Iot and Cities in a Post Covid World

A landscape review by the Business of Cities for PETRAS

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Executive Summary

The 2020s is a decade when the Internet of Things (IoT) is reaching critical mass in how it is applied in the fabric of the world's cities.

What happens at the 'edge' of networks will become central to how cities after Covid-19 look to safeguard citizens, manage human interaction, shift to hybrid services and experiences, utilise space in workplaces and CBDs, and make urgent cost savings. IoT will be enlisted as both a management tool and an innovation driver in cities' quest to recover jobs and productivity, accelerate with net zero transitions, reduce disparities in services and public health, and keep digital infrastructures cybersecure.

What is at stake for cities

This landscape review finds that, in the UK and the wider world, more leading companies are finding additional market uses in urban settings, and more cities and metropolitan institutions are eager to apply IoT effectively and safely. The global landscape of IoT pilots and scale-ups in 2021 sees Oslo and Copenhagen harnessing 'the edge' for the climate change fight, Hangzhou and Seoul tackling traffic and air quality, and San Diego and Dubai adapting public transport and public services. Urban malls, innovation districts and new greenfield cities are all sites of IoT testing.

For cities, the promise of IoT goes far beyond making home lives more convenient. It holds the prospect of optimising complex 'whole city' systems and changing the way we use and move through buildings, real estate and public space. Often overlooked, IoT deployments also enable the kind of customisation and community-building functions for urban asset owners that give rise to new kinds of urban economies in dense cities – the high-interaction innovation economy, the easily reconfigurable sharing economy and the on-demand experience economy to name but three. The effects of urban market applications of IoT also appear to be driving more inter-dependence between public and private space and interests in cities.

Currently IoT technologies tend to land in the rare cities and contexts where there is a simple stakeholder model, a large scale, and a clear business case. Many forecasters are optimistic that the impacts on cities will diversify as the market matures, use cases assemble, APIs are de-siloed, financing is de-risked, the social benefits become more measurable, and - critically – the appetite and know-how within multiple levels of government grows.

The proliferation of IoT solutions and devices also poses a series of profound questions about fundamental aspects of urban living, the role of surveillance and cyber-security, the future of identity and privacy, and the potential erosion of essential public goods. The trade-offs of IoT in cities have become an even more urgent subject of debate during the Covid-19 pandemic. The UK government is far from alone in highlighting that IoT in cities has to very carefully implemented or the hardwiring of data collection will end up having many unintended, unwanted and undemocratic effects. Much is at stake as applied edge technologies may either encourage substantial automation of city decision-making, or instead enable much more co-creation with citizens.

The UK context

Relative to the pace of piloting and adoption in other advanced nations, the overall range and depth of IoT applications in UK cities has been modest. This reflects the highly unusual evolution of cities and the urban system in the UK - the first to industrialise and deindustrialise, highly centralised and asymmetric governance, and significant performance gaps between London, larger UK cities and smaller population centres.

This produces a context where UK cities are currently incentivised to compete and self-promote in a highly constrained fiscal and financial context, while there is fairly limited interaction between smaller and larger IoT-capable firms, and few hubs or pathways exist for shared learning.

More is needed to support UK cities to future-proof for IoT. This is important for security and privacy purposes, even while an IoT-charged economy can also help accelerate the shift towards a more geographically distributed innovation system defined by larger 'digital catchments' around cities and greater agility and mobility. And IoT may in time have wider institutional and regulatory impacts for cities as it transforms the way planning and administrative systems operate. Effective IoT can be catalyst as well as an outcome of better-run cities.

There have been some success stories among different types of UK city – especially those with better-resourced strategies, leverageable land and assets, multi-disciplinary leadership and effective digital ambassadors. There is now a high level of appetite for practical research and toolkits about what it takes to safely deliver IoT in cities.

Looking ahead to the post-Covid cycle, three collective priorities now stand out for which academic research as well as business, civic and government leadership has a central contribution to make:

1. **Foster and convene the urban IoT eco-system** to provide greater clarity about the respective needs and capabilities of city governments, citizens, big corporates, SMEs,

system integrators, and universities, and pool knowledge of the effective practices and financing models to draw on.

2. **Improve the empowerment, funding and co-ordination of cities** to escape lock-in to obsolete technologies and procurement inertia and become custodians of more integrated and secure IoT platforms.

3. **Better shared language and shared stories** around how we describe and conceive of the roles of distributed computing infrastructure in cities, and the ethical and economic implications they have. This can help to shift public perception beyond crude caricatures and stereotypes, and to collectively confront real choices and trade-offs ahead viewed as integral to how more cities look to safeguard citizens, utilise space, and make cost savings.

More leading companies are also adopting and specialising in IoT and finding additional market uses and ways to extract value in more kinds of urban setting. The recent shift to working from home, digital conferencing, tele-medicine, new public health environments, and changes in social interaction, are raising demand and expanding use cases. Cities are also large prospective IoT customers - — some estimates are for cities to spend more than $40 trillion on IoT devices over the next 20 years.

More cities and urban organisations are looking to understand how and where tech can be effectively and safely scaled in urban environments. Many acknowledge that more sensors are set to capture human interaction and inhabitation, not just at home and in the workplace, but to monitor how people move and socialise, as the world navigates what will become our 'new normal'.

What is the 'Edge'?

Edge Computing is sometimes colloquially described as:

- **anything that** is close to the people that use it.
- **everything that** is not in the cloud.
- **data analysis** that takes place either on device or edge computers, in real-time.
- **the internet** transitioning from a series of highways to a spider's web.

It is important because soon more than half of data will be processed near the source. This is primarily being driven by:

- **improved cost** and efficiency of managing traffic loads,
- **safety and** reliability in cases where connections are poor,
- **speed and** quality of data to inform decision-making, given that increasingly the value of data is at its highest

1.Introduction

In 2021, the Internet of Things (IoT) is finding many more applications at scale in the fabric of the world's cities.

The pace of technology change and adoption has combined with the Covid-19 pandemic to accelerate demand for new technologies in the public and private domain of our cities. The level of economic, geo-political, and societal disruption cities now face mean that innovative technologies, including IoT, are

Beyond the Smart City

Covid-19 has also co-incided with growing fatigue with the idea of the 'smart city' in many parts of the world. It is also likely (and necessary) that the 2020s will see greater clarity around the advantages and disadvantages that the new wave of technologies provide to cities. Many expect a better shared language to emerge around how we describe and conceive of the roles of distributed computing infrastructure in cities.

Greater precision of terminologies, implications, and ethical assumptions are on the horizon, spurred on by technological progress and an altered post-Covid landscape.

The ongoing rise in throughput, machine communication, reliability and ubiquity of IoT devices in urban daily life mean that cities find themselves having to respond with policies and strategies to manage, harness and complement these technologies. National governments are also looking to consider the role of IoT in different kinds of places, as they shift from 'place-blind' to 'place-sensitive' approaches.

