany in May 2019, the electric *CityAirbus* heralds a new era of on-demand autonomous air travel, capable of transporting up to four passengers.[71]

Case study: Swvl – Mobility as a Service in Egypt, Kenya and Pakistan[72,73,74,75]

What is the innovation? Founded in 2017, Cairo-based transport startup *Swvl* recognised the strain that rush hours, traffic, unsafe driving and unavailability of parking spots put on consumer travel. In response, *Swvl* developed a platform that connects commuters with private buses, allowing them to reserve seats and pay the fare through a mobile app. The startup operates bus lines on fixed routes with customers boarding from pre-defined 'virtual' pick-up and drop-off spots and able to track the buses in real-time. *Swvl* is currently available in Cairo and Alexandria, Egypt, where it runs over 600 lines, and is scaling its presence in Kenya and Pakistan.

What made it successful (or not)? A key factor of *Swvl*'s success is its innovative operating model – the business does not own the buses or employ the drivers, but has signed different partnerships to help drivers and operators finance their vehicles. Similar to *Airbnb*, this has minimised the capital held in fixed assets. This business model enabled the startup to secure $8 million in Series A funding led by regional venture fund BECO Capital. This is the biggest round of funding for a tech startup in Egypt and one of the biggest rounds in the Middle East. This was followed by a Series B funding round of $42 million, co-led by BECO Capital and Vostok Ventures.

Swvl's affordability is also a key factor in its success, having established itself as a global leader in the affordable smart mobility space. *Swvl* offers fixed routes for a fixed flat fare, at prices that are up to 80% cheaper than on-demand ride-hailing services. Payments can be made in cash or via the app, enhancing convenience while maintaining financial inclusivity. Another aspect of *Swvl*'s inclusivity is from a gendered perspective – *Swvl* has a large portion of female commuters, who want to avoid harassment on public transportation, offering them a safer journey.

While *Swvl* has largely been a success, this is not without challenges. In Egypt, *Swvl* is facing increasing competition in the shape of *Uber*'s *Careem* bus. The company has also received warnings from the Pakistani regional government for operating without route permits and clashed with local authorities in Nairobi due to not operating along set routes.

What is the role of the City? In Nairobi, regulations played a key role; the National Transport and Safety Authority restricted *Swvl*'s operations as it had not secured the necessary licensing. The City could open up conversations with startups like *Swvl*, to reach an agreement that harnesses the affordable, convenient and inclusive transport offered. Some local authorities, such as Karachi, are already collaborating with *Swvl* to integrate it into citywide mass transit solutions, through public-private partnerships. The City could play a facilitative role in conversations between startups like *Swvl* and minibus taxi operators to support the integration of transport solutions.

3.2 City planning and infrastructure

Emerging technologies can help cities better plan its urban form and manage infrastructure, in turn helping its businesses and residents navigate the challenges of efficient mobility, including road quality and parking. The organisation and maintenance of space and physical assets are critical for enabling mobility, however both of these aspects are often disregarded in favour of transport-only planning or a focus on new infrastructure over the maintenance of old.

New investments in transport infrastructure and assets need to be considered in the wider context of urban planning. Compact urban form and mixed use development can significantly contribute to both a reduced need to travel, and more financially viable public transport. For example, the share of operating costs covered by fares in Bogota is 150%, compared with 40% in Johannesburg, due to more than four times higher population densities.[76] For established cities, the **quality of existing transport infrastructure** is also critical for efficient mobility. Of the $35-47 billion required in road and other transport infrastructure investment in Africa by 2025, 80% is expected to be needed for maintenance and rehabilitation, and only 20% for new infrastructure.[77]

Applications of 4IR have the potential to support capital expenditure plans and operating cost reductions. **VR** and **AR** can help cities visualise new urban plans before spending on significant upgrades. **IoT** and **sensors** are already being used to alert drivers of available parking spaces, while these technologies also have the potential to spot issues in real-time, such as road quality, enabling quicker fixes. **Drones** can also be used for monitoring existing infrastructure and assets, while **robots** can be deployed to do the maintenance and **3D printers** used to produce the spare parts.

Planning and testing 4IR mobility in urban environments

Several 4IR applications support the **visualisation of urban design** and the **testing of mobility solutions** in smaller, controlled environments prior to making large investments. These include:

- The *Bike to the Future* project in Singapore lets cyclists take virtual rides, using VR technology, 3D modelling and traffic simulations, to test different street designs to support planning authorities in designing more bike- and walk-friendly neighbourhoods.[78]

- Alphabet's *Sidewalk Labs* venture planned a large-scale urban development in Toronto to introduce innovative forms of mobility and freight, promoting walking, cycling and shared transit options[79] – the project was cancelled in May 2020 due to lack of financial viability.[80]

- Elon Musk's *The Boring Company* built a $10 million test tunnel in California – for which Hawthorne City Council provided planning permission – to test its tunnelling and high-speed, autonomous electric vehicle transport designs.[81]

- *Jätkäsaari Mobility Lab* uses a designated area of Helsinki, Finland as a global testbed for new mobility solutions, before rolling out designs more widely; see the next page case study.

G&SI focus: SDG 11 on inclusive, safe, resilient and sustainable cities and human settlements

The UN's SDG 11 is an urgent call for action by all countries to reduce inequality, spur economic growth and tackle climate change in our cities – both developed and developing. This goal is underpinned by seven targets that are highly interlinked, from broader, participatory urban planning and management to specific ones focused around infrastructure, climate and inclusion. One specific target speaks directly to the provision of safe, affordable and accessible mobility systems. SDG target 11.2 urges governments to "provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons".[82] Measured by the proportion of urban residents with convenient access to public transport (within 500m walking distance of a bus stop and within 1,000m of a railway and/ or ferry terminal), more progress is still needed. An average 53% of residents in 227 cities across 78 countries had convenient access to public transport in 2018, compared with just 18% across sub-Saharan Africa (excluding informal means of transit).[83]

Making better use of existing road space

How existing road space is used can be greatly enhanced by 4IR technologies. Examples include:

- *Westminster City Council* in London developed the *ParkRight* app to reduce congestion by allowing drivers to identify available spaces through the use of 3,400 installed RFID **parking sensors**, using a 'SmartSpot' gateway to transmit live information to SmartRep, a software tool for car parking management that can analyse large amounts of information quickly, communicating with the app to navigate users to vacant spaces via GPS directions.[84]

The *Open Curbs* open data platform provides city agencies with information on their **kerbside use and accessibility points** e.g. for wheelchair users.[85] The platform is developed by *Coord*[86] that reviews curbs and their alternative uses in North American cities, e.g. by identifying needs and pricing for smart loading areas using 4IR technologies such as AR.

Traffic Light Exchange (TLEX) – grown out of the Talking Traffic partnership between the Dutch government, local authorities, companies and private road users – has developed a new generation of **smart traffic lights** (and installed 1,250 of them across the Netherlands) that can identify oncoming traffic and enable automated coordination of traffic flows to address the estimated €90m annual cost to society of inefficient, poorly set traffic lights.[87]

Singapore-based startup *gridComm*'s **smart streetlights** project in Jakarta, Indonesia uses IoT technology to allow remote control of their functionality, enabling longer, safer trading hours, new commuting patterns and more cost-efficient energy use.[88]

Efficient monitoring and maintenance of infrastructure and transport assets

Using 4IR technologies for predictive maintenance and alerting transport operators of potential concerns before critical failures occur can help minimise downtime, improve reliability for passengers and potentially lower costs of repairs by allowing early intervention. Examples include:

The *University of Leeds* in the UK has explored the concept of 'self-repairing cities' by using **drones equipped with image recognition technology** to scan streets for developing flaws and patch the hole with asphalt using its **onboard 3D printer**.[89]

PotholeCoin, based in the USA, uses crowdsourcing and **blockchain to identify and place 'bounties' on potholes** for repair by cities and communities.[90] This builds on initiatives such as Nairobi's #WhatIsARoad Twitter-based pothole location and repair.[91]

TEXA's IoT solution[92] and *ePave*'s[93] network of self-powered wireless sensors also support road users and cities, respectively, to **monitor the state of roads in real-time**.

IBM has developed a **predictive maintenance** analytics solution using sensor data via IoT and advanced analytics to predict future maintenance needs and prevent equipment fails. A rail operator with 20,000 miles of track has implemented 1000s of sensors to monitor track conditions, sounding alarms when critical elements such as wear reach emergency levels.[94]

Case study: Jätkäsaari Mobility Lab – a testbed for new solutions in Helsinki, Finland

What is the innovation? *Jätkäsaari Mobility Lab* is an innovation and co-creation platform, bringing together residents and companies to provide a real-world testing ground for new mobility solutions and showcase smart transport globally.[95] Mobility pilots are chosen through a procurement process and participating companies get facilitation and organisation support for the pilots from *Forum Virium Helsinki*, the City's innovation company.

What made it successful (or not)? *Jätkäsaari Mobility Lab* has broadly been seen as a success. It was part of a three-year, €1.9m EU-funded Last Mile smart mobility project, concluded earlier in 2020 and delivered in partnership with neighbouring cities, local companies and universities, to "test new services and solutions for improving mobility in the city and to collect experiences, feedback and mobility data to support planning".[96] The *Mobility Lab* continues testing and uses a method of agile piloting to verify proofs-of-concept for wider adoption and identify competitive advantages from 4IR technologies for mobility.[97] Pilots have included smart parking for shared-use cars, bicycle tours with audio navigation for tourists, an 'Uber for boats' and ecological cargo bike transports. As the projects are often prepared in collaboration with different City departments, the solutions are more easily able to address the City's particular needs.

What is the role of the City? The City of Helsinki has played a significant role. First it set the vision and leadership for becoming the world's 'most functional city' and allocated specific areas of the city for testing new, innovative approaches, including a smart district called Kalasatama. *Jätkäsaari Mobility Lab* is the creation of *Forum Virium Helsinki*, a non-profit limited liability company fully owned by the City of Helsinki to drive its innovation projects. Its operations – c. €5m per year with 35 staff – are funded by different EU projects, the City of Helsinki as well as its member organisations ranging from academia and utilities to public institutes and companies.[98] Showcasing the role Forum Virium has played in Helsinki's broader digital/4IR adoption, it helped BlindSquare develop a mobility app for the blind, and brought together the right public and private stakeholders to support MaaS Global set up (creators of *Whim*, see section 3.1).

3.3 Data-driven mobility

Digital connectivity, big data analysis and cloud technology are the fundamental building blocks to unlock the potential of 4IR mobility and optimise traffic management. Some 46% of commuters in major cities have seen commute times increase over the past five years.[99] Congestion on roads has reached an unprecedented level globally. The average commuter wastes 54 hours a year in traffic delays.[100] Traffic jams in Mexico City are estimated to cost 33 billion pesos ($1.8 billion) per year in lost time and productivity because 85% of road space is taken up by private cars, which only account for 30% of commutes.[101]

Congestion in urban areas could be alleviated through emerging technologies such as **IoT** and **cloud computing**, utilising data management and analytics for multi-modal transport integration and traffic optimisation. Connected mobility will streamline real-time journey mapping and route optimisation, as mentioned in section 3.1. Deployment of **AVs** could also save every commuter 42 hours in travel time annually and a 20% increase in average commuting speeds per journey due to reduced congestion and smoother traffic flows.[102] Increased connectedness and autonomy of urban mobility would improve the user experience and create new efficiencies by reducing journey times, transport emissions, energy use and incidents of road traffic accidents (see section 3.4).

Using big data analysis to improve the passenger experience

The use of IoT sensors on transport platforms could generate millions of use data points and provide insights on footfall to improve **real-time passenger and transport flow**. Onboard mobile routers not only enable mobile fare payments (see section 3.1), predictive maintenance (see section 3.2) and intelligent vehicle technologies such as collision warning (see section 3.4), but also automatic vehicle location (AVL) and automatic passenger counting (APC).[103] AVL allows for smart, integrated transport networks while APC creates an opportunity for tailored services, such as increasing the number of busier modes of transport while decreasing capacity on quieter routes.

> *Billund Airport* in Denmark leverages an **IoT-based passenger flow system** to improve the whole airport experience from carpark to departure.[104] Passenger data, e.g. APC, is collected in real-time to manage operations, analyse patterns over time, assess disruption impacts on consumer behaviour, and could even tell the airport's future layout to maximise efficiency.

> Big data is stored in the cloud and available for real-time **predictive analysis** in both day-to-day and emergency situations, as discussed in the *Rio Operations Center* case study.

Big data analysis of mobile phone data could enable city officials to understand mobility around the city and how existing transport systems could be integrated.[105] A smart, connected transport system, powered by IoT and AI, has the potential to **enable real-time vehicle tracking**, rerouting vehicles and updating passengers in the case of unexpected events (as discussed in section 3.1).[106]

> The *Ministry of Transport* in the Netherlands provides **up-to-date and integrated travel information** via a website and smartphone app as well as at transit stops and stations.[107] The *Unlimited Public Transport Information* system enables a dynamic exchange of data automatically and in a uniform format between operators and public transport authorities to facilitate **seamless journey planning**.

See box on using IoT and AI to reduce congestion and improve air quality on the next page.

C&E focus: Utilising IoT and AI to reduce congestion and support cleaner air quality

IoT, big data processing and cognitive computing can utilise data from traffic systems, weather satellites and stations to create accurate pollution forecasts and allow city planners to model smarter, green cities. *IBM*'s *Green Horizons* project in Beijing leverages 4IR technology to analyse data from thousands of sensors and detect patterns in air pollution.[108] A system powered by AI and IoT harnesses data on factors which contribute to air pollution (traffic, weather, humidity, wind etc.) and uses predictive analysis to generate pollution forecasts 72 hours in advance. Advanced cognitive technologies can also model different scenarios for restricting traffic to calculate the improvements in air quality.[109] Due to the success of the *Green Horizons* initiative, it will be implemented in other heavily polluted cities like New Delhi and Johannesburg.

Intelligent Transport Systems for optimised and ecological travel

Innovations in 4IR have a huge potential to **ease congestion and optimise traffic control**. Intelligent Transport Systems (ITSs), such as *Microsoft Azure IoT*,[110] can analyse data from CCTV feeds, smart parking sensors, IoT-enabled traffic signals and connected road infrastructure such as lamp posts to improve efficiency and safety. ITSs use AI applications to predict traffic demand more accurately and optimise road networks in real-time.

SWISSTRAFFIC's *Traffic Counts 4.0* analyses multimodal traffic flows of pedestrians, vehicles, cyclists and public transit passengers.[111] The tool uses big data analytics to forecast traffic in real-time, predict congestion, communicate jams and accidents, and organise diversions.[112]

Siemens has implemented an ITS in Zhuhai, China to make the roads easier to navigate and more environmentally friendly.[113] The platform gives passengers travel information, including bike rentals, tram routes, real-time traffic, car repairs, customs queues and driving penalties. In addition to its public use, the ITS displays a green index traffic system for the *Zhuhai Transportation Bureau*, showing the city how its traffic performance compares to others globally and how policies can be adjusted to develop a more ecological traffic system.

