Horizon Scanning Series

The Internet of Things

The Internet of Things (IoT) and key issues for future services

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This Briefing Report examines key issues in relation to the adoption of IoT, with particular focus on areas such as smart cities, public sector service delivery and creative media. The Report reflects the author's understanding of key priority issues relevant to IoT.

1. Introduction: Key Dynamics of IoT

1.1 Definition and approach

The Internet of Things (IoT) broadly refers to the extension of continuous internet connectivity to everyday objects or 'things'. While predicted for some years – and the focus of speculative R&D for decades – a confluence of technical innovations has resulted in IoT-based services and technologies becoming more widespread in impact and influence in recent years.

Understanding the *impacts* of the IoT nevertheless remains a complicated exercise. This is because the IoT is not simply a new technology but a process of **intensification and extension of internet-enabled modes of communication, management, knowledge production, service design, infrastructure provision and creativity**.

As such, the process of understanding *how* IoT impacts on key service areas requires moving beyond relatively narrow, device-oriented perspectives, which focus on the use of sensing tools into new environmental, infrastructural or domestic contexts. Rather, a broader, 'ecosystem-wide' perspective is needed to understand the relationship between separate but interlocking aspects of digital transformation that are happening concurrently. It is these interlocking elements that, taken together, underscore the significance of IoT on service domains.

The difference between a device-centric definition of IoT and an ecosystem definition is detailed below.

Device-centric approaches

Device-centric analyses of IoT have tended to focus on the specific devices of Remote Frequency ID (RFID) tags, sensors and micro-processes embedded in supply chains, infrastructures and everyday objects.

In 2005 the International Telecommunications Union (ITU) predicted an internet of things when the 'users' of the Internet would be counted in billions, extending from human to non-human life forms, as everyday 'things' become receivers and transmitters of data (ITU, 2005).

Another more recent, and more expansive definition described the development of IoT as being enabled by "combining the Internet, near-field communications, hardware, and embedded sensors with real-time localisation" (Leminen et al., 2012: 15; Li, 2015). Approaches such as these focuses on the roll-out of sensors, devices and actuators into everyday things, infrastructures and services, which is driven by reductions in sensors' size, price, and energy consumption, as well as their increased performance (Leminen et al., 2012: 15-16).

The need for an ecosystem perspective

The problem with this approach is that it ultimately focuses on the novelty of internet-enabled 'things', which themselves are of primary significance in the way they *extend and augment* digital ecosystems of management, design, governance and service delivery into new contexts.

As a recent paper published on the social impacts of IoT has recognised:

> *The social interconnectivity of the IoT platform becomes easily overlooked when focusing on the novelty of smart "things." However, the connectivity of the Internet to the IoT should not be neglected when trying to understand how people create, maintain, or absolve social bonds in a networked society* (van der Zeeuw et al., 2019: 1346).

A broader 'ecosystem perspective' recognises how a set of enabling innovations are integrating in significant, compounding ways to facilitate IoT transformations.

The separate but interlocking innovations underpinning IoT can be summarised as follows:

- The integration of microprocessors / actuators and sensors into every objects, infrastructures and environments (sensors or 'things').
- The widespread roll-out of wireless broadband networks, facilitating data sharing between distributed devices and networks (ubiquitous wireless).
- The advance of big data analytics through machine learning techniques, facilitating automation and continuous learning / responsiveness between devices and their environments (big data analytics). The proliferation of intelligent 'things' results in the further intensification of data generation and, in turn, acceleration of machine learning algorithms trained by a greater volume of data.
- The implementation of both cloud and edge computing services, which facilitate greater flexibility (and efficiency) in data hosting and processing in (data triage).

Taken together, these interlocking innovations have the potential to dramatically transform a range of existing service delivery models in significant ways. Some of the key ways in which IoT impact is understood are summarised below.

- *Improved monitoring towards more predictive and/or responsive services*

IoT uses sensors to capture data on dynamic and complex environments, infrastructures and assets. This improved monitoring capability facilitates more efficient use of resources and greater responsiveness, including predictive maintenance, customer responsiveness and improved environmental and asset management.

These developments are particularly relevant to urban and environmental management settings, smart cities and local government, smart home environments, utility management, precision agriculture and smart infrastructure services.