Looking ahead

Covid-19 has brought IoT to wider public attention. IoT has been prominent in everything from virus mitigation apps, infrastructure reimagination projects, and attempts to redesign public space and protect public transport systems in cities' short and long-term recovery strategies. It also underpins cities' use of digital twins and crisis modelling systems and reinterpretation of the social significance of data within cities.

The increased deployment of IoT during the pandemic within cities' health, inclusion and mobility sectors has raised awareness among city leaders of the value of certain IoT-based technologies for data driven development. One survey of 167 cities across the world found that two thirds felt that the pandemic revealed more imperatives to adopt technologies for a safe and sustainable future, and many hope to raise the rate of investment in IoT as a result.

Looking forward, Covid-19's effects also mean that IoT will be enlisted as both a management tool and an innovation driver in cities' quest to ensure:

- **Jobs and productivity bounce back**, through smooth access to work, providing confidence in the health and hygiene of key systems, and effective trade and supply chain management.
- **A revived innovation economy**, eliminating the obstacles to collaborative working environments, and providing urban test beds for new kinds of uses cases and applications to trial and scale.
- **Adapting and cost-minimising public service provision** given likely fiscal burdens.
- **Energy and net zero transitions can be accelerated** through more effective management of city systems, and transformations in homes and buildings.
- **Cybersecure infrastructures** as more of the economy, social life, and government administration is digitised.
- **Reduced inequalities within and between regions,** including whether Covid-19's effects can be leveraged to support a more distributed innovation capacity in different places, despite the pandemic's revealed inequality in terms of jobs resilience and public health.

This paper

This research has been designed to assemble perspectives in business, government and institutions about how the latest cycle of IoT technologies and new branches of computing are landing in cities, and how Covid-19 alters the outlook.

The work is in support of the PETRAS National Centre of Excellence for IoT Systems Cybersecurity, a consortium of 12 UK research institutions now focused on the opportunities and threats that arise when Edge computing is deployed more widely in the economy and society.

The aim has been to map the emerging implications for cities in a context where the next cycle of AI innovation is viewed as happening beyond the central 'cloud', at the 'edge' of networks.

For this paper we have consulted with colleagues at:

- Amazon Web Services
- Arup
- Boston Networks
- CISCO
- City of Barcelona
- Coventry City Council
- Digital Catapult
- Connected Places Catapult
- European IoT Council
- Flying Binary
- Greater London Authority
- HSBC
- Innovate UK
- SOLACE
- Southampton City Council

In the research, interviews and discussion, we have focused particular attention on the opportunities in UK cities, especially beyond London. We have explored the relationships between stakeholders and organisations, the potential to address issues of disparity and inequality within and between cities, and the observed gaps and risks for cities, citizens and businesses. The observations and findings of this briefing paper do not

necessarily reflect the perspectives of participants or their organisations.

2. Why is IoT becoming so important to Cities?

IoT is often thought of as affecting people's lives via devices within homes, with popular devices such as Alexa or Google Home. From a cities perspective, the impacts are much broader. In a post-Covid world, IoT has ever-increasing relevance to the way global cities shape social, economic and public health recovery efforts. The 2020s is also the dawn of 5G technology, whose speed and standards create more enablers to the presence of IoT systems in cities.

For cities, the capability of IoT in particular has the potential to shape:

- urban assets and systems, above and below ground, that are essential to the smooth, safe and efficient daily functioning of the city.
- workplaces, buildings and real estate, across asset classes.
- transportation hubs and the management of overcrowding, dwell time, security and wayfinding.
- public spaces, especially those that host multiple functions (work, play, live) or perform multiple roles over a 24-hour or year-round cycle

IoT pilots and initiatives have already been adopted and integrated into cities internationally, of many different types and development levels, in a number of ways that we review below. These span:

- climate change and pollution
- urban security
- public transport
- city management platforms
- city consumption and innovation economy
- city partnerships
- new districts and cities

Real world examples of IoT landing in cities

IoT for Cities' Climate Change and Pollution Response	
City	Initiative
Oslo's emissions management	Oslo is using IoT sensors to control lighting, heating and cooling to cut emissions by 95% by 2030.
Copenhagen's climate IoT integration policy.	IoT projects cover air quality, waste management, energy use, and traffic, and now also connect parking systems, buildings, smart meters and charging systems.
Malaysian Cities -Kelantan, Pengerang and Penang	A surge in demand for better traffic analytics has been seen in congested Malaysian cities. IoT between traffic lights, cameras and sensors helps to reduce wait times, noise and environment pollution, and operational and maintenance costs.

IoT for Urban Security	
City	Initiative
Amsterdam	Through an open database system loaded with over 12,000 datasets from all urban districts across the country being fed into the IoT Living Lab in Amsterdam (a 3,700m2 area fitted with IoT beacons), users have wide access to data to innovate and learn from.
Gujarat	One of the largest IoT projects in India, Gujarat is focusing on systems that can counteract traffic violations and crime, alongside pollution and traffic flow. This project enlists Indian municipal governments alongside an Orange open source platform.
Tel Aviv	UK IoT provider Telit has been working alongside Israeli IoT firm Sternum on a project to improve cybersecurity solutions for IoT programmes across Great Tel Aviv.

IoT for Cities' Public Infrastructure (e.g. Transportation, Government, Accessible Facilities). Public transportation systems have seen the highest adoption rate of any IoT system and are now ranked as the No.1 IoT city use case.	
City	Initiative
San Diego	The San Diego Metropolitan Transit System has partnered with Cisco, Davra Networks and Intel to tackle maintenance, security and service of its public transport system.
Hong Kong	Hong Kong's popular Mass Transit Railway has integrated IoT through a smart payment system called Octopus. It is founded on HKeRouting, HKeTransport and eTraffic News projects running toward a simple, universal app for users.
Dubai	Dubai has been enacting a plan to digitise all government services by 2021, integrating IoT at every stage possible. Now, 90% of government services are digitised and available on the DubaiNow app. Saving $245m p.a. in paper transactions.
Munich	Munich's IoT infrastructure projects aim to begin collaborative efforts to counter congestion and emissions, and to increase public transport uptake. These projects are being spearheaded by UK AI lab Fetch.ai, and industrial blockchain company, Datarella, to form an open-access ML network.

City management	
City	Initiative
Barcelona	Barcelona's IoT deployments range from LED light pole mounted sensors to monitor air quality, pollution and traffic systems, bike-sharing GPS technologies, to smart bins fitted with vacuums to reduce foul smells.
Saudi Arabian cities	Nokia and Zain Saudi Arabia have been launching IoT services and end-to-end services to deliver Kingdom-wide connectivity that has spillover benefits for major cities in e-government, education and 5G investment.
Seoul	Seoul's Digital Mayor Office has integrated tens of thousands of sensors, tracking traffic flow, speed, and air quality. By 2022, another 50,000 IoT sensors will monitor fine dust, noise, vibrations, wind, and floating population.