In the longer term, AVs could reduce stress on road infrastructure, such as leveraging urban airspace more efficiently and conventionalising drone taxis like Germany's *Volocopter*.[114]

See case study on *Alibaba Cloud's City Brain* traffic management solution below.

Case study: Leveraging routes to collect big data for traffic optimisation in China

What is the innovation? *Alibaba Cloud*'s *City Brain* is a road traffic management solution, powered by AI and IoT, which analyses data gathered by smart sensors across Chinese transport systems.[115] The ITS is a combination of an open IT service, deep learning, data aggregation and integrated computing platform. *City Brain* collects real-time data from buses, taxis, traffic signals, and road cameras and overlays it with a historical bank of GPS, map, signal timing and vehicle flow information. The tool has facilitated capacity-building in optimising urban mobility for passengers, first responders and road users.

What made it successful (or not)? *City Brain* is successful due to its multifaceted potential in detecting traffic accidents, improving public safety, reducing traffic congestion and optimising public transport networks. The ITS has shortened commute and emergency response times, integrated the dispatch of emergency vehicles, improved the accuracy of accident reporting and increased utilisation of public transport. In Hangzhou, emergency vehicle response time was shortened by 50%, while passenger volume on pilot bus routes increased by 17% in Suzhou.

What is the role of the City? To effectively utilise comprehensive real-time city data for traffic optimisation, local governments will need to implement open and standardised data collection (such as GTFS), governance and security policies. ITSs rely upon information sharing across multi-sectoral partners, authorities and stakeholders and this is only possible if the technology systems are trusted. Secure and reliable data management approaches that safeguard privacy will enable synergies across the mobility sphere (more detail in section 4.4).

Case study: An operations centre to keep citizens informed about emergency situations and transport conditions 24/7 – Rio de Janeiro, Brazil

What is the innovation? The *Rio Operations Center* integrates and interconnects information from multiple government departments and public agencies to improve city safety and responsiveness to emergencies.[116] *IBM*'s *Smarter Cities* platform consolidates big data from various urban systems and uses predictive analysis to integrate all the stages of a crisis management situation: from mitigation and preparedness to immediate response. The Center also ensures smooth routine operations and increased efficiency based on real-time information. Real-time traffic monitors allow transit agency employees (bus, BRTS, train, ferry and subway) to redirect traffic around blockages and provide alternate routes for drivers, reducing stall time.[117]

What made it successful (or not)? Following the 2010 landslide in Rio, the city administration leveraged newly-updated regulation which facilitates PPPs. Collaborating with *IBM*, *Bilfinger*, *Cisco*, *Samsung* and *Google* ensured the feasibility and development of a technical solution.[118] For example, *Google Earth* technology enables an integrated system of georeferenced data for Rio's daily operational routine. The project also received strong political commitment from the Brazilian federal government which used social media to raise awareness about the Center, especially during the 2014 World Cup and the 2016 Olympics.[119]

What is the role of the City? Funded by Rio's city administration, with support from IBM, the project's success is partly due to the administration's effective stakeholder engagement across the PPP, including over 30 city authorities, with citizens engaged through social media channels such as Twitter (see section 4.4 on partnering).[120] Rio's city administration also equipped buses, taxis and metro rail with GPS sensors enabling the Center to monitor movements and locations.

3.4 Safety and inclusion

Access to inclusive and affordable mobility options, as well as safe and secure transport systems, demands particular consideration during the 4IR. Globally, the share of urban residents with convenient access to public transport remains low, particularly in developing countries. As already highlighted, an average of 53% of urban residents have convenient access to public transport, a number which drops to 18% in sub-Saharan Africa.[121] In many regions that have low access to public transport, informal transport modes are highly prevalent and can provide reliable, although sometimes unsafe, transport for the majority of urban populations. Given the unevenness of current infrastructure and the potential exclusionary impacts of new technology, development of new and existing transport systems must be approached with a 'leave no one behind' lens.

Technologies are being deployed in support of this ethos, with **crowdsourced data** being harnessed to identify safer areas for women, and **big data** and **location intelligence** being combined in real-time to make city transit safer and easier for the visually impaired. Moving beyond inclusion and to transport safety at large, **AI** and **smart sensors** can monitor onboard transport safety. We are also seeing heightened monitoring of both the potential for and occurrence of road traffic accidents, with **IoT** devices feeding back real-time data for instant **AI** analysis. **Autonomous vehicles** and **drones** are also being increasingly deployed for first response in emergencies, while also expected to reduce the occurrence of accidents in the first instance.

COVID-19 focus: Public safety in a post-pandemic world

The coronavirus pandemic brings new safety-related challenges for commuters and the transit system as a whole. Given public transport is characterised by high numbers of people in confined spaces and a variety of common touch-surfaces, such as ticket machines and handrails, these systems are considered high-risk environments.[122]

Given the importance of hand hygiene and physical distancing during the outbreak, public transit and cash-based transactions pose a huge risk to continued virus transmission. While there are many socio-economic reasons why cash is still the preferred method of payment, such as in informal transport, the pandemic could provide a springboard to test new business models. Indeed, COVID-19 will almost certainly act as an accelerant for the update of digital payment systems, with increasing concerns over the risk of handling cash. In Kenya, the daily transaction limit for *M-Pesa* has more than doubled, while Ghana's monetary body eased the 'know-your-customer' requirements on mobile money platforms.[123] Similarly, in the UK, *Unite* transport union has advised that cash payments should be abolished on all buses during the outbreak.[124]

This 'new normal' could also introduce the need for existing travel-planning apps to introduce capacity indicators or for tech-enabled enhanced cleaning measures. For example, Hong Kong has successfully trialled a disinfection robot that autonomously sanitises train saloons.[125]

Technology as a tool for accessibility and inclusivity

Technologies of the 4IR are also being rolled out to make cities more **accessible for persons with disabilities**, helping them to navigate the streets with more independence and confidence. These include a combination of IoT, smart sensor and AI systems to triangulate GPS-data from the users' devices with their chosen destination.

In Delhi, *Street Rehab* has teamed with local NGOs and wheelchair users to deploy a smart sensor IoT system that maps the physical accessibility in line with mobility requirements.[126]

A number of cities have also implemented innovations for the visually impaired, such as *Neatebox*, which allows people to use their phones or smart watches to safely navigate pedestrian crossings in Edinburgh, or *Wayfindr* which transmits instructions to users audibly in London.[127]

Gender-inclusivity is also a key facet that needs to be considered when designing resilient and safe transport systems for the future. In Mexico City, 70% of women who ride public transportation say they have faced gender-based violence.[128] Additionally, a New York-based study found that as a result of sexual harassment on transport, women were more likely to pay for more expensive, but safer forms of transport, such as taxis.[129] Beyond vehicles themselves, cities must also consider the **safety** at transport interchanges and last mile travel.

The *SafetiPin* app allows female users to track and monitor the safety of their city based on lighting, people density, transport, gender diversity, and just as importantly, how they feel when walking around the location.[130] Rolled out in 20+ cities, data is collected in partnership with city stakeholders and citizens. In Bogotá, the pilot mapped 17,708 road intersections, providing data on safe walking and cycle paths, in turn informing new CCTV installations.[131]

India's *Eyewatch SOS for Women* allows users to share their location with trusted contacts, and captures audio/video of surroundings to send with an alert message, if feeling unsafe.[132]

Lessons from Mexico City's *Hazme el Paro* initiative can be found in the box below.

G&SI focus: Preventing violence against women and girls on public transport – lessons learned from *Hazme el Paro*, Mexico City[133]

In Mexico City, nine in ten women have experienced violence in public transport.[134] *Hazme el Paro* – colloquially meaning 'Have my Back' – is a pilot project from the *World Bank* that provides a smartphone app and free WiFi onboard buses. When riders submit a report of any sexual abuse experienced or witnessed, an alert on the bus will restate the zero-tolerance policy against sexual harassment on public transport.[135] *Hazme el Paro* has generated a number of learnings on how to develop an intervention to prevent violence against women and girls on public transport.

- **Involve local organisations** in the project design and implementation – the World Bank's collaboration with local NGOs helped them adapt their programme to the local context.
- **Engage the private sector** – the World Bank engaged a private ICT company to lead the rollout of Wi-Fi on participating buses.
- **Appeal to the local culture** when campaigning – the colloquial approach of this intervention was proven to help people engage, through messaging that used familiar language, rather than technical.
- **Engage with your audience** – through baseline surveying, the design team identified pervasive social norms around gender, which were then used to shape the campaign.
- **Participatory projects create ownership** – when engaging on sensitive issues such as sexual harassment, ownership is essential to drive change. *Hazme el Paro* supported drivers in creating their own Action Protocol on non-confrontational ways to intervene, meaning they saw themselves as key drivers of the project and its success.

Using technology to enhance road safety

Road traffic accidents threaten safe urban transport. The *WHO* reports that c. 1.35 million people die globally as a result of such accidents each year, with 93% of these fatalities occurring in low- and middle-income countries. Autonomous and connected vehicles are being rolled out, as research suggests they could **minimise the incidence of road accidents** by 99%.[136] Equipped with GPS, tracking cameras, ultrasonic sensors and other technologies, these vehicles can communicate with each other and surrounding infrastructure, enabling them to deploy assistance features such as automated braking and blind-spot detection.[137] On UK roads alone, these technologies could save an estimated 3,900 lives and prevent 47,000 serious crashes between 2019-2030.[138]

California-based *Phantom AI* has developed an advanced driver assist system that includes 360° vision, object-tracking, emergency braking and vehicle spacing.[139]

India's *Aadhaar* biometric ID system supports safer drivers – see case study later in section.

Innovations in 4IR also have huge potential to **optimise accident reporting and response times**. Through leveraging road-based connected data systems (see section 3.3), emergency response teams could be immediately alerted when an incident has occurred, meaning that they could be on the scene sooner. AI and drone technologies are also being used to equip response teams with accident information in advance of their arrival.

Tel Aviv-based startup *MDGo* is developing a medical AI system to provide first responders with real-time alerts on the injuries they can expect to encounter at the scene, enabling them to route patients to the right hospital with the right doctors and equipment.[140]

The UK's *National Health Service* is using drones to investigate accidents before staff arrive on the scene. The agility of drones help grant advanced access to hard-to-reach areas and provide paramedics with an overview of the patients' condition and location before they reach the scene.[141] See also medical drone delivery case study in section 3.5.

Safe vehicles play a critical role in averting road traffic accidents and reducing the likelihood of serious injury while travelling. There is an increasing prevalence of real-time data collection to **improve safety onboard public transport**. These methods of real-time data collection could be linked together through IoT and rolled out across the public transport system, offering an opportunity to continuously and centrally monitor the capacity of city transport fleets.

In Kerala, students at *St Thomas Engineering College* have developed a '**Vehicle Overloading Detection System**' that can detect vehicle weights on the move. If overloaded, the vehicle will sound an alarm and cut off the engine if the load is not reduced.[142]

Infrared and treadle mat sensors are also being deployed on public transport to count the number of passengers boarding and disembarking (see section 3.3).[143]

VR and AR are realising major safety-related benefits in the transport sector, helping to **train and test employees** against health and safety procedures,[144] including the simulation of realistic scenarios and high-risk environments.[145]

Dubai's *Roads and Transport Authority* has launched immersive VR training for its drivers, aiming to uplift their driving performance, contribute to customer satisfaction, and also rehabilitate drivers who have been involved in road traffic accidents.[146]

US-based distribution company *UPS* trains its student delivery drivers using VR, simulating real-life road environments and testing their ability to identify and react to pedestrians, parked cars, and oncoming traffic.[147]

Case study: SafeBoda – Enhancing motorbike taxi safety in Sub-Saharan Africa[148, 149]

What is the innovation? *SafeBoda* is an app-based motorbike e-hailing service, which takes a safety-first approach. Similar to other e-hailing apps, customers can plan, book and pay for their journeys on the app. It completes background checks, provides first aid and road safety training and equips drivers with recognisable (and safety-enhancing) orange jackets and helmets. To further strengthen its safety management system, the online platform instructs customers to rate their previous trip before they request a new one. *SafeBoda* also introduced a cashless transaction system in 2017, allowing customers to choose between cash or electronic payments. Drivers can then use their *SafeBoda* wallet to purchase fuel, food and other services.

What made it successful (or not)? Across a 5-year period, the company has enrolled around 25% of Kampala's boda-boda drivers onto their app, and won the 2018 AppsAfrica Award for Best African App. The app is particularly favoured by women, as they feel reassured by the accreditation of drivers, given the backdrop of sexual harassment and violence in Kampala, and are no longer burdened with having to haggle with male drivers as the price is automatically calculated by the app.

However, barriers to uptake do exist. Mobile internet is needed to access the app, which immediately excludes those without a personal device. There is also a gendered aspect here, as women are 41% less likely to use the internet than men in Sub-Saharan Africa. There is also a barrier around embracing the cashless payment aspect, given low literacy levels, limited mobile internet access and proportionally low bank account ownership.

What is the role of the City? SafeBoda's innovation plugged a gap in the enabling environment, in terms of regulating the safety of boda drivers and passengers. Moving forward, the City could advocate for all e-hailing companies to insure their drivers and users, as well as educating on and enforcing responsible helmet wearing for passengers (see section 4.3 on governance and regulation). Already, the Minister of Lands, Housing and Urban Development (previously the Minister of Kampala) has made a commitment to supporting the development of separate motorbike lanes at traffic lights to enhance safety. Beyond actions that promote safety, City bodies could also establish punishment mechanisms for non-compliance, such as license revocations for transgressors. Additionally, if city governments were to establish partnerships with mobility startups similar to *SafeBoda*, they would have the opportunity to aggregate mobility data and use this to inform future transport and infrastructural planning.