- *Construction, supply chain management and manufacturing*

IoT can be used to track and monitor inventory and supplies, to improve manufacturing and also to improve the efficiency of the construction sector. These benefits and impacts are underpinned by improvement to management of complex processes that involve multiple inputs, supply chains, services and materials. IoT can be used to reduce latency in these domains and improve productivity.

- *Business model disruption*

IoT is associated with the proliferation of data-generating assets and, in turn, the extension of digital business models that use service delivery or even product sales as a 'loss leader' for the accumulation of data assets.

This has implications for privacy and conditions of 'data surveillance' which can be extended into more diverse domains of human activity. As has been evidenced by the impact of major digital platforms on media and online service industries, the extension of data-driven business models into domains of infrastructure and utilities has economy-wide implications and the potential for major disruptions to a number of existing industries.

This transformation can be expected to shift consumer expectations around products and product life-cycles. As examples, consumers can be better equipped to rent or reuse a product rather than owning it, with benefits for the circular economy. Products are also equipped with software services (e.g. speakers become 'smart') which allow manufacturers to add software subscription services and therefore develop more iterative and ongoing relationships with customers over a longer period of time.

- *Interaction design*

IoT introduces a vast array of new design possibilities that reshape the way people interact with environments and services. These implicate the creative industries in domains such as museums and interpretation, and design – particularly architecture, urban design, and experience design. In many respects, IoT can enable what is known as more 'ambient' technology interactions, which do not require interaction with a screen or physical device to generate a response.

- *Interlocking impacts*

An ecosystem perspective also highlights the need to consider IoT as an integrated dimension to wider digital disruptions and transformations.

For example, the significance of digital platform business models, and their regulatory implications across media, telecommunications and competition law, as examined in the recent ACCC Digital Platforms Inquiry, cannot be set apart from attempts to understand the impact of IoT on key services.

IoT represents ***an extension*** of the issues and concerns raised in the Digital Platforms Inquiry into broader service domains. This is acknowledged in a recent *Economist* report on the IoT, which observes:

> *The logic of data-driven businesses, which do ever better as they collect and process more information, will replicate the market dynamics that have seen the rise of giant platform companies on the internet* (Economist, 2019).

It is worth noting that while major IoT impact studies, including a 2018 PWC on IoT Impact (PWC 2018), highlight significant gains to Australian productivity, what is not factored into these impact studies are the consequences of new competition dynamics that occur between major data-driven technology platforms and companies that lack access to global data resources.

Likewise, IoT services extend the influence of machine-learning algorithms into everyday objects and infrastructures, and are therefore part of a wider shift towards automation and the applications of artificial intelligence (AI).

The outnumbering of humans connected to the internet with the billions of 'things' speaks to a layer of autonomous systems that require less human input to manage them. These issues have been widely addressed in existing research and public debate over the future of AI and its impact on future jobs.

For this reason, it can be less useful to consider IoT as a stand-alone topic, and instead part of a wider set of digital transformations – broadly characterised by the ***extension and deepening of data-driven modes of knowledge generation, management, service delivery and commercialisation.***

1.2 Mapping IoT ecosystems and applications

There are a number of definitions, frameworks and digital innovations encompassed by IoT that point to a set of complexities associated with understanding the impacts of IoT on a range of service delivery areas.

The table overleaf summarises the diverse enabling innovations associated with IoT, their different applications and associated terms or industries.

Table 1: Mapping IoT applications

Enabling IoT innovation	Nature of enabler	Inclusions	Associated terms (indicative only)	Application examples
Miniaturisation and integration computational processing power in everyday geographical contexts	Hardware	Semiconductors Actuators Microprocessors Sensors GPS-equipped mobile devices	Distributed computing Pervasive computing Ubiquitous computing Cyber physical services Urban informatics	Smart cities Environmental monitoring Smart infrastructure Locative arts Urban media
Internetworking of devices and objects using Internet Protocol (IP) services over wireless broadband or satellite-internet	Networking	Wireless networks, including LPWANs Unique Identifiers (UIDs) Near Field Communications	Remote sensing Machine to machine (M2M) communications	Data-driven services Automation Responsive environments Locative media Smart objects Smart cities Smart infrastructure Smart homes
Data processing and triage	Storage & hosting	Off-site Data management and integration Data centres Edge devices	Cloud computing Edge computing	Software as a service On demand services
Big data analytics	Software & Automation	Machine learning Big data Artificial intelligence (AI)	Data-driven services AI Data economy value chains Platform economy	AI platforms Data-driven services Building information management (BIM)

The implications of IoT are also often *embedded* within wider industry transformations associated with the integration or application of data-intensive services and analytics. The table below provides a summary of example industry transformations, of which IoT is a contributing, but not sole, element.