IoT for city consumption and innovation economy	
City	Initiative
Helsinki	The Mall of Tripla in Helsinki combines IoT and 5G in order to map the movement of shoppers, the temperature of the mall, the air quality, and the footfall both within and outside of the Mall. Projects such as these are informing the strategy for retail post Covid.
Boston	The roll out of IoT in its Seaport Innovation District has helped the city to create over 200 related start-ups. The City Council acclaims the participation that these integrative technologies foster.

City Partnerships for IoT	
City	Initiative
Grenoble (France), Bristol (UK), Fujisawa and Tsukubai (Japan)	A multilateral initiative funded by the EU and NICT in Japan, BigClout combines IoT, cloud computing and big data in an integrated model to increase the efficiency of urban infrastructure.
100+ cities in Mastercard's City Possible co-creation framework.	City Possible aims to scale IoT and integrative technologies within transport and city systems. Four Brazilian cities, for example, are part of a PPP to integrate IoT into healthcare, infrastructure and agriculture.

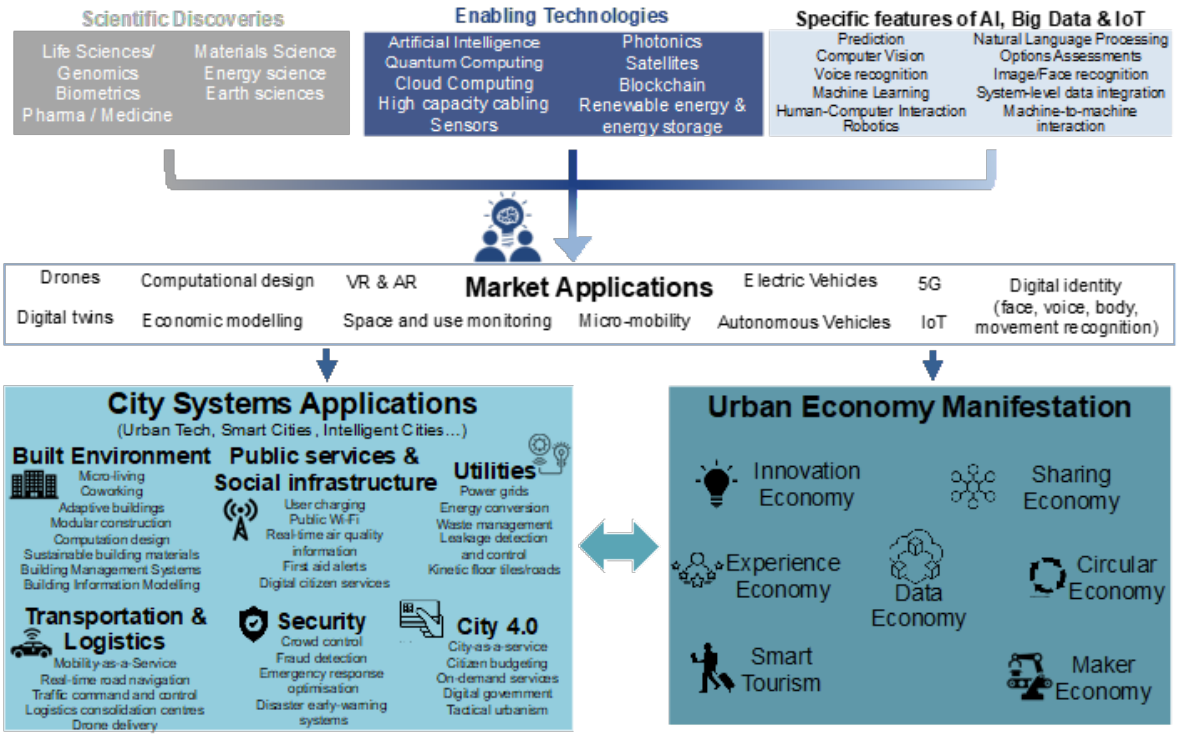
IoT for New Districts and Cities	
City	Initiative
Woven City - Toyota's Living Laboratory.	In an entirely new city crafted by Toyota and its partners, Toyota, researchers and Toyota are able to carefully observe resident behaviour and how they engage with next generation technology and IoT.
Almere	Almere, the Netherlands is the first test case for Californian ReGen, which uses IoT to develop off-grid and integrated settlements that are renewable and power positive.
Sidewalk Labs Project, Toronto.	A now aborted project, Alphabet subsidiary Sidewalk Labs had tried to develop a prime waterfront neighbourhood in Toronto from the 'internet up'. Ambitions for IoT to underpin ride-sharing vehicles, self-driving cars, heated pavements, and underground delivery bots, ultimately failed to win buy-in amid data protection concerns for current and future residents.

In addition to the direct effects of IoT on urban systems, importantly IoT also helps to give rise to new kinds of Urban and Metropolitan Economies. By promoting greater intensification of space, more customised environments, more resource efficiency, and increased eco-system awareness, they are accelerating the rise of economies that thrive in the more dense, clustered settings that cities provide. Specifically, these are:

- The **innovation economy**, with new enterprise models demanding more flexibility of space, fewer barriers between building uses, and more focus on 'whole places' as sites of collaboration and commercialisation.
- The **sharing economy,** which grows when data systems support rapid sharing of assets, and easily reconfigurable environments for co-working and co-living.
- The **experience economy**, which responds to customer expectations for on-demand services and more personalised content facilitated by data collection.
- The **circular economy**, which aims to achieve operational efficiencies, better water and waste management, and extended lifespan and usability of assets.
- **Smart tourism** that harnesses computing technology to track, analyse and enhance visitor experiences and immersion, improve services and manage flows.
- The **data economy**, where eco-systems of data owners, producers, buyers and sellers, and system integrators come together in new forms of collaboration and competition, with few services provided completely in-house.

These new economies have an impact at the level of places and buildings in cities, because they create a premium on places that can harness data to become more customised, responsive and resource efficient.

The potential of IoT and in particular edge computing is giving rise to a new way of thinking about how urban space can function, how it can serve interaction, and how it can become efficient and societally productive. This paper includes examples and cases of where IoT has allowed a total upheaval in pre-existing notions of how cities operate in almost every regard. IoT has historically focused largely around efficiency and innovation. Now, IoT has been layered with public health concerns and population management considerations.



At the wider level of whole cities, the market applications of IoT technologies also appear to be driving greater integration of public and private asset holdings in cities. A more intensive and more inter-dependent use of space enables the advantages of density, footfall and scale to be achieved more manageably.

One result is that more specialised districts and places are emerging across the city, that offer particular ingredients to certain kinds of business, talent and communities.

Where are the impacts already visible in UK cities?

Currently business and technology leaders are seeing applications of IoT technologies land, especially in a few segments where there is ownership and stakeholder simplicity, a large scale, a clear business case, and potential to engage people.