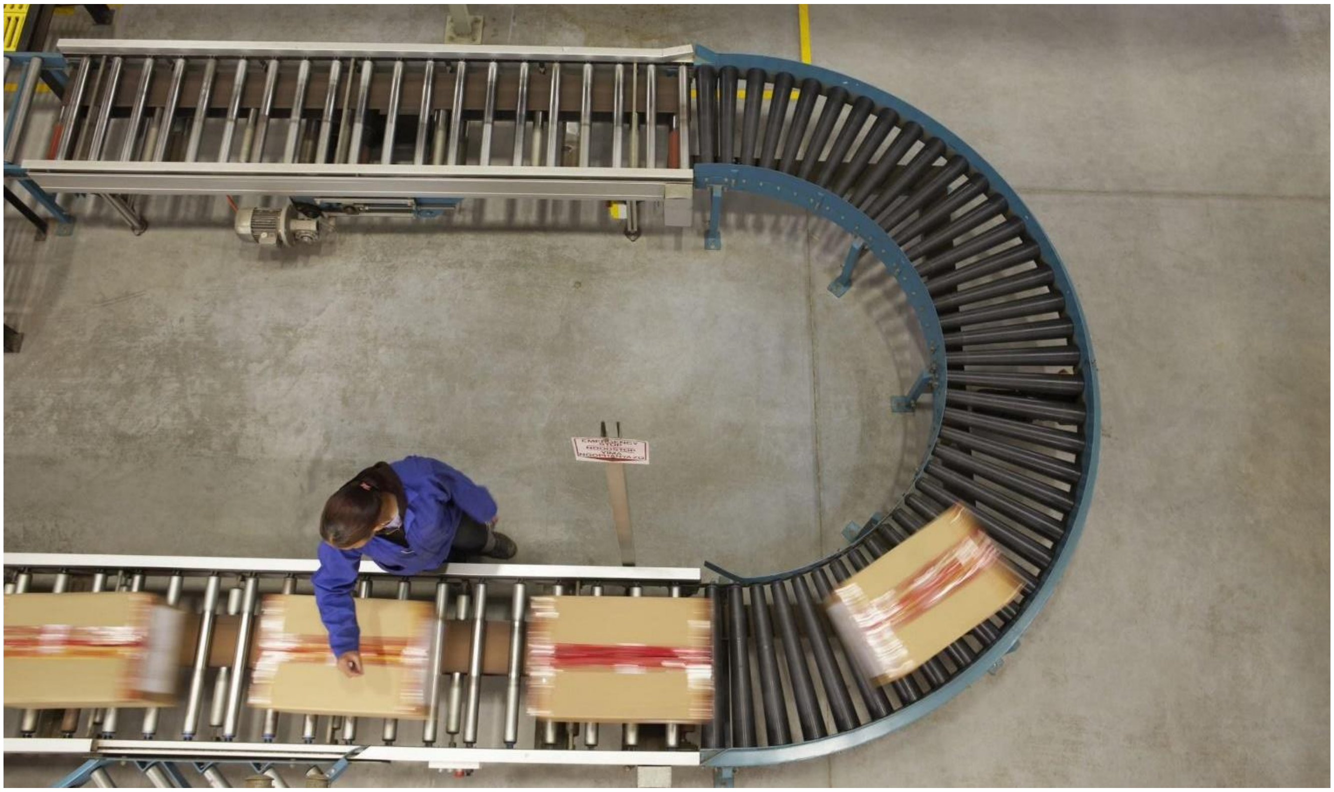
Case study: Aadhaar – Biometric identities in India[150, 151]

What is the innovation? India's *Aadhaar* biometrics-based ID system is the largest of any in the world, with 1.2 billion Indian residents registered. The *Government of Delhi* is using *Aadhaar* to conduct driving tests, through a combination of biometrics, video analytics, machine learning, and radio frequency identification (RFID) technologies. Drivers book and pay for their test online, then receive a code to access the test centre. The system biometrically confirms their identity, to eliminate fraudulent tests, and they are then tracked by RFID through test manoeuvres, for which they are scored instantly by an IoT system of sensors and CCTV cameras.

What made it successful (or not)? The *Aadhaar* system will expand Delhi's capacity to test new drivers, with testing capacity no longer limited by assessor scheduling. Trials also reflect how the system enhances the accuracy of test results and increases its resistance to corruption – the failure rate of *Aadhaar* automated tests sits at 49%, while the prior failure rate for manual driver tests in India was 16%. However, high technology investment costs could hinder the widespread adoption of *Aadhaar* and other automation and biometric systems, as well as costs associated with capacity building. There are also ongoing concerns around the readiness of data privacy protocols and processes in India.

What is the role of the City? The *Government of Delhi* led the roll-out of the biometric ID system, to increase the participation of the city's poor in the formal economy and markets – 99% of all Indian adults are enrolled on *Aadhaar*. Cities could support the utilisation of biometric ID systems across transport verification processes, such as licensing for public transport operators or truck drivers, as well as ID and payment management for passengers.

3.5 Distribution and delivery



The international freight industry, including urban distribution and delivery services, has already seen many of the possibilities presented by 4IR innovations. The sheer volume of transported cargo and associated GHG emissions highlight the potential impact of **electric vehicles** on improved air quality and public health. Costly and inefficient operations in sorting centres also makes distribution and delivery a prime market for **robotics** and **automation**.

Constraints in logistics and supply chain resilience are aggravated by poor road and rail infrastructure, incomplete or fragmented mobility networks outside the metropolis, and congestion during peak travel hours. Challenges posed by terrestrial transport networks encourage 'blue sky thinking', quite literally, as short-haul delivery by **UAVs** is already upturning business conventions. In fact, the necessity to deliver goods, products and cargo could largely be negated by **3D printing** and additive manufacturing which enable local, or even on-site, production.[152]

COVID-19 focus: Fast-tracking robot and drone pilots to limit contamination and virus spread

Teleworking has reduced passenger transport during the pandemic, but increased demand for e-commerce and home deliveries – presenting a huge opportunity for 4IR innovations given restricted movement during city lockdowns. Robots and drones can help manage staffing shortages in manufacturing, logistics and supply chains. Many AV companies have seen demand jump and investments soar as the idea of human-free delivery became key.[153] *Kiwibot*, a robotic sidewalk delivery startup; *Refraction AI*, an automated delivery startup; *Phantom Auto*, a delivery robot software company; and *Manna Drone Delivery* have all raised more funds in the pandemic. This funding is likely to accelerate development and uptake of these services in the longer term.

Due to the contagiousness of COVID-19, AVs have facilitated delivery services to adhere to social distancing restrictions and quarantine policies. *Starship Technologies* launched a 'contactless delivery' service in US states Arizona, Virginia and California to plug the gap created by the close of traditional restaurants during the pandemic.[154] The autonomous robots extended accessibility to grocery stores and restaurants for the most vulnerable citizens in the community, who are in the 'high risk' category or quarantined. Meanwhile, *Antwork* aimed to reduce cross-infection within healthcare by transporting medical supplies using drones in Xinchang county, China.[155]

Automating distribution and sorting centres

Automation and robotics are deployed to **streamline warehouse operations**. Currently, 80% of warehouses are manually operated, mechanised equipment is being augmented by unloading and piece-picking robots to raise productivity.[156] DHL sees robotics as the most important emerging technology to transform distribution, both the manufacturing and logistics side of the supply chain.

Logistics, storage and handling company *SSI SCHAEFER* completely automated furniture retailer *JYSK*'s distribution centre in Nässjö, Sweden in 2015.[157] The new high-bay warehouse contains automated conveying systems for 165,000 pallets and robotic arms for ergonomic depalletising, among other features. These automated machines are controlled by an extensive logistics software system, such as the *Fetch Cloud Robotics Platform*.[158]

In Saudi Arabia, dairy company *Almari* has invested in fully automated picking, stacking and storing solutions for palletised foods in their distribution centre.[159]

Streamlining the freight industry

Another market facing disruption by 4IR innovations is freight, since EVs, IoT, cloud technology and AVs are being leveraged for more **efficient supply chain management, operations and distribution**, with blockchain supporting **transparent and traceable supply chain monitoring.**

China COSCO Shipping is leveraging IoT and 5G communications for seamless ship loading and unloading by automated driverless trucks at the Port of Xiamen.[160]

Leading Nigerian startup *Kobo360* uses a combination of IoT, mobile technology and data analytics to boost speed, efficiency and profit margins for manufacturers and farmers in five African countries.[161] The smart logistics platform also enables transparency, reliability and accessibility in the freight industry by providing real-time visibility on cargo and trucks.

South Korea's e-commerce platform *TEMCO* tracks product journeys from factory to retail, using blockchain, and makes complete product information available to consumers, including accreditations such as pesticide-free.[162]

C&E focus: Emissions-free electric vehicles make freight a greener industry

Advancements in battery technology and energy utilisation & storage alternatives present a huge opportunity for the freight industry to reduce transport emissions associated with both maritime and terrestrial distribution. Most ambitiously, *Port-Liner*'s all-electric container barges set sail from the ports of Antwerp, Amsterdam and Rotterdam in 2019. The zero-emissions barges are driven by 20-foot batteries that are charged on shore by the carbon-free energy provider *Eneco*, potentially removing 23,000 diesel-powered trucks from Belgian and Dutch roads per year.[163] Similarly electric lorries and carbon-neutral rail transport solutions are helping to decarbonise the mobility industry. *Nikola Motor Company* produces heavy-duty hydrogen EVs, with range and fuelling time equal to diesel trucks.[164] Its trucks are emission-free, producing only water as a by-product, while the H_2 fuel is produced by electrolysis from renewable sources such as solar power.

Optimising last-mile road and aerial delivery

While 3D printing and additive manufacturing support more efficiently organised distribution networks, **short-haul transport of goods** such as raw materials and fresh produce is still needed. Last-mile logistics and delivery is thus a testbed for 4IR innovations, especially given the impact of e-commerce on light goods vehicle activity in urban areas. Drones can alleviate pressure of on-land distribution systems, faster and cost-effectively, reducing the need for last-mile road connectivity.[165]

Singapore courier company *Ninja Van* uses cloud technology and machine learning for data processing to increase efficiency and **optimise delivery routes** across Southeast Asia.[166]

Last-mile delivery can also be fully automated as small mobile robots, like those developed by *Starship Technologies*, can complete food and grocery deliveries within 30 minutes.[167] The concept of ground delivery robots for cargo carrying is a companion to UAVs.

Drones are increasingly used for last-mile delivery of parcels.[168] *Amazon Prime Air* is trialling the delivery of light packages in <30 minutes using small drones.[169] See also the *Zipline* case study.

Case study: Efficient planning and management of shipping in the Netherlands

What is the innovation? The *Port of Rotterdam* has implemented an IoT platform to optimise shipping management and planning. The IoT platform uses a network of 44 sensors incorporated on and in quay walls, buoys, waterways and traffic signs to provide real-time infrastructure, hydro and meteo data such as wind speed and water temperature.[170] The platform processes 1.2 million data points daily to optimise berthing, loading/unloading and departure times using sensors, prediction models, astronomical calculations and *Rijkswaterstaat* data.[171]

What made it successful (or not)? Construction and implementation of the IoT platform was facilitated by collaborating partners *IBM*, *Cisco*, *Esri* and *Axians* and delivered under the Port Authority's direction. Its success lies in Rotterdam's creation of an enabling environment and marketplace for innovative solutions. The hyper-precise data processed by the cloud platform will pave the way for rapid innovation with access to complementary technologies, including blockchain and AI. The Port Authority also uses global, open interoperability standards to enable external parties access to real-time data online, such as the *Pilotage Service*, *Rijkswaterstaat*, and *DCMR*.

What is the role of the City? The initiative to develop Rotterdam as the 'smartest port' is enabled by the city's innovation ecosystem, in which a four-stage process drives the market (ideation, validation, acceleration and growth).[172] The *Municipality of Rotterdam* and the *Port of Rotterdam Authority*, together with 57 cross-disciplinary partners and the *Erasmus Centre for Entrepreneurship*, connect and strengthen all stakeholders in this ecosystem. As such, the city has enabled innovation and disruption, and created a platform for triple-helix partnerships.

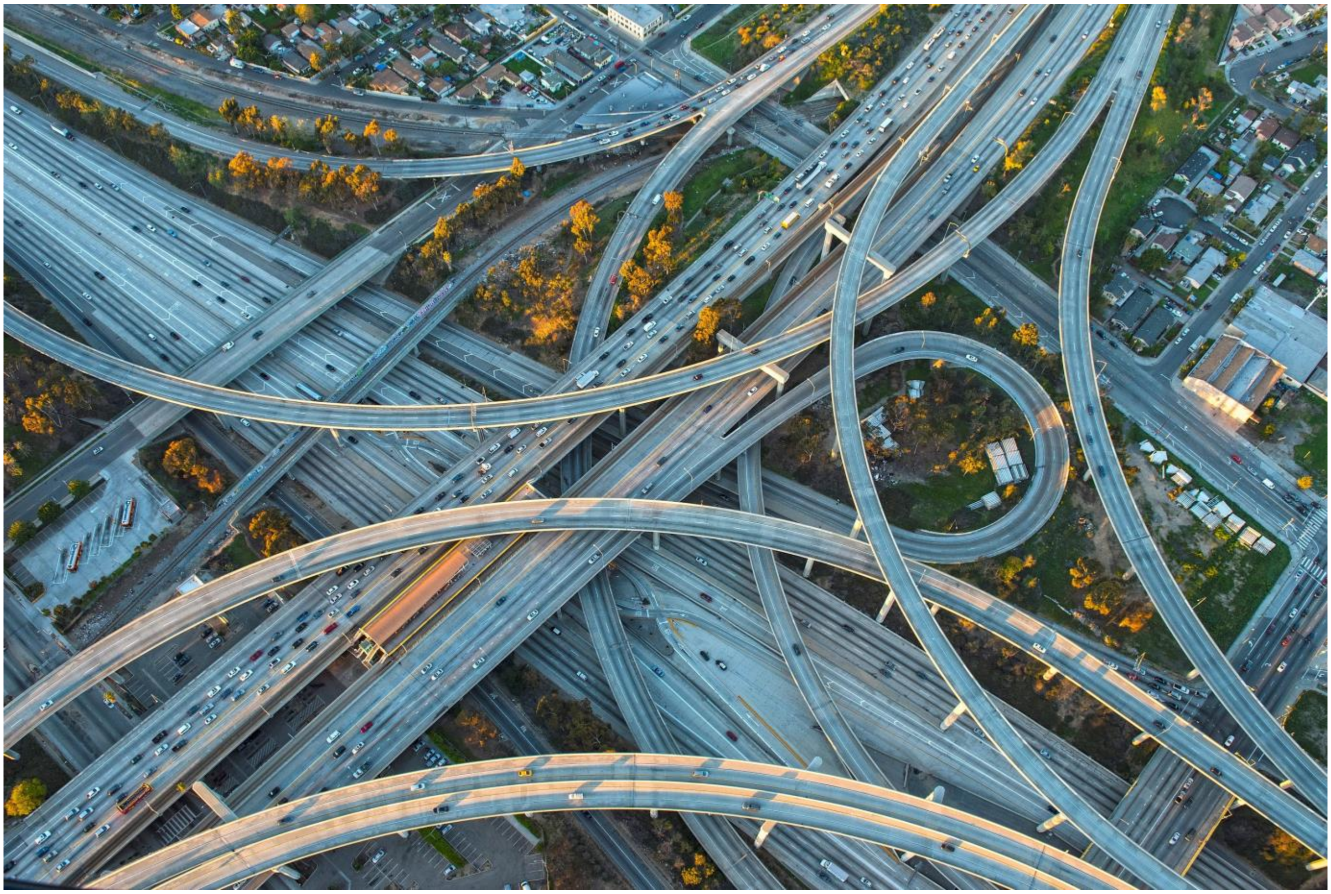
Case study: Medical drone delivery for humanitarian services in Rwanda and Ghana

What is the innovation? Drone technology has scaled to a point where two African countries can achieve greater access to healthcare. *Zipline* is a drone delivery company, now valued at $1.2 billion, which operates at a national level to provide instant medical access to nearly 22 million people in East Africa.[173] Medical drone delivery was launched in Rwanda in 2016 and two distribution centres have been opened in Ghana in 2019, with two others in construction. Each distribution-cum-medical centre makes up to 500 deliveries a day of life-saving health supplies, including over 170 different vaccines, blood products and medications.