Table 2: IoT and clustered digital innovations

General	Creative Industries	Government and urban planning
Digital twin Edge computing Software as a service The Internet of Everywhere (IoE) Industrial internet	Locative media Responsive environments Immersive and/or experiential design Software as a service Urban media Spatial media	Smart cities Smart infrastructure Government as a platform Digital service design Platform urbanism

1.3 Framing impact: from speculation to commercialisation

Many of the critical impacts and issues that are today being considered important to the roll-out of IoT are not new, but have been anticipated for decades. Over this time, the shift towards embedding computational intelligence within everyday environments, things, and infrastructures has gone by many different names.

As is widely known, the term 'internet of things' was specifically coined in 1999 to describe the use of Remote Frequency ID tags (radio transceivers) in supply chain management (Ashton, 2009). However, ideas and practices exploring the potential for computational intelligence to be embedded within broader environments has a much longer history.

Over the past few decades, many of the analytical approaches established to understand the potential for more distributed computational intelligence have been highly speculative and future-focused. Computer scientist Mark Weiser adopted the term 'ubiquitous computing' (Weiser, 1991), to describe the work of his team at PARC to put wireless computing devices everywhere. Weiser argued that ubiquitous computing required a rethink of human-interface design, operating systems and networks that no longer put the computer at the foreground of human attention – informed by the potential for computers to operate as an invisible, unobtrusive backdrop to life:

> *It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere.* (Weiser, 1991)

Ubiquitous computing has been associated with speculative approaches to human-computer interaction (Bell and Dourish, 2011), focused on promoting cross-disciplinary approaches to computational design. This work has given rise to a range of experimental technology practices over many years, with strong links to creative fields such as architecture and media design (Wiethoff and Hussmann, 2017: 9).

Pervasive computing, popularised by IBM, is likewise a forerunner to IoT. In 2001 Paul Dourish described the rise of 'tangible computing' (2001). New media theorist Lev Mannovich popularised the term 'augmented media' to describe the "introduction of dynamically changing information and multimedia that is diverse in form and localized for each user, and where the data form an always connected, pervasive or 'immersive' environment" (Mannovich, 2006: 220).

A range of other analytical approaches to distributed computing have also grappled with the potential for computational intelligence to be embedded in urban infrastructures and services. Terms like 'everyware' (Greenfield, 2006), 'sentient' cities (Crang and Graham, 2007), 'real-time' cities (Kitchin, 2014; Barns, 2010; Townsend, 2000), 'ambient' computing (Daecher and Galizia, 2015) 'urban informatics' (Foth et al., 2011; Barns, 2016; Foth et al.,

2008) and ' ' (Townsend, 2013; Shelton et al., 2015; Kitchin et al., 2015) are just some of the terms historically used to describe a set of shifts often associated with today's IoT transformations.

'Locative media' (Galloway, 2008; Hemmet, 2004; Goggin, 2006), while largely associated with the adoption of location-aware (GPS-enabled) mobile devices, also incorporates the use of remote frequency identification (RFID) tags into everyday surfaces and environments, and in this sense also has integrated elements of today's internet of things (IoT).

In 2004, UK creative practitioner and researcher Drew Hemmet helped define an outpouring of creative media innovation associated with this embedding of computational integration in everyday spaces and surfaces when he described locative media as using "portable, networked, location-aware computing devices for user-led mapping, social networking and artistic interventions in which geographical space becomes its canvas" (Hemmet, 2004).

Given this backdrop, it is therefore important that a contemporary analysis of IoT – particularly in relation to creative and urban design sectors – be situated within existing and highly active fields of research and creative practice, which span design computing, urban planning, media arts and human-computer interaction.

These fields include a breadth of existing engagement with the potentials and challenges of distributed computational and networking capabilities across design, creative sectors and urban governance fields.

Nevertheless, there are also important differences in the way pervasive, distributed computing has been envisaged in the past, and the application of IoT services today.