Many are hopeful that UK cities can also expand the city and local government applications and help move beyond the caricatures of the smart city and towards superior delivery of frontline services. The UK Government is exploring ways to harness emerging IoT technology as a driver of a more equitable economic recovery given the nation's deep and persistent regional disparities.

Reasons for Optimism

Interviewees and analysts pointed to several reasons to expect that the scale of IoT impacts on cities in particular will grow in the next 3-5 years. Three primary reasons have been proposed:

1. Gradual market maturity

- More use cases have accumulated, led by larger cities with sizeable bids to proof concepts.
- Promising B2B collaborations are notionally delivering end-to-end solutions.
- Commercialisation of open data platforms with a single API structure appears to be emerging, to reduce vertical silos.

2. Breadth of social impacts

- The character of the tech solutions are increasingly viewed to have more than just cost-saving effects. For example, traffic re-routing can take into account not just efficiency, but social effects (e.g. of using back streets as short cuts), or risks to children.
- Opportunities are noted to shift the shifted towards more balanced spatial models of metropolitan development as opposed to the disparities of a core/periphery model.
- More solutions are becoming more affordable and implementable for cities without access to the 5G network, potentially easing the disadvantages for cities with less core digital infrastructure.

3. More conducive governance and administrative confidence

- Some cities and local governments are viewed to be making good progress. Especially cities with greenfield prototyping opportunities, or with fewer cycles of legacy

infrastructure and department siloes, or with the kind of visionary leadership to drive down an IoT mission through board level to lower reaches of administration.

- An increasing acceptance at different levels of government that IoT is the enabler for making cities more efficient and productive through data analysis underpinned by ML, AI,

  Blockchain, and other enablers.

3. Covid-19 and towards a new cycle

Covid-19 has clearly added impetus to the role of IoT in shaping the mechanisms and infrastructure of cities.

If the last cycle was principally oriented towards data management platforms, and the operational efficiencies of interoperability, the next cycle in principle provides the potential to bring connected vehicles, buildings and places into more systematic interaction with city systems and citizens, creating the possibility for a new scale and density in the way IoT shapes the functioning of cities. This transition is captured in the chart below which observes our journey so far as to the role of data and technology in city systems.

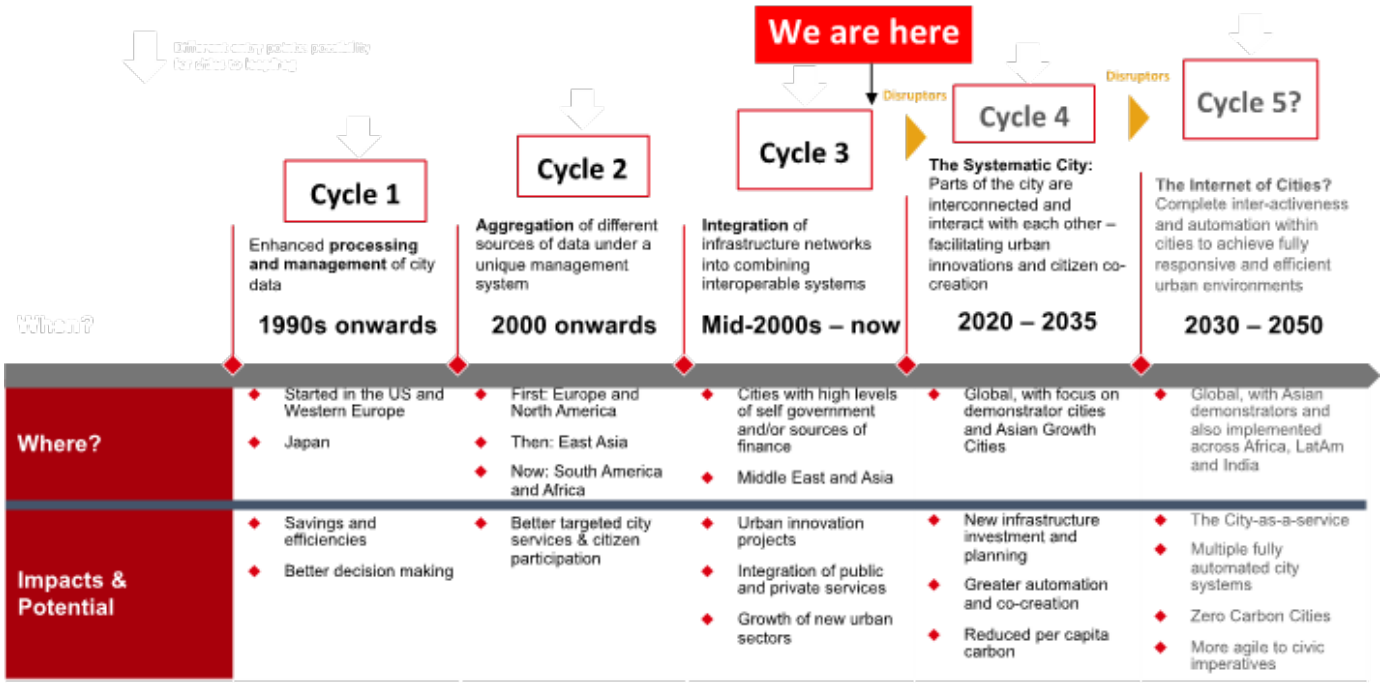
IoT platforms have potential and incentive to make relevant real-life differences to cities' commerce, culture, retail and quality of life as cities look to rebound and build back better. The question that is being debated is what it really takes to decisively enter this new cycle, and what impacts and risks for host cities will be most keenly felt.

Covid-19 has shed new light on the role of technology in everything from cities' supply chains, future industry mix, changing lifestyle and workplace preferences, public health management mechanisms, and social behaviour and cohesion. Cities have so far diverged rapidly in their appetite for technological innovation, to reimagine key systems, and to confront the complex landscape of data protection and privacy concerns.

Initial surveys of cities and city leaders show that Covid-19 has highlighted the urgency of improved cybersecurity measures, as cyberattacks were observed to have increased by 50% during the pandemic. 60% of surveyed cities were concerned by cybersecurity vulnerabilities when it comes to the deployment of urban technologies. This risk is perhaps even more acute among smaller, lower capacity cities, with only 29% of city leaders feeling sufficiently secure against cybercrime.

Among the prominent examples where IoT has been used in a bid to combat the virus in cities, include:

- **Hong Kong**, where inbound travellers have been issued with a wearable GPS tracking device and told to download a 'StayHomeSafe' app for their phones, to ensure that they do not break quarantine measures.
- **Geneva and Zurich**, where anonymised cellular location data informs the authorities when more than 20 devices are recorded in a 100m2 area- complemented by the widespread introduction of drone technology, Internet of Drone Things (IoDT).
- **London**, where Vodafone's IoT-enabled heat detection camera has been used in many organisations to scan up to 100 people per minute upon entry to a building to measure their body temperature.