What made it successful (or not)? Aside from the expertise of their robotic engineers, *Zipline*'s success in Africa is due to its ground-breaking regulation and cross-sector partnerships with healthcare facilities, pharmaceutical businesses and governments.[174] Before *Zipline* went live in 2016, it held a testing period partnering with the Rwandan government, setting the foundations for the medical drone delivery programme. Rwanda has also pioneered drone legislation, becoming the world's first country in 2018 to adopt performance-based regulations in its national airspace to allow both a dynamic response to technical challenges and ensure public safety.[175]

What is the role of the City? While not at city-level, the Rwandan Government is accelerating the adoption of emerging technologies through policy frameworks and strategic partnerships. As the main barrier to expansion of UAVs is regulatory, governments should prioritise the set-up of regulatory structures (see section 4.3). For example, commercial drone laws are needed to train and license pilots as well as to address safety, insurance and airspace concerns. Partnerships with non-profit and private drone operators will also build an enabling environment to leverage the 4IR for air mobility.

4. HOW ARE CITIES IMPLEMENTING 4IR MOBILITY?



The 4IR technologies and innovations set out in section 3 will need to be implemented in a considered and integrated way, to ensure they are contextually appropriate and supported by the necessary enabling environment and risk mitigation measures. Technology and infrastructure investments, new skills, adaptive governance and wide-ranging partnerships are all needed to take advantage of the 4IR for urban mobility and ensure that solutions are inclusive and sustainable. While cities are not expected to deliver 4IR innovations on their own – in fact that would be counterproductive – urban authorities have a key role to play in setting the vision, showing leadership and creating an enabling environment for success.

This section looks at four key areas enabling implementation of 4IR, as well as examples and success stories from cities around the globe. These areas are: financing and procurement of infrastructure and technology; upskilling and building digital readiness; facilitating change through adaptive governance, policy and regulation; and engaging stakeholders and developing partnerships. It is important to note that 4IR is still a relatively new concept. Cities around the world are, therefore, still learning by trial and error so there are few 'plug and play' options, given the importance of local context in shaping implementation. Figure 4 below links the application areas discussed in section 3 to the 4IR implementation considerations for cities explored in this section.

Table 1: Key considerations for cities around the process of implementing 4IR mobility

	Finance & procurement	Upskilling & digital readiness	Governance, policy & regulation	Stakeholders & partnerships
The Passenger Journey	How can the city play a role in creating the right opportunities for third parties to solve urban issues?	Do passengers need smartphone access? Can the city support incremental changes (e.g. zero-rated data)?	What policies and regulation already enable innovation in passenger journeys? What else is needed?	Which stakeholders must be consulted to 'leave no one behind'? What partnerships are required?
Planning & Infrastructure	What new tools can the local government explore to address funding gaps for city infrastructure?	Do planning officers/ maintenance workers have appropriate digital skills to use new technologies?	Do governance structures and regulatory processes enable or stifle innovation?	How can the city authority draw upon local and technical knowledge?
Data-driven Mobility	Is the city thinking long-term to invest in interoperable intelligent transport systems?	Do transport staff have access to data analytics training to enable efficient use of data collected?	Are there appropriate regulations in place to manage privacy and data security concerns?	Are partnerships set up to collect and share data across all parties in the mobility sphere?
Safety & Inclusion	How can city authorities embed safety and inclusion when financing and procuring projects?	How can transit operators and service providers train their staff to improve safety and inclusion?	Do policies and legislation account for safety and inclusion considerations?	Are the appropriate stakeholders engaged to prevent reinforcing barriers to inclusion?
Delivery & Distribution	Can the city engage directly with the public sector to pilot and scale innovations in this sector?	Are delivery operators and logistics staff adequately upskilled to use 4IR tech in their daily lives?	What new or existing regulation should be implemented or updated to enable automated delivery?	How can the private sector share best practice with public players to optimise urban mobility?

4.1 Financing and procurement of infrastructure and technology

Digital connectivity is an essential foundation for future 4IR mobility applications in urban areas. Technological advances of the 4IR call for strong network ICT and power infrastructure, requiring transversal government and public-private collaboration, as well as investment in mobility assets and new technology. While specific needs will be unique to each city, dependent on local context, demand and ambition, cities share similar challenges in **investment, financing and procurement of enabling infrastructure and innovative 4IR technologies**.

Investing in city infrastructure and technology

High bandwidth and low latency networks are essential for the functioning of IoT devices, autonomous delivery and integrated transport systems. While network infrastructure is the purview of national governments, cities need to consider investments in smaller-scale digital infrastructure to proactively grasp the 4IR opportunity. Ranging from **data centres** to support advanced computing technologies to **IoT devices** for parking and transport infrastructure maintenance, cities that are able to set a clear longer-term ambition are better equipped to make decisions around incremental investments in **interoperable systems**. Partnering with the private sector can also facilitate the development of essential infrastructure in the city (see section 4.4).

Cities can focus on deploying local infrastructure to support 4IR mobility, such as electric charging points, dock-based shared bicycles and smart streetlamps (see section 3.2).[176] Investment in **local road infrastructure provision and upgrade** is key to create new efficiencies in urban mobility.

The *City of New York* is modernising its mass transit networks and expanding sustainable transport modes. From 2019, the *Department of Transportation* (*DOT*) has worked to double the pace of implementing transit-signal priority intersections to prioritise bus routes on city streets. The South Bronx has already seen bus speeds rise 15-45% due to implementation of a two-way centre-running bus lane and repurposing of a pre-existing tunnel to bus-only.[177]

Reliable and readily available **charging infrastructure** will dictate the widespread uptake of electric vehicles in urban areas. In planning terms, it is important that cities engage with the utilities industry when determining locations for high-speed charging stations.[178]

New Delhi encourages EV uptake by collaborating with private players to address consumer concerns of 'range anxiety', the fear of no charging options if the vehicle runs out of battery. In March 2019, the *Government of Delhi* approved a plan to set up 131 public charging stations in the Indian capital, to be built at public transit stations, petrol stations, and parking areas around the *Indira Gandhi International* airport and *Jamia Millia University*.[179]

Revenue generation and cities' access to finance for 4IR mobility

Urban mobility and transport sit in a complex web of other city administration functions, including spatial planning and economic development programmes (see section 3.2). Data platforms and digital tools, increasingly to deliver broader e-government services, could also be used to **raise and manage local revenues** for 4IR mobility implementation. For example, MaaS operator revenues, which can include local government-led transit, are expected to grow fastest in Latin America, by a compound annual growth rate of 132% by 2030, and by nearly 71% in Africa.[180] Using blockchain in MaaS could also increase the transparency and trust around revenue allocation and sharing.[181]

As a stepping stone to 4IR-enabled payment systems, *Nairobi City County* has created an e-payments portal to secure a 30% rise in revenue collected from parking, alongside lower administrative costs.[182]

City municipalities can also explore **new finance mechanisms** such as green bonds for clean transport initiatives, innovation loans from regional organisations, or **blended public and private finance** through focused loans, grants and startup funding for new innovative PPPs.

The *Zero Emission Bus Rapid-deployment Accelerator (ZEBRA)* will work with Mexico City, São Paulo and Medellín, Colombia to support the deployment of electric buses – it expects commitments from regional finance institutions for $1 billion investment in zero-emissions EV technology in Latin America by 2021 and from major bus and engine producers to collaborate with cities on piloting, charging technology and financing.[183]

The *City of Sacramento* launched the *Sacramento Urban Technology Lab* (*SUTL*) to make the city a testing ground for future mobility technology and policy. It catalyses innovation by leveraging its network for triple-helix collaboration and innovation grants, and offers e.g. Ecosystem Building Grants to enact or expand mobility infrastructure and programming.[184]

Innovative public procurement at the city level

The role of cities in innovation is often as enabler and partner, but sometimes it will also act as the direct client. Scaling 4IR mobility applications in cities requires bold and proactive action on conventional processes of procurement and revenue sourcing. Representing 12% of GDP in OECD countries, **public procurement** is not only a huge market, but an opportunity to boost mobility innovation.[185] Changing cautious and complex public procurement can attract innovators, developers and entrepreneurs to provide solutions directly to city hall.

> The *City of Barcelona* has created an ethical digital standards toolkit for cities globally. It includes guidance on public procurement of ICT and innovation, based on new relationship models, ethical data management, agile methodologies and technological sovereignty.[186]

Engaging directly with private-sector companies through **reverse pitching, open competitions** and **requests for proposals (RFPs)** can accelerate the piloting and scaling of urban innovation.

> *Citymart's BidSpark* supports local governments in sourcing innovative bids at lower procurement cost and often with contracts won by smaller businesses boosting inclusion and economic development. Boston used the platform to procure a Senior Shuttle Scheduling Software, with the winning vendor delivering a 70% cost saving.[187]

> *Startup in Residence* (*STIR*) is an online procurement platform that connects startups, SMEs and social entrepreneurs with state agencies to tackle key urban and social issues. The *Municipality of Amsterdam* has used *STIR* as part of a wider incubator/accelerator initiative where the City acts as an investor or launching customer.[188] Through the reverse pitching platform, Amsterdam sought innovative solutions e.g. to a challenge of optimising traffic flows. The resulting *Balanced City* programme identified *Wander* as the chosen solution.[189]

G&SI and C&E focus: Gender-inclusive open competitions to showcase mobility innovations

C40's *Women4Climate Tech Challenge* is an international contest open to female designers and innovators focused on Climate Tech solutions to accelerate the decarbonisation of cities and achieve gender-inclusive climate action.[190] One of the finalists in the 2020 Tech Challenge was the *EcoLocal Market* project for green logistics. Co-founders Elizabeth Ledesma and Monica Pulido developed a mobile app that geolocates farmers and local producers to consolidate deliveries to improve transport efficiency in Barcelona.[191]

4.2 Upskilling and building digital readiness

Readiness to use 4IR-enabled mobility solutions often requires digital literacy, access to smartphones, as well as specialist skills for those who implement and use the technologies themselves. Given digitalisation, a growing set of jobs require digital skills; in Sub-Saharan Africa, 230 million jobs are predicted to ask for this by 2030.[192] Digital upskilling must keep pace with rapid technological change, with skills gaps set to grow across all industries as the 4IR shapes the future of work.[193] In South Africa, for example, 90% of businesses are engaged in *some* sort of digital transformation and 40% are struggling to recruit staff with adequate digital skills for related roles.[194]

Fears that the 4IR technology uptake threatens existing jobs are well-founded, given c. two-thirds of jobs are susceptible to automation in the developing world.[195] Yet new jobs may emerge; over 133 million job roles are estimated to open globally by 2022 due to the new division of labour between humans, machines and algorithms.[196] These jobs will, however, require enhanced digital skills.

Overcoming physical barriers to digital access

If cities want to realise the potential of 4IR mobility innovations, they must also support the consolidation of associated 3IR technologies. For example, mobile and e-ticketing will only offer significant benefits where users have access to a smartphone and can access the relevant app.[197] Broadly speaking, there are two types of initiatives that can be supported here.

First, **improving access to smartphones and the internet** is vital to ensure 4IR mobility innovations are equitable for urbanites, given several discussed in section 3 rely heavily on their use. In lower income economies, only 40% of adults have both mobile phone and internet access, compared with 82% in high-income economies.[198] There are also digital divides within countries, with richer households 20% more likely to have access, and between genders, with men twice as likely as women to have access in developing economies such as Bangladesh, Ethiopia and India.[199] Many partnerships have been forged to improve mobile technology access in developing countries, particularly for marginalised groups. However, upfront costs are not the only barrier to smartphone utilisation, which can also be affected by digital literacy, safety concerns and **data affordability**.

> *Sonata Finance*'s partnership with *Samsung* and *Savex* provides discounted smartphones to women in rural India through microfinancing. It offers weekly or monthly repayments and has successfully provided 15,000 smartphone loans across three states.[200]

> *Mobisol*'s partnership with *MTN Rwanda* and *Tecno Mobile* offers a rent-to-own smartphone model for low-income and off-grid populations in Rwanda.[201]

> *Vodafone* has partnered with *Hand in Hand* which expands access to smartphones for women micro-entrepreneurs in low- and middle-income countries.[202]

Second, **alternative engagement mechanisms** refer to different access routes, developed by the transport body or operator, that do not rely on *smart*phone access or internet use.

> *Uber* is testing a dial-in service in Arizona that allows users to book a ride via phone and receive driver updates via SMS messaging, without smartphone or internet access.[203]

> *AliPay*'s QR code-based payment system is able to operate without internet connection, allowing for payments to be made in-transit, even if the user's phone is 'offline'.[204]

Building readiness through digital literacy, upskilling and reskilling

For the general public to actively support and engage with 4IR mobility, adequate levels of **digital literacy** are needed. In Africa, 70% of those who do not use the internet say they do not know how to use it, and almost 40% say they do not know what the internet is (figures from 2016).[205] City governments have a role to play in understanding the need for digital skills, and building the **digital readiness of urban populations** to use 4IR technologies.

> The *City of Barcelona* has developed a **digital education and training programme** that aims to foster greater public awareness of emerging technologies and empower people to use them in their daily lives.[206] The programme established a *Cibernàrium,*[207] which allows people to train in technology and prepare themselves professionally through digital skills. Across its first 20 years, the school has held over 52,000 training sessions attended by 140,000 people, covering the four levels of upskilling below:
>
> - **Basic training:** Using day-to-day tools; computers, mobile phones and the internet.
> - **Specialised training:** Targeted programmes and technical training that can develop professional technology-related skill sets, across a range of industries.
> - **Advanced training:** An ICT academy to develop skills specific to a career in ICT.
> - **Promotion of technological careers:** STEAM training and activities for boys and girls, families and teachers.

In 2017, the *Singaporean Government's Ministry of Education* launched their *SkillsFuture for Digital Workplace* initiative,[208] which aims to **build digital confidence** and adopt a positive mindset towards change, innovation and resilience. This two-day training programme covers topics such as cyber security, data interpretation and how to use e-payment systems. Through partnering with technology companies such as *Microsoft*, *Samsung* and *Lazada*, the initiative set a target to train 100,000 Singaporeans over the course of three years. The wider *SkillsFuture* programme also offers a skills framework for public transport, which covers technologies such as IoT, robotics, and automation, amongst other technical skills.[209]

The *University of Helsinki* and *Reaktor* have created a free 'Elements of AI' online course to empower people with AI skills, with students from over 170 countries, c. 40% women.[210]

Governments and private companies are also investing in the **upskilling of their own staff:**

The *UK Government* is building the 4IR digital readiness of staff through the *Government Technology Innovation Strategy*. The Government Digital Service, as part of this strategy, provides in-house digital upskilling for government staff and has trained over 10,000 people to date, in topics such as AI, AR, VR, blockchain, geospatial technology and quantum computing.[211] A ten-week *Emerging Technology Development Programme* has also been launched, to provide tailored **expert-level learning on emerging technologies** equipping staff with the skills, knowledge and expertise to act as specialist advisors across government bodies.[212] The *Strategy* also seeks to support industry secondments for staff to transfer best practice and experimentation culture from innovation technology firms.