- Many previous responses to distributed or networked computing devices did not incorporate innovations in data analytics and processing, and their associated business model implications.
- They took place at a time when data hosting and wireless communications services were far more costly than is the case today.
- As a consequence, the potentials to engage with distributed networking devices were relatively *experimental and speculative*, and framed in terms of the new kinds of relational, social and design-led experiences made possible when networked devices, locations and their users could be put in relationship with each other.
- These creative and design-led responses to ubiquitous and 'real-time' services took place in relatively *confined* contexts of experimentation, often in research-led environments (Foth et al., 2008).
- Automation, machine learning and artificial intelligence were not yet advanced, sensors were not being rolled out at scale, and major technology players were not competing for market reach, data assets, and consumer uptake.

This period of experimental engagement with emergent, responsive computing can be characterised by this quote by leading interaction designer Paul Dourish in 2001, writing in relation to the potentials of 'tangible' computing:

> *Embodied interaction is not a technology or a set of rules. It is a perspective on the relationship between people and systems. The questions of how it should be developed, explored and instantiated remain open research problems* (Dourish, 2001: 192).

Examples of IoT integration which build on these more creative, experimental endeavours are discussed in Section 2 on creative services.

1.4 What *is* distinctive about IoT?

As stated, the implications of IoT today are best understood as part of ecosystem of related transformations – which include widespread adoption and integration of low cost sensors, wireless networks, big data analytics and cloud computing or 'data triage' services, but also the extension of digital business models and feedback loops. Today's emergent IoT has also emerged against a backdrop of experimental engagement with the potentials and challenges of ubiquitous, pervasive computing.

Unlike earlier experimental work with pervasive and ubiquitous computing, many of today's IoT applications are being developed with a view to industry-wide, commercial applications. This reflects the increasingly 'infrastructural' nature of contemporary digital connectivity, whereby more and more industries and services are dependent on digital networks, data platforms, and analytics. This process of platform 'infrastructuralisation' (Plantin et al., 2016) associated with the widespread adoption of digital platforms and intensification of data-driven services, is critical to understanding the impacts of IoT.

IoT today encompasses *billions* of connected devices, many of which are integrated with industrial services and infrastructures – whether energy services, water, transport and logistics, consumer services or retail. The industry-wide applications of IoT are for this reason sometimes described as the 'Industrial Internet of Things' (IIoT) operating in fields like manufacturing, logistics and transport, and utilities.[1]

IIoT is a term sometimes used to differentiate between more consumer-oriented applications, such as smart home devices or personal tracking devices. As one commentator has described it:

> *If you've ordered a pizza with Google Home, monitored your sleep patterns with your Fitbit or unlocked your bike lock with your smartphone, you are part of the IoT revolution changing how we interact with the world (Morrison, 2018).*

A number of analysts also examine IoT through the particular technology configurations or 'stack' that are implemented to integrate distributed 'things' with wider data platforms. The particular software configurations required by this IoT stack are, to some, what define today's IoT as a specific software platform that is required to connect the edge hardware, access points, and data networks to end-user application (S.T., 2019).

The IoT platform technology stack

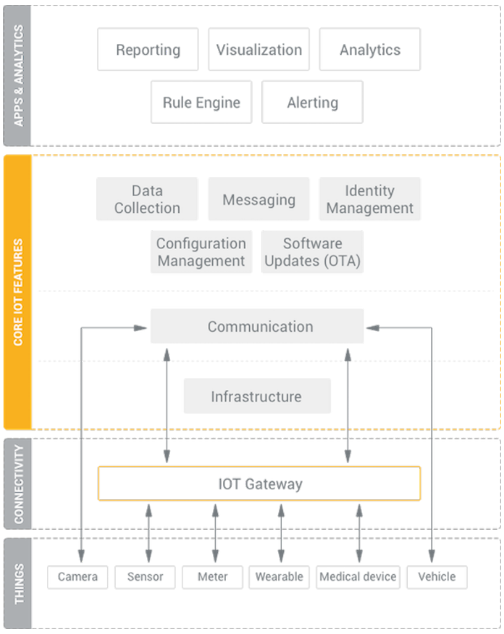
IoT platforms are frequently characterised as incorporating distinct layers of connectivity. A typical characterisation of an IoT platform or stack will include:

- Things;
- Connectivity;
- Core IoT features, inclusive of data collection, device management, configuration management, messaging, and OTA software updates; and
- Applications & analytics.

The following visualisation below represents a relatively typical characterisation of these interlocking technology layers, sourced from a commercial IoT platform provider (Kaa, n.d.).

Figure 1. Indicative IoT technology stack (Kaa, n.d.)