Health passporting and contagion control	Optimising the urban day	Health crime protection	Built environment agility	Climate and environment control

Meanwhile commercial uptake by affected businesses of IoT will be an important outcome of Covid-19. One major recent study shows that two thirds of businesses with active IoT projects reported that they had increased the pace of their deployment, and of these, 78% noted that the technology has been integral to the continuity of their business during lockdown. Supply chain resilience has been one of the catalysts for greater investment in IoT. This is thought likely to trigger wider uptake in private and publicly owned urban environments.

Covid-19 appears to be an accelerator of five areas in particular where IoT has particular potential or influence. These include: health; daily life in a city; rethinking of 'crime'; adaptability of the built environment and infrastructure; climate and environment control systems.

Health passporting and contagion control

Many cities are seeing the rise of digital health passports to allow for population tracking to aid contagion control. The demand to facilitate safe returns to work, travel, and social participation in city economies are driving the expansion of this tech. These documents certify whether or not an individual has been tested for Covid-19 and the results of any tests taken. Manchester-based firm VST Enterprises is a partner of one the world's leading passports, known as the Covi-pass, supplying 50 million such passports.

This approach contrasts and complements with approaches in other cities – for example in Russia, Singapore, China and South Korea – which are experimenting with facial recognition software to enforce and monitor compliance within their cities. Biometric scanning and temperature monitoring are also a favoured approach in UAE and Chinese cities, to detect Covid-19 symptoms from a distance. This has been piloted in Shanghai, Chengdu and Shenzhen.

Optimising the urban day

IoT is being used to better manage how and where the citizens of a city move, live, socialise, and spend. The need both to safeguard spaces but also to optimise how they are used, is driving innovation to ensure more places in a city can perform more roles in a 24-hour cycle. IoT allows for close attention to be paid to the number of people occupying a specific area or transportation system not only for virus management, but also to guide movement flows and allow spaces to be activated in different ways at different times according to a changing audience or user profile.

This has a role in the events and services industries, for whom it is important to manage the safe use of space, gauge demand effectively at different times, and enable 'attendance' that is no longer defined by being in a physical environment. This can also result in adaptive pricing on roads, at events, on public transport systems and in restaurants, whose net effect can be a more well managed and seamless city.

Protection against 'health crime' for urban citizens and systems

More cities are set to experiment with the use of IoT to guard against anti-social and criminal behaviour caused by the deliberate spread of infection, failure to vaccinate, and other health vulnerabilities that may prevent cities from resuming normal operations. IoT technology to track individual acts or large gatherings of people through GPS tracking and drone technology, as well as temperature checking technology to monitor possible carriers of the virus, is in increased demand.

Adaptability of the built environment and infrastructure

The disruption to city centres, high streets, major commercial and retail infrastructure, means that buildings and spaces within them will have to demonstrate agility and flexibility to serve changing demands and preferences.

Intelligent buildings providers are increasingly rethinking how to make the most of public spaces and homes during the global pandemic. By integrating IoT into the very fabric of the real estate that they build, they can inform building owners of vast amounts of information, such as how to optimise energy usage, when equipment needs to be replaced, how users of the building travel throughout, and even operate complex facility, work-orders and tenant billing processes.

In a post-Covid world, IoT will be more often used to track how users occupy a building, how the building performs, and how to maximise the efficiency of the building itself. Through pattern analysis, desk occupancy technology, social distancing measures and environment control, IoT can shape how users will interact with their office spaces in a safe and Covid-friendly manner. Covid will also increase the role of the hybrid workplace, that combines in-person and virtual presence, to support a more discretionary workforce.

Other related effects include the rise of Digital Twin modelling to adapt economic and infrastructure policy in cities like Rotterdam and Gothenburg, and a dual 'algorithms register' in Helsinki and Amsterdam, which have joined to showcase transparency in their operations. Nesta has recommended that the UK Government use this opportunity to build testbeds to stimulate innovation in urban economies.

Climate and environment control systems

Mapping and controlling air pollution through IoT technology is a definite growth area, as cities look to demonstrate to their citizens, they can achieve the kind of environmental benefits experienced in early lockdown. Barcelona is just one of many cities that has been using complex models to map air pollution at street levels as predictors of contamination volumes over time to shape preventative action.

More broadly IoT is being utilised to create pollution-reducing effects, such as to calculate shorter and safer routes. Researchers at Carnegie Mellon University are even deploying a system that can reduce travel time by 25% by engineering traffic signals to communicate.

Summary

The extent to which these five Covid disruptors will be adopted, embraced and scaled in cities depends significantly on political and cultural dynamics at play.

The democratic or non-democratic character of nation-states has not been the only variable that has shaped the technology dimension of virus mitigation efforts. A variety of nations and cities of different political stripes have adopted policies such as Track and Trace, wearable GPS devices, location monitoring technologies and population control tools.

One factor that is relevant to uptake is the influence of social and political norms. Cities often inherit more collectivist or more individualist outlooks – there are very different patterns of population obedience, social conformity, and participation rates of society in mitigation and control policies. This affects how policies are enacted and what kinds of technologies are feasible and legitimate.

Although the first phase of Covid-19 has tended to see those cities with more individualist and libertarian approaches be less effective at virus mitigation, there have not yet been sweeping changes in attitude towards technology deployment in the urban fabric. Covid-19 is likely, however, to create more experimentation, hybridity, and cross-cultural learning about the appropriate use of IoT in cities.

Examples of prominent businesses and cities applying IOT and edge tech in 2021	
Businesses	Cities
Alibaba – Sells platforms to manage urban public resources in real-time, especially focusing on rapid responses to accidents and congestion from video footage, and asset management. Large impacts in Tier 2 Chinese cities are now being applied internationally.	**Barcelona** – Pioneer of IoT-enabled bus shelters, parking, route advice. Early to involve citizens and give the private sector open access to this rich sensor data via the Sentilo platform.
ADLINK Technology – A leader in automated parking systems, shuttle buses and smart urban logistics that apply Edge technology.	**Shenzhen** – An early adopter of a new generation of IoT based solutions in public security, telemedicine, and transport. Established ecosystem of private companies contributing to public service dilemmas.
Amazon Web Services (AWS) – Provides many edge solutions applied to connected vehicles and operational efficiencies. Helps cities such as Recife in Brazil on optimising urban waste and cleaning services.	**Pittsburgh** – A post-industrial city whose Living Edge Lab uses the city as a test bed for instant socially-minded data applications in partnership with Microsoft.
Cisco – A leading provider of city IoT solutions in security, energy, retail, buildings, strong presence in multiple markets.	**Brussels** – Overstretched transport infrastructure means system provider STIB–MIVB has worked to become a leader in harnessing analytics to improve customer service, run the system more efficiently, and be more transparent with public funds.
Nokia – Collaborates with alternative energy provider ClearWorld to provide a portfolio of smart city solutions on solar powered smart poles for US cities, as it expands its IoT offer in mobility, energy, and public safety.	**Kochi** – a leading Indian city adopter of IoT solutions on buses and roads. The Kerala Startup Mission is establishing a leading startup ecosystem in growing AI and IoT sectors.