In South Africa, Kenya, Nigeria and Ghana, *Uber* has partnered with insurance company *Old Mutual* to provide their drivers with free money management workshops, supporting them to start, run and grow small mobility enterprises on their own terms.[213]

Nigerian ride-hailing platform *Gokada*, also provides their employees with training on how to use the mobile technologies involved in their day-to-day operations.[214]

Developing a digital economy across the ASEAN region[215]

The *WEF* is leading the *Digital ASEAN* initiative, which aims to support the region in unlocking the benefits of the 4IR. Under the digital upskilling workstream, the initiative has launched the *ASEAN Digital Skills Vision 2020* programme in November 2018, a collective pledge among companies and organisations to train workers, digital regulators and the wider consumer public.

As of August 2019, signatories have pledged the following, against the initiative's 2020 targets:

- The **training** of almost 9 million ASEAN SME workers (target of 20 million)
- Raising over $4.4 million for **scholarships** for ASEAN technology students (target of $2m)
- Hiring over 38,000 additional **digital workers** (target of 200,000)
- More than 1.1 million citizens engaged through **Digital Inspiration Days** (target of 20,000)
- Offering 30,000 **internship opportunities** to ASEAN students (target of 2,000)

- Training 3,580 ASEAN **regulators** (target of 200)
- Over 4,000 commitments to shape the **curricula at ASEAN universities** (target of 20)
- Training over 3 million ASEAN citizens on **digital literacy and online safety** (target of 40 million)

Given the risk of job losses in transport and mobility due to 4IR technologies, overcoming public fear by **reskilling in line with new jobs** that will emerge should be considered beyond upskilling. Over 50% of jobs in the transport sector are highly susceptible to automation, emphasising the importance of reskilling in helping displaced workers secure comparable or better jobs.[216] While there is limited evidence of mobility-related reskilling initiatives to date, this is undoubtedly an area for city and national government departments to develop in support of wider 4IR initiatives.

Strengthening public trust in 4IR technologies

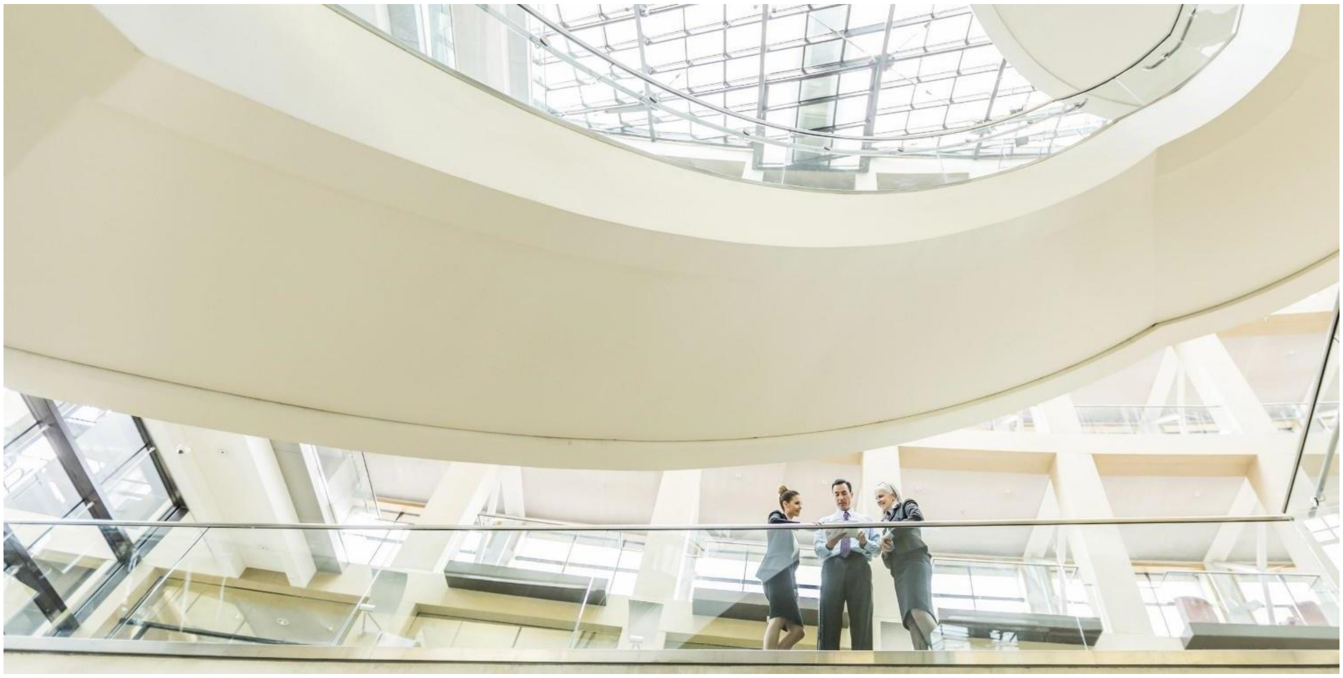
A significant barrier to readiness for 4IR mobility is the **public perception of safety and security**, preventing potential users from trusting 4IR systems. While governments should resist the impulse to enact highly restrictive policies for new technologies, lack of regulation can also be problematic, failing to mitigate risks and negatively influence the media's portrayal of 4IR innovations.

> The operation of e-mobility in London for years without explicit governmental approval is a powerful example of when policy lagged behind innovation and failed to adequately protect road users. The death of a pedestrian in 2018, who died after being hit by an electric bike, prompted a debate about the safety concerns of e-bikes and a call for tougher laws.[217] While e-scooters are expected to be legalised on roads and cycle lanes later in 2020, e-bikes still have lax regulations and can be used by anyone over 14 years.[218] Proactive and evolving policymaking to prevent dangerous situations is thus key for successful 4IR application.

Through enhancing public understanding of new technologies and digital systems, cities can **build trust** in these innovations, reducing its potential to act as a barrier to implementation and uptake.

> Public resistance to AVs due to safety concerns and discomfort with the lack of human control is a key example. To accelerate the public shift towards the technology, the AV industry has assembled organisations such as the *Self-Driving Coalition for Safer Streets* and *Partners for Automated Vehicle Education (PAVE)*. These bodies convene AV technology developers, startups, research experts and private companies to enhance public acceptance through factual, digestible information about AVs and their development.[219] *PAVE* hosts 'hands-on' AV demonstrations with the general public, releases educational toolkits, and facilitates policymaker workshops alongside major academic institutions.[220]

4.3 Facilitating change through adaptive governance, policy and regulation



The rapid pace of 4IR calls for new modes of city-level governance, policies and regulation that are agile and adapt to the changing mobility landscape. As recently demonstrated by the COVID-19 pandemic, such qualities are important to meet new challenges and build resilience for future disruption – as well as the pandemic offering opportunities to accelerate the development of 4IR policy itself. Unlike the pandemic, city governments can more easily expect and prepare for impacts of the 4IR, by creating conducive policy and favourable regulatory frameworks. These can help incentivise the application of technology, mitigate significant risks, and create an ecosystem where innovation can thrive. All levels of government (national, regional and local) need to set clear signals and lay out a roadmap for enacting regulations for emerging technologies. For example, legal frameworks for AVs require updated insurance policies to clarify responsibility in accidents.

Agile governance to promote innovation

Governance must evolve in response to disruption in the marketplace, favouring **adaptability and flexibility** over incumbency and restriction. Eric Schmidt and Jonathan Rosenberg, the former CEO and former Senior Vice President of Products at Google, simply state that "the role of government isn't to prevent change but to allow disruption to occur".[221] With regards to the 4IR, proactive principles, protocols, rules and policies can accelerate the positive impacts of emerging technologies and business models, while minimising their potential exclusionary consequences.

One feature of agile governance is a preference for **proactive and enabling policymaking**, which defines the protocols for technology developments. Promoting innovation through city governance can allow for a faster spread and greater scale of advanced technologies.

> Three government agencies of the *Beijing Municipality* jointly released two publications to allow *Audi*, *BMW* and *Daimler* to test AVs in China's capital city.[222] The *Guiding Opinions* and

the *Implementation Rules* mark a significant move in China's implementation and legislation of intelligent and connected vehicles.

Rwanda is also placing technology at the heart of its economic transformation and has spearheaded drone performance regulations for the commercial use of UAVs.[223] The Minister of Information Technology and Communications emphasised that this regulation sets the stage to "accelerate the adoption of emerging technologies to transform people's lives".[224]

A pragmatic approach to interpret existing policies and govern emerging technologies is a **regulatory sandbox**. These sandboxes are safe spaces for companies to test innovative products and services for a limited time period in a real-life environment, where risks are clearly identified and mitigated.[225] Governments can use regulatory sandboxes to encourage innovation through flexible regulatory frameworks and processes that keep up with the fast pace of 4IR.

The *Monetary Authority of Singapore* is currently pioneering this agile approach with their *FinTech Regulatory Sandbox* application process and system.

In the mobility sphere, Sweden's *Elmob* project utilised a regulatory sandbox to test electric-powered shared transport in Gothenburg, without requesting any changes to national or EU laws.[226]

See also the *Jätkäsaari Mobility Lab* case study in section 3.2 on how Helsinki designated an area of its city to pilot new mobility solutions, and the box-out in section 4.4 on how Mexico City's regulation has enabled startup collaboration with informal transport operators.

Establishing policies to build transparency

The pace and novelty of technological development often renders previous policymaking cycles inadequate, as new technologies scale and mature much quicker than in the 3IR. Innovations of the 4IR inherently build on and diffuse over digital networks, converging and combining to create ever stronger ecosystems governed by algorithms, coding rules and robotic process automation, independent of human action. Thus these technologies require regulation to **set best practice for data governance, protection and sharing** to enhance transparency between all stakeholders, and to build trust in 4IR technologies and implementation (see also section 4.2). With increasing big data drawn from IoT devices and stored on the cloud, privacy and surveillance sectors are concerned by the lack of meaningful consent to the collection and processing of personal data, despite stringent data security provisions e.g. in the EU (GDPR), in turn posing a possible threat to personal privacy.

Regulation that facilitates **interoperability and open-source technologies** has both commercial and non-commercial benefits for organisations and customers. An open data approach encourages development of innovative solutions, as urban data on the use of public space and infrastructures is shared with users, cities, third-party apps, operators, developers and innovators.[227] 'Opening' big data is key to establish integrated transport networks for seamless urban mobility.

Waze Connected Citizens is a public-private **data collaborative** promoting efficient traffic monitoring. *Waze* is a two-way, data-sharing platform that receives real-time data from road sensors and incorporates publicly available incident and road closure reports.[228] Leveraging open data to gain better insights, the application returns a succinct and thorough overview of road conditions to improve urban road management and reduce congestion in cities.[229]

Incentives to influence the consumer market

Fiscal policies are a highly efficient means to shape the market, influence consumer behaviour, and promote cleaner, more sustainable mobility options. Effective government action can even mitigate the perceived negative factors of emerging technologies through subsidies, innovation support or differentiated taxation schemes. Cost savings in incentive payments, for example, can encourage the purchase of EVs.

Volkswagen identifies attractive purchase incentives as one of the main reasons why China recorded 788,000 pure electric car registrations in 2018 (compared to 24,000 in the USA).[230] Purchase incentives in late 2019 stood at CNY 25,000 for EVs with a range over 400 km and CNY 18,000 for electric ranges between 250-400 km.

Similarly, car buyers in Norway benefit from 25% savings when buying an electric car as EVs are exempt from VAT for regularly fuelled vehicles.[231]

C&E focus: Fiscal incentives to maximise the commercial uptake of electric vehicles

'Feebates' can incentivise vehicle makers to provide more efficient technologies and drivers to choose cleaner cars.[232] Uber's *Clean Air Plan* is one feebate initiative which is designed to tackle urban air pollution and incentivise the electrification of its entire London fleet by 2025 (40,000 cars).[233] From early 2019, a 'clean air fee' of 15p per mile is included on every trip booked through the Uber app which complements their ambition to encourage up to 20,000 drivers to upgrade by the end of 2021.[234] The commitment supports the Mayor of London's vision to reduce pollution by encouraging cleaner vehicles, launching the Ultra Low Emission Zone, implementing Low Emission Bus Zones, investing in EV infrastructure and undertaking air quality audits.

Multi-stakeholder collaboration can achieve international standardisation

Policymaking is no longer limited to governments, but rather is an increasingly **multi-stakeholder endeavour**, including governments, companies, academic institutions and NGOs (see also section 4.4). The *World Economic Forum* elaborates on this trend: "as traditional policy development processes lag behind the rapid pace of technology innovation, citizens increasingly expect the private sector and other non-government entities to take on new responsibilities and develop new approaches to support the diversification and speed of governance".[235] The pace of technological innovation creates a new role for the **private sector and academia** to provide public officials expertise on the technologies they develop, their applications and potential consequences. Technology pioneers are increasingly developing **private rules, accreditation schemes, standards, social norms or policies** that, by default, influence the changing social and economic structures.

The *Alliance for Internet of Things Innovation* (*AIOTI*) is a consortium initiated by the European Commission in 2015 to strengthen interaction among IoT players, contribute to the creation of a dynamic IoT ecosystem and accelerate IoT uptake.[236] Members include big firms, successful SMEs, dynamic startups, research centres, universities and associations. The *AIOTI* gathers evidence on market obstacles for IoT deployment and maps global, EU and Member States' IoT innovation activities to bridge standardisation gaps. It has already begun removing deployment barriers in EU Member States: its partnership with the *5G Infrastructure Association* will strengthen end-to-end digitalisation and explore IoT use opportunities that can be built on these world-class digital infrastructures in Europe.[237]

4.4 Engaging stakeholders and developing partnerships

Widespread collaboration and partnerships between city government, industry, academia and civil society will be key to successful 4IR implementation. Consensus-building involves multiple actors operating across all market sectors and requires experimentation, learning and flexibility for institutional design.[238] This is particularly relevant for the mobility sphere as transport services are provided by both the public and private sectors, with local authorities or transport operators often acting as the travel information service provider for a specific area. The inherent nature and purpose of transportation networks demand that citizens and the community are consulted as key stakeholders to address ethical issues such as affordability, safety, accessibility, reliability and integration. Therefore, there is a need to understand the interests and concerns of stakeholders, while developing widespread partnerships to make the 4IR mobility business model viable.