4. The Wicked Issues

There is no doubt that the proliferation of IoT solutions and devices poses a series of profound questions about fundamental aspects of urban living, the role of surveillance and cyber-security, the future of identity and privacy, and the potential erosion of essential public goods.

The appropriate future suite of uses of IoT in cities has become an even more urgent debate during the Covid-19 pandemic, as demand for personal health data grows and technologies viewed as intrusive by many become more widely encouraged and adopted.

Beyond these broad themes, there are a number of dimensions through which stakeholders perceive these risks as they now apply specifically to cities.

Security threats and trade-offs

Many accept that IoT security has not kept up with IoT connectivity for urban solutions. The challenges in finding ways to get IoT devices into core systems because of security issues are widely noted. The trade-off between security and constraint means that independent devices are more used for additional data rather than core provision. Similarly, platform-to-platform data sharing is viewed to create new forms of interdependencies that limit the usefulness of the technologies in lieu of much more robust standards setting.

These trade-offs are now even more keenly contested as cities consider the applications of IoT networks for health or professional services benefits against the clear risks of data and cloud breaches and a variety of other nuisances. The rise in urban employees working from home and visiting their doctors from home, is raising questions of how cities and urban infrastructure providers can ensure cybersecurity. The safety and cyber-security of these systems as they are expanded are viewed to be a public good but require clearer shared understanding and priorities.

Risks associated with IoT in cities An analysis of 20 years of academic literature has summarised three broad groups of frequently cited and well known risks that have emerged surrounding deployment of IoT in cities in particular:	
Organisational Risks	
Risks	Initiatives for Possible Mitigation
Governance and upskilling of city authorities in transport, healthcare and infrastructure does not keep up with new technologies.	Invest in city government training and upskilling in cybersecurity and data loss, especially those involved in implementation, operation and maintenance of technologies.
City management processes may become excessively complex if solutions are not integrated into a single package.	Optimise city procurement and solution design processes to minimise lock-in.
High financial costs by city governments for the implementation and maintenance of technologies.	Develop a response and recovery plan for smart city leaders and authorities to follow during and after cyber-attacks.
Social Risks	
Amplified ethical issues in dense urban environments surrounding privacy, data protection and uninformed consent.	Expansion of privacy-aware technologies sensitive to thresholds in urban environments.
Disappearance of significant fraction of urban jobs due to IoT-related automation	Effective whole-city economic development strategies that prioritise up-skilling and re-skilling initiatives.
Growing digital divide in cities, as some citizens fail to access benefits of the technologies.	Proactive policies for citizen participation in decision making and co-creation of public services through voluntary apps/personalised feedback.
Technology Risks	
Increased chance of cyber-attacks, especially affecting cities that lack comprehensive cyber-security measures.	Clear control policies on access to particular systems through appropriate authentication and encryption, plus specialised recovery and response technologies to mitigate impacts.
Compromise of key urban assets or sensitive data due to viruses, human error, and power issues.	Fully audit the risks for cities' most valuable assets and infrastructure, and regularly test the security of active technologies.
Difficulty in the uptake of smart systems, especially in parts of cities which lack the infrastructure and capacity to integrate technologies.	Living labs to test the security of technologies before wider deployment in urban environments.

The automated city vs the co-created city

There is significant debate about the extent to which applied urban technologies will encourage substantial automation of city systems and decision-making, or instead enable cities to interface much more seamlessly with citizens to shape services.

Many are concerned that IoT's feedback control systems will bring into being a model of 'surveillance capitalism' that threaten important personal and social values, and erode the tenets of regulation, privacy and data protection. However, others continue to observe potential for greater transparency and participation in data-informed decision-making.

Conflicts between consumer appetites vs citizen interests

Cities have not yet resolved the question as governments as to how they balance their willingness to adapt to support the demands and interests of city consumers (of technology-enabled services and experiences), versus their obligations to the rights and protections of their citizens. These tensions also exist in terms of the roles and perspectives of different levels of government, and cities have to make their case for a co-ordinated approach.

Public perception

Caricatures, stereotypes and negative narratives surrounding IoT deployment in cities are viewed to be dominant in the public, media and policymaking conversation.

Many have seen people and businesses in their cities lose confidence in IoT due to poorly installed solutions, inadequate IoT connectivity options, low sensor quality, and no proper resiliency or planning.

Covid-19 has also created divergent viewpoints about the emancipatory or constraining power of IoT technologies, and concerns about how communications tech may in future be subject to geopolitical rivalry and disruption. This will affect in which cities applications that rely on high or unanimous buy-in – for health, security or other reasons - can realistically be implemented

Governance gaps

Low levels of empowerment, organisation and innovation within local/city governments remains a critical deficit holding back expansion of effective citywide scale IoT applications. This is a phenomenon of UK cities in particular, outside a handful of exceptions, but also a majority of cities in nations where most powers are held at the national or state/province level.

Siloes, short-termism and lock-in to existing technologies is compounded by low levels of funding to catalyse or monitor new approaches. One interviewee observes that "there is still no single data management/centralisation platform - we are just doing the same thing over and over again. We are not able to build a smarter city, just a smarter waste management system, a smarter water network, and so on."

Procurement inertia is another by product of underpowered cities. Cities are used to working with tech businesses that have particular ways of working and their processes are viewed to stifle new start-ups that may not pass credit and compliance restrictions.

Hasty adoption of technologies has been a hallmark of some governments during the pandemic. However, the implications of these toolkits are often either not understood or are poorly aligned with a city's long-term priorities. This raises the risk that privacy and data transparency may be sacrificed through the handing over of personal data and preventing an easy opt-out for citizens.

Entropy in the IoT eco-system

Deep fragmentation of providers is a challenge in terms of city-level integration. IoT vendors in cities typically want to become a platform vendor, while customers are more interested in the app, not the platform. The proliferation of small players, and the rise of numerous apps and systems, is viewed to create confusion and wasteful duplication in the UK and international IoT market. The process of how businesses build genuine partnerships with each other to solve complex problems and assembling the diversity expertise required to build real capabilities, is seen as poorly developed and convened.

Establishing a few recognised financial models that share appropriate risk is seen as a priority. Insufficient consideration of the value chain is a concern for many. Many approaches assume too much up front cost and risk either for the city government or for the private provider.

Many interviewees observed that there are few clear best practice models to draw on. Several remarked that they are yet to see real-time data accuracy from more mature systems. Caution or scepticism surrounds online content of companies claiming to be doing enormous amount of work on IoT, but with few technical issues in-house being communicated.

These six wicked problems will remain paramount through the 2020s. The precise way these wicked issues will be tackled and resolved is likely to look very different in different contexts and cultures, depending on a variety of political and commer

Early adopter areas in UK cities

Source: Ian Dick (2019), CC-by-SA 2.0

cial factors. We explore how these are being addressed in a UK context.