Transversal collaboration across government and community

Collaboration across regional, national and local authorities can help enable a **holistic government approach** to the implementation of 4IR mobility, encouraging that the interests of all key stakeholders be taken into consideration in the early stages of a project lifecycle.

> Denmark's *National Centre for Public Sector Innovation* has sought to foster innovation within and across government by developing a step-by-step guide to help apply the 4IR in new contexts, encourage self-organisation and support dialogue between innovators and the public sector.[239] The *Spreading Innovation* guidebook stemmed from its study, which found that almost 80% of public-sector innovations were carried out with third parties.[240]

> The *European C-ITS Corridor* is a multinational collaboration to create a connected V2X motorway along the 1,300 km Rotterdam-Frankfurt-Vienna route.[241] Through implementing

cooperative intelligent transport systems (C-ITS), it aims to improve road safety and reduce congestion due to roadworks, accidents and other disruptions. The *Ministry of Infrastructure and the Environment of the Netherlands*, Germany's *Federal Ministry of Transport and Digital Infrastructure* and Austria's *Ministry for Transport, Innovation and Technology* are providing necessary network infrastructure, in partnership with the automotive industry

Another important component in multi-stakeholder collaboration is **grassroots innovation and crowdsourced policymaking**. Initiatives to engage citizens and the community should go beyond market research, instead focusing on a process of **co-creation**.

GovLab's *CrowdLaw* is a platform where the American public can propose legislation, draft bills, monitor implementation and supply data to improve the quality and effectiveness of lawmaking through the use of websites, apps, social media and offline engagement.[242]

The Finnish government has already adopted this grassroots approach to build public trust and transparency, address societal challenges and encourage a culture of innovation and experimentation. The digital platform *Place to Experiment* upholds two-way, crowdsourced collaboration and aims to "shift the method of developing services from a top-down dictated process to a more co-created process for public sector innovation".[243]

See box-out below how Mexico City has influenced collaboration between a startup and a community of informal transport operators.

G&SI focus: City role in collaboration between startups and informal economy operators

A high prevalence of informal modes of transport characterise many cities in the developing and emerging world from minibus taxis in Johannesburg, to matatus in Nairobi and daladalas in Dar es Salaam. *Jetty*, an app-based collective transport platform in Mexico City, works in partnership with informal minibuses (jitneys or colectivos) and offers insights into how cities might harness the network of informal 'public' transit while enabling technology and safety upgrades.

In Mexico City, the local government grants concessions for minibuses to operate and approves their driving routes, which are subject to intense competition for passengers. The City created a regulatory framework for app-based services in 2015 in response to the market entry of ridesharing players, allowing operators to charge market prices as long as vehicles are modern, drivers agree to background checks and 1.5% of gross fare revenues are set aside in a *Taxi, Mobility and Pedestrian Fund*. This brings both revenue and data on the number and length of trips to the City.[244]

Adequate, responsive regulation is key. The city's app-based regulation enabled *Jetty* to operate in the first place, but its particular service created initial misunderstandings and conflict with the city and regional governments.[245] *Jetty* aims to standardise and upgrade the quality, safety and reliability of services of existing operators to reduce congestion and offer an alternative to private vehicle use. Its business model enables operators to be more responsive to passenger feedback, and incentivises higher quality services through driver training, fixed salaries and insurance.

Jetty shows that incremental digital and quality upgrades are possible without needing to bypass existing operators or jump to the latest, expensive technology to bring about upgrades in quality and safety of mass transit.[246] The startup also faced difficulties in recruiting transport operators to supply rides, given fears related to competition, unproven methods, and security concerns for drivers that are associated with *Jetty*. Building trust between stakeholders is key as is access for lower income groups, given its app-based nature and slightly costlier service.

Public-private partnerships (PPPs) and entrepreneurial innovation ecosystems

Partnerships across the **public and private sectors** enable technical experts, innovators and investors to present novel solutions to the socio-economic challenges faced by communities across the world. PPPs provide the space for private sector technological innovation and experimentation to join forces with governance, policymaking and regulation for **aligned outcomes**. PPPs can also offer a feasible, financially-attractive, and potentially accelerated, option for cities to finance new technology or upgrade infrastructure.[247] However, given greater data sharing and collaboration in the 4IR era, terms of PPPs need to consider appropriate incentives, revenue and risk sharing.[248]

The *City of Boston* kicked off a partnership with the *WEF* in July 2016 to explore the use of AV technology. It focused on creating policy recommendations and developing a framework for on-street testing of AVs to create "a safe, reliable and equitable mobility plan for Boston's residents".[249] The potential of shared, autonomous vehicles to enhance accessibility and increase road safety were identified as key factors in the *Go Boston 2030* project.[250] After the one-year partnership with WEF, Boston is currently conducting AV tests in the South Boston Waterfront and Raymond Flynn Marine Park with partners *Aptiv* and *Optimus Ride*.

The *Living Roads* partnership between *IBM Research* and *Nairobi City County* enables data collection on the condition of the city's streets and the location of traffic delays due to potholes, speedbumps, flooding and other road obstructions.[251] Smart devices mounted on 10 waste collection vehicles transmit data to *IBM* researchers to address the challenges faced by the Kenyan county.

City governments also play an important role in **fostering innovation ecosystems** that encourage developers, startups, incubators and entrepreneurs to explore and experiment with innovations, new approaches and technologies to change society. Creating a space for accelerated ideation will attract third parties who can collaborate or even lay the foundations for implementing 4IR mobility.

The *City of Barcelona*'s *Digital City* initiative creates an innovation ecosystem that attracts public, private and academic partners to implement urban technology to improve services for city residents. The *5G Barcelona* project aims to transform the city into a lab to validate 5G technology and related IoT applications, such as AVs and drone-based services.[252]

The *Los Angeles Cleantech Incubator (LACI)*, set up as a city-led innovation initiative and a vehicle for economic development by the City of Los Angeles and its Department of Water &

Power (LADWP), has supported the development of an innovation ecosystem in Los Angeles through piloting urban innovations including in mobility and helped 78 portfolio companies raise $221 million in funding, $220 million in revenue, create 1,750 jobs, and deliver more than $393 million in long-term economic value.[253]

Academia completes the triple-helix partnership

Partnering with **academic institutions, research associations and universities** can enrich a PPP by pooling the expertise needed to rapidly scale 4IR technologies from concept to implementation.

The *HydroFLEX* project, which developed the first hydrogen-powered train in the UK, was only possible because of the strong partnership between the *University of Birmingham* and rail rolling stock company *Porterbrook*.[254] The university has converted *Porterbrook*'s 'Class 319' electric unit into a hydrogen fuel cell train to demonstrate how EVs can be deployed across the UK.[255] The zero-emission train supports the British Rail Minister's challenge to remove diesel-only trains from the rail network by 2040.

Similarly, Sweden's *Next Generation Travel and Transport* programme has led to the launch of self-driving electric buses at the Chalmers University of Technology, Gothenburg.[256] Behind this venture is a partnership between 15 organisations and companies related to mobility, urban planning and transport across business, academia and public sectors.[257]

International collaboration can create new efficiencies

Collaboration and partnering is not confined to geopolitical boundaries, but should be a **transnational endeavour to share best practices, lessons learnt and success stories**. Given the term 4IR was coined by the *World Economic Forum*, the organisation also acts as a global facilitator for public-private cooperation to carefully blend and balance the offerings of business, political and academic institutions. The international partnering of stakeholders in the mobility sphere can encourage efficiency and resilience through **digitalisation and standardisation**.

Networks such as C40 Cities bring together city authorities from around the world to connect with their **urban peers**, inspire innovation, provide advice on lessons learned and influence broader policy agendas across initiatives such as land use planning, mass transit, mobility management, walking, cycling and zero emission vehicles.[258]

In Europe, the *Knowledge and Innovation Community on Urban Mobility* (EIT Urban Mobility) is developing novel solutions to transport networks.[259] The €1.6 billion project is led by the *MOBILus* consortium, composed of 48 cities, 12 businesses and 18 universities in 15 countries. Expected outcomes include the creation of 180 associated startups, reduced congestion in participating cities, the upskilling of 1,450 graduates in transport-related specialties and increased shared mobility.[260]

The *International Port Collaborative Decision Making Council* recently partnered with the *International Maritime Organization*, *World Customs Organisation*, *ISO* and *UN Economic*

Commission for Europe to support the digitalisation of maritime operations and harmonisation of data standards.[261] The partnership paves the way for actors in the shipping industry to exchange real-time data and efficiently coordinate port operations.

G&SI focus: Setting ethical standards for 4IR mobility

In the absence of an organisation that sets universal technology standards, industry leaders have collectively called for the adoption of ethical principles to guide R&D activities. One example of such an initiative is the *Asilomar AI Principles*, designed to guide the fair, safe and responsible development of AI in the spirit of 'beneficial intelligence'.[262] To date, 5,322 AI researchers and other endorsers are signatories of the 23 *Principles*.[263] As a result, standardisation and interoperability pilots are emerging in which solutions are designed for societal use-cases. The *European Commission* also set up a 'High-Level Expert Group on Artificial Intelligence' in July 2018 with 52 experts from the private sector, academia and civil society – within a year, it had developed 'Ethics Guidelines on Artificial Intelligence', to be updated in 2020 after pilot testing.[264]

5. CONCLUSIONS AND LEARNINGS

This section summarises – and draws lessons from – the international trends, 4IR mobility use cases and implementation considerations presented in this report.

5.1 Summary conclusions and 4IR mobility learnings

Key trends

The five **key trends** shaping 4IR mobility today can inform planning and implementation strategies for cities across the world.

- **Rise of Automation** reflects the growing trend of AVs and other robotic devices operating without direct human control or oversight, with risks of job losses and safety concerns.
- **Intelligent and Connected Systems** optimise processes for communicating and sharing data across wider networks, yet also introduce a host of data and cyber security risks.
- **Electrification for Greener Transport** has led to a rise in EV uptake, with the demand for electric charging infrastructure crucial to recognise and incorporate into city planning.
- The **Sharing Economy** expands the range of shared, as-needed mobility options, though, accessibility and affordability remain key concerns to ensure inclusion.
- A **Responsive and Evolving Enabling Environment** supports all the above, to effectively respond to, and promote, the development and adoption of 4IR mobility technologies.

Use cases

The international 4IR mobility **use cases** showcase the range of potential innovations. Many are only just reaching widespread deployment and thinking on best practice will continue to evolve.

The Passenger Journey

Further consolidation of transport modes on shared platforms is expected alongside the continued rise of MaaS platforms and apps, enabled by the development of digital payment systems and decentralised ride-hailing services. These innovations offer a number of flexible ways to enhance the user experience of transport use across cities, with the potential to increase inclusivity, enhance convenience and streamline travel. The implementation of such innovations, however, is not without challenge. Cities must not only facilitate effective collaboration between transit stakeholders, but also engage the urban public in behavioural change – failure to do so could risk resistance from both incumbent public transport providers and users themselves.

City Planning and Infrastructure

Coordination across siloed city departments to plan and manage space holistically can be a challenge, but also an important first step to consider innovative 4IR planning tools. VR/AR for real-time planning, RFID sensors for optimised parking and 3D-printing drones to repair potholes, are just some of the ways which 4IR technologies are being used in this area. These innovations can support urban planning and the ongoing management of infrastructure, effectively remedying problems of depreciating assets, ineffective use of space and insufficient parking. Potential for job displacement and losses, and hence resistance to technological advances, are risks that need to be addressed in the context of automating more labour-intensive monitoring and maintenance tasks, so reskilling should go hand-in-hand with these 4IR applications.

Data-driven Mobility

Innovations of the 4IR to optimise traffic management are currently immature in cities globally, but offer exciting opportunities in the long-term. Big data analysis can identify new efficiencies in public transportation logistics, traffic management and seamless journey planning. Connected devices and Internet of Things enable urban planning authorities and transit operators to integrate transportation networks, offer real-time insights and reduce congestion. Along the need to add supporting technology and infrastructure, a key challenge is building trust across mobility players and ensuring data security to enable V2V, V2I and V2X communications.

Safety and Inclusion

Increased focus on the safety and inclusion of 4IR mobility are expected, given these are imperative to consider across all aspects of change in the urban transport system. Safety and inclusion agendas are benefiting from 4IR innovations, including 'accessible' routes identified through IoT, cars that can automatically report accidents, and crowdsourced data on safer areas for women within the city. Leveraging these solutions could democratise movement across the city, helping people with disabilities navigate streets, enhancing safety for women, and reducing the incidence of road traffic accidents. Key challenges include access to smartphones and the internet, as a number of these innovations rely on real-time data collection and reporting.

Distribution and Delivery

While emerging technologies are already being leveraged, the uptake of robotics and drones will remain sporadic until the cost and regulation challenges are addressed. Industrial robotics and UAVs present many opportunities to optimise and integrate the movement of people and goods around cities. These innovations could reduce congestion and alleviate pressure on road infrastructure, speed up delivery times as well as improve the transparency and cost-effectiveness of supply chains. The most important barriers to entry are the costly implementation of robotics and the need to remain abreast with regulatory needs for drones.

Areas of implementation

Four **areas of implementation** were discussed in this report, underscoring the importance of cities in creating an enabling environment for 4IR innovations to flourish in the mobility sphere.

Financing and procurement of infrastructure and technology

City investment in, and support of, local infrastructure and technology development is a crucial catalyst for 4IR interventions. Direct city contributions can include the upgrade of local roads, allocation of specific bus lanes and installation of electric charging stations. Cities should also explore alternative mechanisms to **financing**, including blended finance, as well as to **public procurement**, such as reverse pitching and competitions, to boost 4IR innovation adoption.

Upskilling and building digital readiness

Cities can play a key role in overcoming physical barriers to access 4IR mobility innovations, improve digital literacy, upskill and re-skill staff, as well as build trust among the public in emerging technologies. Methods include the facilitation of rent-to-own smartphone schemes, or alternative engagement mechanisms that do not require internet or mobile access. Enhanced digital readiness, through digital education programmes and training, by both public and private institutions is also needed. Similar educational techniques can also be used to build public understanding of and trust in 4IR technologies, which is fundamental to their lasting success.

Facilitating change through adaptive governance, policy and regulation

City governments can support the adoption of 4IR mobility by developing governance structures that allow for proactive and enabling policymaking. These policies are vital to set best practices around data governance, protection and sharing to build trust and transparency across all stakeholders, including users. **Fiscal policies** and **regulatory sandboxes** also offer ways for cities to proactively shape the market, influence consumer behaviour and promote more sustainable mobility options that suit the city's needs. Collaboration across 4IR mobility planning and implementation will help cities learn from the expertise of academia and the private sector.

Engaging stakeholders and developing partnerships

Transversal collaboration across government and community is vital to enable a holistic approach to 4IR mobility that accounts for the needs and interests of all concerned parties. Mechanisms can include crowdsourcing platforms and innovation guidebooks. There is also great value in engaging in **PPPs**, **innovation ecosystems** and **triple-helix partnerships**, with both academic and private institutions, to pool knowledge, experience and capital. These partnerships should not be confined to the city-level context, rather considered and executed at an international level to share best practices, lessons learnt and success stories.

5.2 Moving forward and implications for cities

The range of innovations in 4IR mobility, and the significant technological and skills investments required, may seem daunting. For cities wanting to keep up with the rapid pace of change, which will happen regardless of their action or inaction, this report highlights these key considerations:

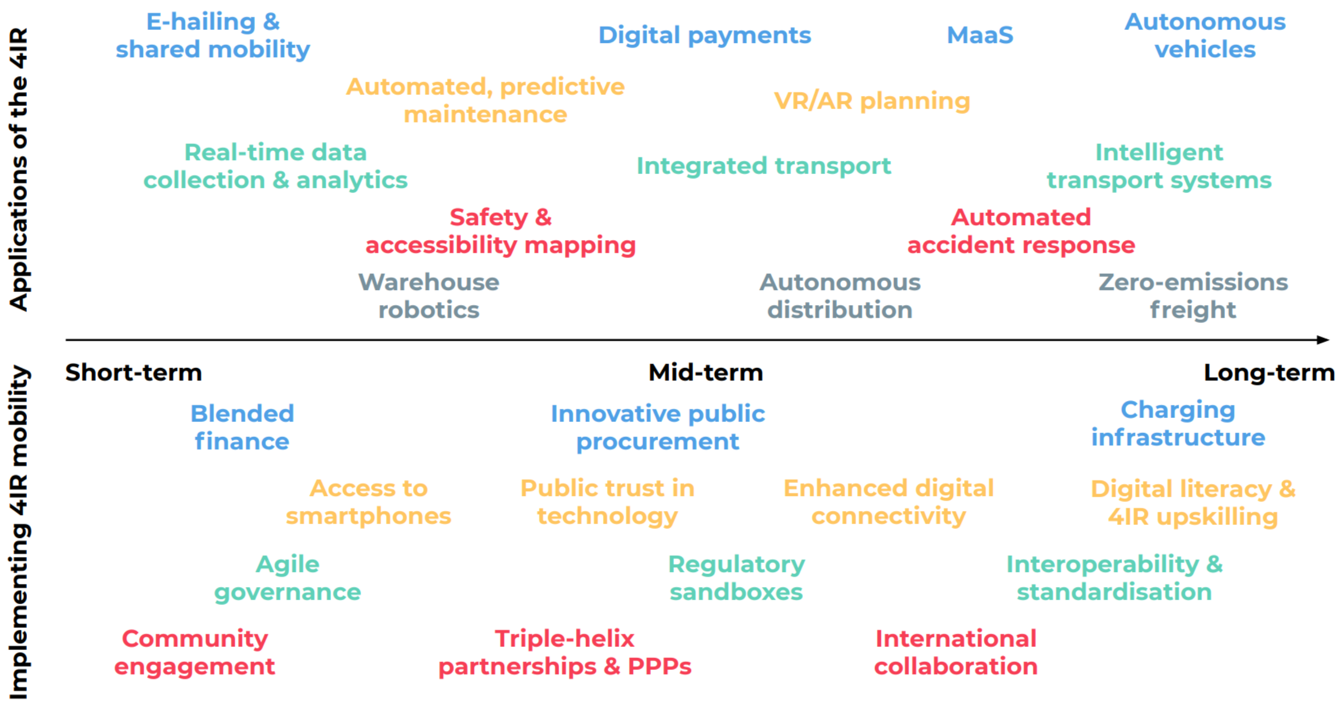
> **Context matters:** Ultimately, each city needs to decide which technological innovations can enhance its overall developmental agenda and how to identify and mitigate potentially negative impacts of these innovations and platforms.

> **Process of change:** Whichever mobility innovations are chosen for implementation, the process will require a willingness from cities to be more agile and adaptive in governance, policymaking and regulation, and accept that failures and missteps are part of testing

> **Empowering transformation:** Successful 4IR mobility draws on wide-ranging partnerships and creates a sense of ownership among stakeholders, while building trust and skills for 4IR readiness will help mitigate the very real risks around exclusion and the digital divide.

What 4IR mobility innovations might be deployed and how cities can enable their implementation, discussed in sections 3 and 4, differ by urban context, foundations and experience, but **indicative timelines for adoption** can be drawn between different solutions. Figure 5 ranks these according to the requirement of: new infrastructure or technology, capital expenditure, partnerships, regulation and digital readiness. The short-term examples include applications that already exist and/or are used in cities globally or could be readily deployed through apps. Where smaller-scale or modular options can leverage existing tools, but only scale with additional expenditure, these are considered as mid-term examples, while long-term use cases require greater investment in infrastructure and technology, appropriate partnerships and enabling policies to scale.

Figure 4: Timeline of 4IR mobility innovations and implementation



Finally, cities play several important roles in 4IR mobility, as regulator and policymaker, financier and investor in the ecosystem, open-access partner, stimulator of the modal shift and in some cases the user. Starting points for action include setting and communicating a clear vision, exploring finance mechanisms for implementation and identifying quick wins to gain buy-in for larger-scale adoption of public-facing 4IR mobility applications that may prioritise safety, access, affordability and sustainability.

ENDNOTES

[1] Jadhav, A. (2019) Autonomous Vehicle Market Outlook – 2026
[2] Cisco (2019) Internet of Things (IoT) – The future of IoT miniguide: The burgeoning IoT market continues
[3] World Economic Forum (WEF) (2016) The Fourth Industrial Revolution: what it means and how to respond
[4] United Nations (UN) (2020) Cities – United Nations Sustainable Development
[5] World Bank (2017) Africa can enjoy leapfrog development
[6] Adapted from PwC & WEF (2017) Harnessing the 4th Industrial Revolution for Sustainable Emerging Cities
[7] "For something to be innovative, it needs to be new, surprising, and radically useful". Source: Schmidt & Rosenberg (2014) *How Google Works*
[8] European Bank for Reconstruction and Development (EBRD) (2019) Disruptive technology and innovation in transport: Policy paper on sustainable infrastructure
[9] LiDAR technologies calculate distances by illuminating the target with a laser and measuring the reflection with a sensor.
[10] The five levels of driving automation are described here: SAE International (2018) Releases Updated Visual Chart for Its "Levels of Driving Automation" Standard for Self-Driving Vehicles
[11] EBRD (2019) Disruptive technology and innovation in transport: Policy paper on sustainable infrastructure
[12] A cost-benefit analysis compares the calculated delivery for Amazon Prime Air ($0.06 per drone delivery) against delivery by UPS ($1.20 by delivery truck). Source: University of Tennessee, Chattanooga (2015) A cost-benefit analysis of Amazon Prime Air
[13] Bloomberg (2019) Initiative on Cities and Autonomous Vehicles
[14] Statista (2020) Global car sales 1990-2020
[15] SMMT (2019) Connected and Autonomous Vehicles: Winning the Global Race to Market
[16] PwC's Strategy& (2019) Digital Auto Report: Time to get real – opportunities in a transforming market
[17] McKinsey (2016) Automotive revolution – perspective towards 2030
[18] Transparency (2019) Autonomous Trains Market is expected to grow at a CAGR of 13% from 2019 to 2027
[19] TechNavio (2019) Autonomous Bus Market | Size, Share | Growth, Trends | Industry Analysis | Forecast
[20] Navya (2018) Tepco chooses Autonom Shuttles to Improve Mobility within Fukushima Power Plant
[21] CNN Travel (2020) Dubai unveils plans for electric sky pod network
[22] The 'fifth screen' refers to information and content displayed on digital signs, with movies, TV, personal computers and mobile devices being the first four screens.
[23] Cisco (2019) Internet of Things (IoT) – The future of IoT miniguide: The burgeoning IoT market continues
[24] PwC's Strategy& (2019) Digital Auto Report: Time to get real – opportunities in a transforming market
[25] WEF (2019) The EU wants to create 10 million smart lampposts
[26] EDF Energy (2020) How Much Does it Cost to Charge & Run an Electric Car?
[27] WEF (2018) Electric Vehicles for Smarter Cities: The Future of Energy and Mobility
[28] PwC's Strategy& (2019) Digital Auto Report: Time to get real – opportunities in a transforming market
[29] Japan Automobile Manufacturers Association, Inc. (2010) Japanese Government Incentives for the Purchase of EVs
[30] Local Motors (2020) Meet Olli
[31] WEF (2019) China is building a floating train that could be faster than air travel
[32] Tesla (2020) Tesla Supercharger
[33] BMW (2020) BMW ChargeNow Stations
[34] Ofgem (2018) Ofgem proposes system reforms to support electric vehicle revolution
[35] WHO (2018) Ambient (outdoor) air pollution
[36] UN (2019) UN announces 2019 Climate Action Summit 'Clean Air Initiative', calls on governments at all levels to join
[37] PwC's Strategy& (2019) Digital Auto Report: Time to get real – opportunities in a transforming market
[38] For example, the number of CitiBike shared bikes will increase by 230% between 2019 and 2024 in New York City and the size of the service area will be doubled (another 35 mi^2 of coverage). Source: The City of New York (2019) OneNYC 2050 | Efficient Mobility
[39] Schmidt & Rosenberg (2014) *How Google Works*
[40] McKinsey (2016) Automotive revolution – perspective towards 2030
[41] PwC (2018) Five trends transforming the Automotive Industry
[42] PwC's Strategy& (2019) Digital Auto Report: Time to get real – opportunities in a transforming market
[43] PitchBook (2020) PitchBook Analyst Note: A Watershed Moment for Shared Mobility
[44] Civitas (2017) Nudging towards sustainable mobility in Antwerp: post-COVID-19
[45] Triple Helix partnerships facilitate collaboration between university, industry and government bodies to encourage knowledge-sharing, creativity and innovation. Source: Ranga & Etzkowitz (2013) Triple Helix system
[46] National Transport Commission (2020) Automated vehicle program
[47] Smart Dubai (2020) Smart Dubai Government | Smart City Initiatives
[48] 'Creative destruction' explains the impact of technological change which often results in traditional businesses either needing to adapt to the changes (and incurring costs) or potentially closing down, with resultant job losses. Source: KPMG (2017) Dubai Open and Shared Data Economic and Social Impact Study
[49] The Guardian (2020) Electric scooters to get green light to go on Britain's public roads
[50] UN Department of Economic and Social Affairs (2018) 68% of the world population projected to live in urban areas by 2050

[51] European Commission (2019) Remaining Challenges for EU-wide Integrated Ticketing and Payment Systems
[52] Visa (2019) The Future of Transportation: Mobility in the Age of the Megacity – survey consisted of 19,384 consumers living in either of the two biggest cities in 19 countries.
[53] Ibid.
[54] Autovista Group (2020) The side effects of COVID-19 on vehicle demand
[55] Royal Society of Arts (2020) Low pay, lack of homeworking: why workers are suffering during lockdown
[56] Forbes (2020) HTC Launches VR Meeting App To Help Work 'Face-To-Face' During Coronavirus Lockdown
[57] Fast Company (2019) Microsoft uses Spatial 3D mixed reality for virtual meetings
[58] Abrate *et al.* (2007) The impact of Integrated Tariff on Public Transport Demand: Evidence from Italy
[59] AfDB (2019) Study Report: Unlocking the potential of the Fourth Industrial Revolution in Africa
[60] Tech Cabal (2018) Lara.ng Is Getting People Around Lagos In A Way That Google Maps Can't
[61] Transport for London (2020) Oyster online – Transport for London – Oyster cards
[62] Ramboll (2019) WHIMPACT
[63] ITS International (2020) Visa and the power of mass transit transactions
[64] Finextra (2018) Alipay targets China's public transportation networks
[65] Intelligent Transport (2019) Santander partnership brings blockchain to Madrid buses
[66] Cryptopolitan (2019) Bitcoin for public transport now available in Brazilian city
[67] Uber (2020) Uber Cities – Rides Around the World
[68] Catapult Transport Systems (2018) Are You Decentralised Yet?
[69] Forbes (2018) World's First Self-Driving Fare-Paying Taxi Starts Trials In Tokyo
[70] The New York Times (2019) A Real Tube Carrying Dreams of 600-M.P.H. Transit
[71] Electric VTOL News (2020) Airbus CityAirbus – Electric VTOL News™
[72] Menabytes (2019) Cairo-based Swvl raises $42 million in the largest-ever funding round for an Egyptian startup
[73] DiGAME (2018) Egyptian startup Swvl raises $8 million Series A
[74] Disrupt Africa (2019) Egyptian transport startup Swvl raises $42m funding round
[75] Nikkei Asian Review (2020) Egypt-born minibus-share Swvl to debut in Southeast Asia
[76] New Climate Economy (2018) Developing Prosperous and Inclusive Cities in Africa – National Urban Policies to the Rescue?
[77] AfDB (2018) African Economic Outlook 2018, Chapter 3
[78] ETH Zurich (2019) Bike to the Future
[79] Sidewalk Toronto (2020) Sidewalk Labs Toronto: Mobility
[80] D. L. Doctoroff (2020) Why we're no longer pursuing the Quayside project — and what's next for Sidewalk Labs
[81] The Boring Company (2020) The Boring Company Test Tunnel
[82] UN (2019) Sustainable Development Goal 11
[83] Ibid.
[84] Smart Parking (2020) SmartPark is being used by the City of Westminster to make life easy for motorists
[85] Coord (2019) Open Curbs: The First Open Data, Multi-City Platform to Unlock Curbs
[86] Coord (2020) Coord
[87] Talking Traffic (2020) Traffic Light Exchange (TLEX) facilitates real-time data exchange between traffic lights and road users
[88] Smart Energy International (2015) GridComm enables 10k smart streetlights in Indonesian capital
[89] Digital Trends (2018) In the future, potholes could be repaired by asphalt-printing drones
[90] Pothole.info (2018) Can blockchain fix potholes?
[91] Twitter (no date) #WhatIsARoad
[92] Microsoft (2017) TEXA's revolutionary IoT solution for vehicle owners helps save time, money, gas—and possibly lives
[93] ZDNet (2018) Self-powered road sensors detect potholes before they bust your tires
[94] IBM (2013) Predictive maintenance analytics for travel and transportation
[95] Jätkäsaari Mobility Lab (2020) Helsinki's testbed for smart mobility
[96] Intelligent Transport (2020) Helsinki smart mobility pilots deemed a success
[97] Smart Kalasatama (2019) Guidebook for urban innovators
[98] Forum Virium Helsinki (2018) Forum Virium Helsinki; Forum Virium IoT programme
[99] Visa (2020) Digital Payments for Urban Mobility: Helping Cities Become Greener and More Connected
[100] CNN (2019) Commuters waste an average of 54 hours a year stalled in traffic, study says
[101] Ciudad de México (CDMX) Resilience Office (2017) Latest News From Mexico City
[102] SMMT (2019) Connected and Autonomous Vehicles: Winning the Global Race to Market
[103] Intelligent Transport (2019) The Internet of Things: a roundtable discussion
[104] Internet of Business (2017) Billund Airport invests in IoT system to improve passenger experience
[105] IBM (2013) IBM Report: Technology Holds the Key to Economic and Social Reform in Accra, Ghana – United States
[106] HERE Mobility (2020) IoT in Transportation: Benefits, Challenges and Uses
[107] Ministry of Transport, Public Works and Water Management (2010) Public transport in the Netherlands
[108] IBM (2016) Air pollution in China and IBM green initiatives
[109] IBM (2020)IBM – Green Horizons
[110] Microsoft (2020) IoT in transport and logistics
[111] SWISSTRAFFIC (2020) Traffic counts 4.0
[112] Yenlo (2017) 3 ways to include Real-time Analytics in your Digital Transformation
[113] Siemens Mobility (2020) Zhuhai Traffic Management System | References
[114] Volocopter (2020) The VoloPort