5. IoT in the UK City context

UK cities have seen a number of noteworthy successes at demonstrating the potential of IoT-based solutions. Three examples are Synchronicity, Vodafone and City Verve, all of which have engaged proactive city governments, anchor universities, larger businesses and SMEs, around new models of urban services.

These examples are the exception rather than the norm, and relative to the pace of piloting and adoption in other advanced nations, the overall range and depth of adoption has been modest.

There is an observed propensity of the conversation around smart cities and IoT in cities to overlook the very particular context of UK cities in favour of universalist ideas about what a future city may look like. The evolution of cities and the urban system in the UK is highly unusual in many respects, and this shapes capacity and appetite to implement solutions safely and effectively. These include:

1. **UK Cities were the first to industrialise**, and the first to deindustrialise in the 1970s. The extent to which this process was managed and mismanaged, both nationally and locally, has implications for the type and scale of urban regeneration that is and can be undertaken in UK cities, the role of technology in the process, and the contributions of private sector partnership in city development and urban renewal. In general, the UK more commonly engages market-based players in the redevelopment and reinvestment and technology upgrades of urban places.
2. **Larger UK cities typically experience much more positive economic outcomes**, driven principally by London which is a large outlier in terms of size, productivity and positive agglomeration economies. The under-performance of the UK's 2nd 'Core' cities, and associated high levels of deprivation, has been a distinctive feature that compares starkly with the system of cities in Germany, Spain, Japan and elsewhere. However, in general, population growth and demand is now orienting strongly in favour of larger population centres, and several larger UK cities are leaders in the knowledge economy, innovation, and creativity, which informs the direction of the IoT market.
3. **Monocentric cities with dominant city centres and greater challenges in suburbs.** UK cities tend to have a more fully redeveloped city centre that has benefited from 2 or 3 cycles of re-investment in physical fabric, visitor economy and destination development. Meanwhile suburbs have been much slower to deploy digital infrastructure or seek intensification of uses and optimisation of flows. Technology enabled environments are much more common in the city centres where the highest value corporate and retail communities are clustered.
4. **An asymmetric governance system** which has a very strong central state combined with diverse arrangements

whereby cities are on a continuum stretching from metropolitan government with significant competences (Greater London), metropolitan combined authorities and Mayors with some competences (Greater Manchester), city-level Mayors in collaborative metropolitan systems, and other models. This results in large discrepancies in technical and investment capability, and in general low levels of resource devoted to the risks and implications of technology adoption.

5. **High levels of disparity and inequality** within and between regions of the UK, with strong geographical determinants of life outcomes in cities, creates particular patterns of demand and concentrations of need for technology enabled services, alongside imbalances in financial resources or the business case for investment. These also translate into highly uneven supply and demand in technological innovation and access, and resilience to economic shocks.

Implications for the UK IoT and Cities Eco-system

This highly distinctive context for UK cities produces a number of outcomes and tendencies in the way IoT is conceptualised and adopted.

The first is unhelpful **competitive behaviour**. Relative to other systems of cities, there is a tendency for every city in the UK to make claims about being a digital and IoT leader, as a form of self-promotion and in attempts to win grants. Meanwhile in practice most UK cities are still viewed to be "in the foothills" in terms of genuine delivery of IoT.

The second major challenge is **information and co-ordination gaps**. There are currently few players with a bird's eye view of what is going on or clear pathways for shared learning. Network operators and technology providers in particular are unclear about who they can or should learn from, how and why. Partly for this reason there is **fairly low commercial trust or know-how**, a lack of data or experience sharing, patchy business acumen, and a general sense of caution that bigger companies will trump or devour smaller scale innovations.

Part of this challenge is also to creates a shared language. **There are low levels of awareness so far in the cities space about some specialist terminologies, including 'the edge'.** A significant process of translation may be required to ensure all parties can relate to each other. By the same token there are also large **epistemic gaps** even among players in the same space. Some leading businesses, for example, are not concerned with security failures and view it as a function of inadequate people or processes and failure to implement best practice, not the technology itself.

The third influence of the UK's peculiar urban character upon the IoT scene is **speed**. The model of funding and development of business cases is seen to be too slow, because of the absence of local finance, lengthy and uncertain grant processes, and inadequate know how.

For these reasons there is **widespread frustration** about the unrealised potential and the slow pace of progress of IoT in cities and local places. Some larger players have withdrawn the scale of platform ambition after accepting they misread the landscape of how solutions can be delivered and budgeted in complex cities. Overall UK cities were perceived to have mostly fallen behind in adoption until Covid-19, and now there is more momentum albeit the investment horizon is very uncertain.

Case Study: Manchester – capacity creates capability

Manchester's transition to a Combined Authority and Metro Mayor has helped it to scale and pursue a number of IoT innovation projects, as the city has started to become a leader in convening IoT technologies and testing their deployment for specific urban priorities.

CityVerve was a two year project undertaken in Manchester as the UK's IoT demonstrator city, whose aim has been to stimulate new IoT projects and engage public opinion, art, and human design in the conversation and design process of pursuing 'smart city' characteristics in a Manchester idiom. More recently Transport for Greater Manchester, Immense (a simulation company) and Vivacity (an AI firm) have been working collaboratively on a project to understand how to make the traffic enforcement process more streamlined and cost-efficient.

Manchester is also deploying IoT in its main innovation districts. Along the Oxford Road Corridor, IoT is integral to its cloud-based energy management systems as 'virtual power plants'. And in early 2021 a testbed was launched in Salford's MediaCityUK district, to demonstrate how IoT can be used to adapt to changed urban behaviours in a post-Covid world. Start-ups can draw on the district's 5G incubator space to deploy and test technologies, for example to monitor pedestrian footfall and mobility to help adapt public space in the post-pandemic recovery, to create workspaces, or to monitor the health of elderly residents in care homes.[11]

Greater London

After nearly a decade of practice and experience with open data, Greater London Authority's approach to managing and steering the data eco-system now includes:

- A Federation of Data Stores – act as Central register of APIs as a service
- Setting civic problems to solve
- Clearer standard-setting for private and civic partners
- Leadership and oversight on data security and ethics

One of the impacts of opening data was to enable the creation of CityMapper which has had a large equalising effect in terms of how lower-income London citizens use buses and optimise their journeys. In the next cycle London's Digital team is focusing on:

- Building trust between citizens, public sector and business, given public scepticism that local governments will do bad deals with their data with tech companies. This includes a clearer explanation of the purpose of tech and IoT.
- Wifi data on systems, Data trust pilots and ICO Sandboxes
- Workshops to bring organisations together
- A Charter providing guidance on sensory information for public/private spaces
- Developing a user-friendly framework of accountability for public servants. Some have observed that data ethics guidelines are inadequate for the granularity of experience working with citizens.
- Open calls to set terms of engagement.
- An explicit balance of public value vs private value.

For these reasons there is a high level of appetite for research on what it takes to safely deliver IoT in cities, that includes the practical risks and challenges, especially for research that is implications-focused and solutions-oriented.

Which cities are making progress?

Whether IoT can serve to reduce regional disparities in the UK and directly impact on performance in lower-productivity cities already set to recover unequally is an important question many are asking.

The question extends not only to whether IoT enabled systems produce certain efficiencies or direct advantages, but also opens up the possibility that an IoT-charged economy will alter commuting patterns in favour of smaller cities and suburbs, re-distribute economic activity by reducing some of the advantages of proximity, scale and frequency.

Currently there is a view that some cities are moving quicker than others to resource and accommodate IoT as a positive disruptor to their economies and services. Interviewees observed that the cities that are making progress in harnessing IoT tend to benefit from:

- Fibre connectivity platforms
- Cities working with their universities
- Possess large landholdings
- Solid eco-systems of social entrepreneurs
- Strategy that is well resourced
- Digital lead who isn't techie but design + tech combine.
- Ambassadors and Champions

Milton Keynes, **Coventry**, **Bristol**, **Glasgow** were named as examples of leaders. Particularly in the previous cycle **Manchester** was also viewed to be a leader.

But overall most cities do not possess these levels of engagement among city departments, and here the impacts and risks of IoT is viewed to still be entirely peripheral to the strategic conversation. The opportunities and the risks associated with IoT, and in particular the edge, are not yet viewed to be aligned or synchronised with existing know how of UK cities. There is a widespread view that UK cities need powers to permit that are devolved from Government on tech.

Covid-19 compels UK cities to innovate and reimagine, and there is optimism about the potential ingenuity of different levels of government to successfully create a step change in cities' potential to embrace secure technologies and align them with wider development imperatives.

Many therefore see a particular contribution now being required to improve UK cities':

- Leadership know-how and vision.
- Incentives to adopt and future-proof.
- Organisational preparation for IoT impacts, whether in terms of existing departmental capacity-building, or the creation of separate units with the remit and agility to create roadmaps and visions.
- Open-mindedness with 'thinking outside the box' to overcome stagnancy in policy proposals and technological approach.

Case Study: Glasgow, Edinburgh, Stirling, Dundee and Perth - Scottish Cities turning toward IoT innovation at scale

The Scottish government is actively encouraging local governments in cities to realise the benefits of IoT technologies into their urban environments, as part of the Covid-19 recovery.

A £6 million development of IoT Scotland has established a pioneering national network to link IoT technologies across all urban areas. During the pandemic, all developers, adopters and users have been offered free-access to the network, to trail solutions to address solutions to issues such as health and mobility. The network itself includes a LoRaWAN (Long Range Wide Area Network) that can be used by applications to collect real-time data from devices with no need for connectivity. This project has given rise to applications spanning the analysis and reporting on workflow management systems in essential sites such as city hospitals and supermarkets, and the asset tracking of integral critical healthcare equipment.

The government has also provided all local councils with free access to government-funded IoT Accelerator Packs on a 12-month trial basis. The pack offers technologies and back-end services for intelligent lighting, waste management, air quality and social housing solutions. Councils can investigate how such technologies can be used in their urban contexts and can benefit from mentorship from North, the UK's leading IoT service and solutions provider. The accelerator packs have so far been utilised in schools, care homes, leisure centres and council offices, with the aim of creating safer and more sustainable smart buildings, with lower costs and wider community benefits.

Glasgow has been one of the cities at the forefront of IoT in Scotland - working for over a decade on IoT project-oriented traffic and public safety management systems, built upon complex data and video analytics platforms. There is also a citizen app being launched, My Glasgow, allowing individuals to interact with city-wide services and report infractions. Glasgow is also exploring full integration of smart grid technology that can be used to keep up with the increasing demand for renewable energy sources to work toward low carbon energy.

More broadly there are a series of potential broad-based impacts on UK cities that have yet to be fully traced, that suggest that technology adoption could initiate a wider set of benefits and effects on how UK cities modernise their institutions, manage costs, and transform their operating systems. In effect, IoT can be an enabler of overdue change in UK cities' capacities and capabilities, as well as an imperative to improve them.

Who knows and needs what?

Our interviews and feedback from participants indicate, that in relation to the nuances of IoT's effects and risks:

- Chief Executives of Local Governments in cities have a solid grasp of what IoT can do for their area - both in a council sense (efficiency, cost, etc.) but also in a broader sense (what benefits and opportunities can it bring - business, consumer habits, etc. e.g. wearable tech for social care). Many learn from platforms such as SOLACE.
- Businesses are seeking help finding the right players, the right vision, to understand what they are trying to accomplish, bringing different viewpoints together.
- Major firms currently learn mostly from start-up and SME communities trialling new ideas, and at larger business events and gatherings. Many find it hard to engage with public sector leaders on joint approaches. One remarked, "I haven't found thinkers in the public sector who are able to redraw their boundaries, even the DevoManc process has yet to produce capacity for IoT strategy work."
- There is an under-recognised role of the system integrators with the enabling capability - with a big stake in the game. These include Vodafone, Orange and others who are buying lots of smaller firms. Options to partner with big system integrator players merit exploring.
- Many welcome the expansion of multi-stakeholder approaches, including healthcare providers and private sector organisations as well as local councils and UK government agencies

Potential range of impacts with implications for cities

Institutional Impacts	Cost Impacts	Regulatory Impacts	Service Impacts
Necessitate institutional reforms & mergers.	Potential to save money to free up for alternative investment priorities	Transformation of planning systems, security laws, procurement, and relations with other governments.	Render many services obsolete, enhance demand for others.

Case Study: Hull's transition toward IoT integration and a city-wide OS

Hull has begun its move toward using IoT to de-silo information and integrate citywide data insight into a central dashboard. Monitoring systems are helping to build a citywide operating system to make Hull 'programmable', through sensor monitoring systems that allow for effective monitoring and adjustment of lighting, pollution and pedestrian movement. As with other cities, the advantages are also perceived to include the potential to engage more business and innovators around Hull's technology transition.

Perceptions of academic contribution to IoT and cities

Interviewees widely recognise that it is very important that academics work with business more effectively on how to wisely prepare and proof their IoT systems for their application to the complex environments of cities. Many expressed enthusiasm for Public-Private Partnerships with academic institutions and centres as a key stakeholder.

There is a desire for academic specialists to be able to show and visualise realistically what the practical challenges are, and to reveal issues that are currently hidden from public domain. Many in business, government and institutions are eager for these 'translation' and 'dissemination' roles to be scaled up quickly and for there to be clearer 'one stop shops' for commercially relevant insight.

In all, on the divisive questions of IoT's responsible future in cities, academic researchers are highly valued for their capability to play a sensitive and mediating role between citizens, city governments and disruptive business – when equipped with familiarity of the stakeholder vantage points and with suitable messaging and engagement tools.

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