[115] Alibaba Cloud (2020) City Brain: Empower Cities to Think with Data-Driven Governance
[116] IBM (2010) City Government and IBM Close Partnership to Make Rio de Janeiro a Smarter City
[117] C40 Cities (2012) Case Study | Rio Operations Center
[118] Urban Sustainability Exchange (2020) Rio Operations Center Case Study
[119] Centre for Public Impact (2016) Rio de Janeiro's centre of operations: COR
[120] Department for Business, Innovation and Skills (2013) Global Innovators: International Case Studies on Smart Cities
[121] UN (2019) Sustainable Development Goal 11
[122] International Association of Public Transport (2020) Management of COVID-19
[123] Counterpoint (2020) COVID-19: A Catalyst for Digital Payment Platforms
[124] The Guardian (2020) Union calls for cash payment ban on UK buses over coronavirus
[125] International Association of Public Transport (2020) Public Transport Authorities and COVID-19
[126] Holloway *et al.* (2017) Street Rehab: Bridging the Gap Between Accessibility and Rehabilitation in Delhi
[127] The Guardian (2014) The new technologies helping visually impaired people navigate cities
[128] CityLab (2015) A Mexico City Bus Line Aims to Stop Sexual Harassment Without Segregating Men and Women
[129] Wired (2020) Making Public Transit Fairer to Women Demands Way More Data
[130] ITU News (2017) How the Safetipin app is making Delhi's streets safer for women
[131] Infrastructure and Cities for Economic Development (2017) Addressing VAWG through co-ordinated urban planning.
[132] Eyewatch (2020) The worlds most advanced personal safety solution
[133] World Bank (2016) "No one helps...nadie me hace el paro"; preventing violence against women in public transport.
[134] UN Women (2016) Improving women's safety in Mexico City.
[135] CityLab (2015) A Mexico City Bus Line Aims to Stop Sexual Harassment Without Segregating Men and Women
[136] EBRD (2019) Disruptive technology and innovation in transport: Policy paper on sustainable infrastructure
[137] SMMT (2019) Connected and Autonomous Vehicles: Winning the Global Race to Market
[138] Ibid.
[139] Phantom AI (2020) Democratizing advanced driver assistance systems
[140] USA Today (2019) Could a computer predict auto crash injuries? Volvo and Hyundai are betting it can
[141] Drones Safe Register (2017) Drones for Emergency Services
[142] The New Indian Express (2018) Kerala engineering students develop tech to stop overloaded vehicles in their tracks
[143] Intelligent Transport (2010) Automatic passenger counting systems for public transport
[144] FleetPoint (2018) How VR can improve health and safety in the transport sector
[145] PwC (2019) Seeing is believing: How virtual reality and augmented reality are transforming business and the economy
[146] Intelligent Transport (2019) RTA Dubai introduces VR technology to train drivers
[147] Viar360 (2017) Using VR for Employee Training | Here are real-world examples!
[148] International Transport Forum (2019) Transport Innovations from the Global South Case Studies, Insights, Recommendations
[149] Tech Jaja (2019) SafeBoda could win government support in boosting the boda hailing industry
[150] International Transport Forum (2019) Transport Innovations from the Global South Case Studies, Insights, Recommendations
[151] Oncioiu, I. (2016) Driving Innovation and Business Success in the Digital Economy
[152] AfDB (2019) Study Report: Unlocking the potential of the Fourth Industrial Revolution in Africa
[153] Reuters (2020) Automated delivery cashes in on pandemic-driven demand
[154] TechCrunch (2020) Starship Technologies is sending its autonomous robots to more cities as demand for contactless delivery rises
[155] Terra Drone (2020) Terra Drone business partner Antwork helps fight coronavirus in China with medical delivery drones
[156] DHL Trend Research (2016) Robotics in Logistics
[157] SSI SCHAEFER (2020) Case Study JYSK
[158] Fetch Robotics (2018) DHL & Wärtsilä: Achieving true automation flexibility with the Fetch Cloud Robotics Platform
[159] Swisslog (2020) Almarai, Saudi Arabia: Refrigerated high volume palletizing and storing
[160] Port Technology (2020) COSCO Shipping Ports completes smart port trial
[161] Start Up Magazine (2019) Kobo360: Revolutionizing the Global Logistics Supply Chain – Starting with Africa
[162] TEMCO (2020) Use Case: Nenia X TEMCO
[163] The Guardian (2018) World's first electric container barges to sail from European ports this summer
[164] Nikola Corporation (2020) Nikola Energy
[165] AfDB (2019) Study Report: Unlocking the potential of the Fourth Industrial Revolution in Africa
[166] Google (2019) Ninja Van Case Study
[167] Starship (2020) A revolution in local delivery
[168] DHL Trend Research (2016) Robotics in Logistics: A DPDHL perspective on implications and use cases for the logistics industry
[169] Amazon (2020) Amazon Prime Air
[170] Supply Chain Dive (2019) Port of Rotterdam begins IoT-based operations
[171] Port of Rotterdam (2019) Port of Rotterdam puts Internet of Things platform into operation
[172] Port of Rotterdam (2020) Innovation partners
[173] Zipline (2020) How It Works
[174] TechCrunch (2019) Drone delivery startup Zipline launches UAV medical program in Ghana
[175] The Innovator (2018) Rwanda Pioneers Drone Regulation

[176] PwC (2018) Charging ahead! The need to upscale UK electric vehicle charging infrastructure
[177] City of New York (2019) OneNYC 2050 | EFFICIENT MOBILITY
[178] WSP (2017) *New Mobility Now: A Practical Guide*
[179] Delhi News (2019) Delhi to get 131 charging stations for electric vehicles
[180] Frost & Sullivan (2019) Emerging Technologies to Help Generate New Revenue Streams for Mobility-as-a-Service Providers
[181] ITF-OECD (2018) Blockchain and Beyond: Encoding 21st Century Transport
[182] Mwaniki, Kinyanjui & Opiyo (2017) 'Towards Smart Economic Development in Nairobi', in *Smart Economy in Smart Cities*
[183] P4G (with C40 Cities and the International Council on Clean Transportation) (2020) ZEBRA
[184] SUTL offers up to $1 million in grants annually. Source: SUTL (2018) Innovation Grant: Ecosystem Building Grant Guidelines Background
[185] LACI, C40 Cities and PwC (2019) Cleantech Cities: Accelerating Climate Action through Startup and Corporate Innovation
[186] Barcelona City Council (2020) Ethical Digital Standards: A Policy ToolKit
[187] CityMart (2019) Success Stories
[188] Startup in Residence (2019) Startup in Residence | Impact Report
[189] Ibid.
[190] Women4Climate (2020) Women4Climate | Tech Challenge
[191] Women4Climate (2020) Women4Climate | Elizabeth Ledesma & Monica Pulido
[192] International Finance Corporation (2019) A New Study Explores Digital Skills in Sub-Saharan Africa Key Findings
[193] WEF (2019) The digital skills gap is widening fast. Here's how to bridge it
[194] International Data Corporation and Microsoft (2019) Future of Work Skills
[195] World Bank (2016) World Development Report 2016 – Digital Dividends
[196] WEF (2018) The Future of Jobs Report 2018
[197] UK Government Office for Science (2018) Data and digital systems for UK transport: change and its implications
[198] World Bank (2017) Access to Mobile Phones and the Internet Around the World
[199] Ibid.
[200] GSMA (2020) Accelerating affordable smartphone ownership in emerging markets
[201] Ibid.
[202] Ibid.
[203] The Verge (2020) Uber is testing out a new 1-800 number for people who don't use apps
[204] Finextra (2018) Alipay targets China's public transportation networks
[205] World Bank (2016) World Development Report 2016 – Digital Dividends
[206] City of Barcelona (2020) Digital education and training | Barcelona Digital City
[207] City of Barcelona (2020) Barcelona Cibernàrium
[208] Singapore Government (2017) Launch Of SkillsFuture For Digital Workplace – Building Confidence in All Singaporeans for the Digital Economy
[209] SkillsFuture (2020) Skills Framework for Public Transport
[210] University of Helsinki and Reaktor (2020) Elements of AI
[211] UK Government (2019) Government Technology Innovation Strategy
[212] UK Government (2018) Emerging Technology Development Programme – GOV.UK
[213] Transformational Upskilling (2019) Uber
[214] Gokada (2019) Gokada
[215] WEF (2020) Digital ASEAN and WEF (2019) The private sector steps up, pledging to train millions of youth in ASEAN to unlock the region's digital potential
[216] PwC UK (2018) Will robots really steal our jobs?
[217] The Guardian (2018) E-bike crash death prompts debate over safety on UK roads
[218] UK Government (2020) Electric bikes: licensing, tax and insurance – GOV.UK
[219] WEF (2019) Look no hands: self-driving vehicles' public trust problem
[220] Partners for Automated Vehicle Education (2020) Pave Campaign
[221] Schmidt & Rosenberg (2014) *How Google Works*
[222] Global Compliance News (2018) Beijing Issued First Rules on Road Tests for Autonomous Vehicles
[223] Taarifa (2018) Rwanda becomes first country to approve regulation for drone usage
[224] Rwanda Podium (2017) KIGALI : Rwanda Takes the Lead in Adopting Performance-Based Drone Regulation
[225] A 'regulatory sandbox' is a testing ground for new business models, innovative products and services that do not need to overcome the normal regulatory and financial hurdles such as licensing. Source: BBVA (2017) What is a regulatory sandbox?
[226] The *Elmob* project aimed to facilitate sustainable transport in Gothenburg, with a focus on electric bike sharing, electric car sharing, electric taxis and plug-in hybrid buses. Source: Nest (2014) Elmob – electric vehicles for sustainable travel
[227] EBRD (2019), Disruptive technology and innovation in transport: Policy paper on sustainable infrastructure
[228] Waze (2020) Connected Citizens Program by Waze: Live Traffic updates
[229] A similar use-case is Transport for London's open data approach, under a version of the Open Government Licence, that makes data available (incl. air quality, network performance and accessibility) in APIs, static data files and different feeds.
[230] Volkswagen (2020) How electric car incentives around the world work
[231] Ibid.
[232] 'Feebates' impose a *fee* or award a *rebate* to vehicles that perform worse or better than a specified benchmark. Source: International Council on Clean Transportation (2010) Best Practices for Feebate Program Design and Implementation
[233] Uber (2018) The Clean Air Plan—Helping London go electric

[234] International Council on Clean Transportation (2019) EV Ridehailing Commitment
[235] WEF (2018) Agile Governance Reimagining Policy-making in the Fourth Industrial Revolution
[236] Alliance for the Internet of Things Innovation (2018) AIOTI SPACE
[237] 5G Infrastructure Association and AIOTI (2018) Partnership to strengthen end-to-end digitalisation in Europe
[238] Laplane & Mazzucato (2020) Socializing the risks and rewards of public investments: Economic, policy, and legal issues
[239] The central government agencies, local municipalities and Local Government Denmark in collaboration with the three organisations for public sector employees: Organizations of Public Employees, Confederation of Professionals in Denmark, and The Danish Confederation of Professional Associations. Source: Center for Offentlig Innovation (2020) About COI
[240] The COI conducted the study in October 2016 across the Danish public sector. Source: WEF (2018) Agile Governance Reimagining Policy-making in the Fourth Industrial Revolution
[241] German Federal Ministry of Transport and Digital Infrastructure (2013) Cooperative ITS Corridor
[242] CrowdLaw (2017) CrowdLaw | ABOUT
[243] OECD (2017) Place to Experiment – Finland
[244] ITDP (2019) Ride Fair: A Policy Framework for Managing Transportation Network Companies
[245] GIZ TUMI (2020) Sustainable Urban Transport in Latin America
[246] OECD/ITF (2019) Transport Innovations from the Global South
[247]APM Group (2020) Reasons Claimed: PPPs as a Financial Mechanism for Governments to Develop Infrastructure Projects
[248] PwC & WEF (2017) Harnessing the 4th Industrial Revolution for Sustainable Emerging Cities
[249] City of Boston (2016) Boston selected by the World Economic Forum as focus city for the future of mobility
[250] City of Boston (2020) Autonomous vehicles: Boston's approach
[251] IBM Research (no date) IBM Research THINKLab: Developing solutions in Africa, for Africa and the world
[252] City of Barcelona (2019) 5G Barcelona – Who we are
[253] LACI, C40 Cities and PwC (2019) Cleantech Cities: Accelerating Climate Action through Startup and Corporate Innovation
[254] Railway Technology (2019) HydroFLEX Hydrogen-powered Train, United Kingdom
[255] BCRRE researches hydrogen fuel cell technology and has worked with rail businesses to identify opportunities for a clean alternative to diesel. University of Birmingham (2018) University of Birmingham signs joint initiative to develop HydroFlex
[256] The project is led by the Research Institutes of Sweden (RISE). Source: Drive Sweden (2018) The Premiere of Self-Driving Buses in Gothenburg
[257] The alliance includes autonomous technology company Holo, research and training institution Chalmers, Härryda municipality, public transport company Västtrafik and traffic office Göteborgs Stad. A full list of partners is available here.
[258] C40 Cities (2020) C40 Cities: Networks
[259] City of Barcelona (2020) Urban mobility project, the MOBILus consortium
[260] New Mobility (2018) EU partners with MOBILus consortium to develop a community on Urban Mobility
[261] Splash 24/7 (2020) Why maritime digitalisation is paramount for tomorrow's port calls
[262] Future of Life Institute (2017) Asilomar AI Principles
[263] Future of Life Institute (2020) Principles signatories
[264] The European Commission (2020) High-Level Expert Group on Artificial Intelligence

FUTURE CITIES SA

The Future Cities South Africa programme (FCSA) is a project funded by the UK Government's Prosperity Fund, overseen by the UK's Foreign, Commonwealth and Development Office (FCDO) and is led and administered by PwC UK, working with organisations including Aurecon, Open Cities Lab, Isandla Institute, Palmer Development Group (PDG) and Violence Prevention through Urban Upgrading (VPUU NPC).