[1] This definition fails to recognise that the earliest uses of the term Internet of Things were associated with supply chain management.



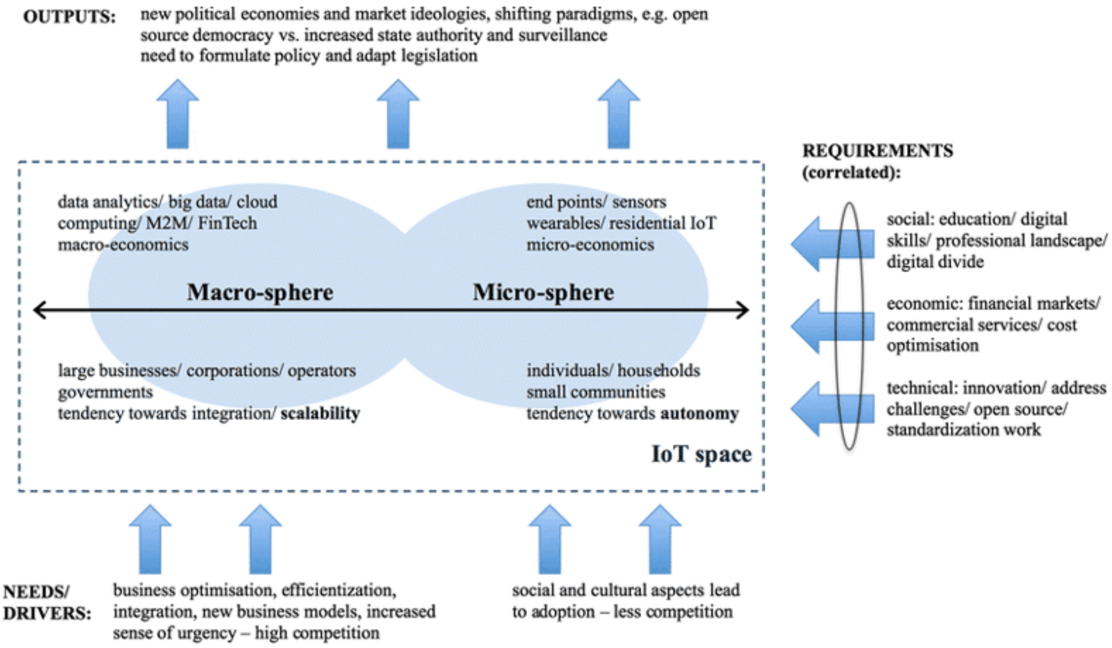
For IoT researchers Nicolescu *et. al*. (2018), what is distinctive about IoT technology stacks or platforms is that they integrate both 'macro' and 'micro' levels of engagement with digital technologies and services (Nicolescu et al., 2018: 348). The researchers argue that this introduces unique dynamics for innovation and service delivery. At a 'micro' level, IoT is associated with the introduction of wearable devices, home sensors, and other intelligent devices at the citizen or consumer level (the Fitbits, Google Home and smartphone-enabled bike locks) allowing services to become more 'intelligent' and responsive to context, user and/or other devices.

Concurrently, the ensemble of IoT related devices and processes (named within the 'Core IoT Platform' domain in the visualisation above) is usually accessible primarily to larger entities such as large businesses, corporations and governments. As is evident within the above IoT platform technology schema, the majority of data processing, analytics and service integration takes place at this macro sphere. As Nicolescu et al (2018: 348) have subsequently argued:

> *What is characteristic for the IoT is the complementarity, interdependence, and co-evolution of the two spheres. For example, innovation in start-up cultures (micro-sphere) needs the infrastructure and support of bigger industrial players and the public sector (macro-sphere). At the same time, major players in the macro-sphere need the levels of flexibility and risk-taking that start-ups can provide and internalise when needed.*

This approach to understanding IoT ecosystems is captured by these authors in the schematic below.

Figure 2: Conceptual IoT framework (Nicolescu et al 2018).



This conceptual framing of IoT, using the lens of macro and micro scale services, provides a useful schematic through which to understand how IoT may impact different services settings. However, arguably these dynamics are not confined to IoT, but are typical of the dynamics of *value-centralising* and *value-sharing* of digital networks and platforms.

1.5 The importance of platform business models

The platform business model is widely recognised as having a transformative impact on many industries and services.

Initially associated with the development and roll-out of social media platforms such as Facebook, search platforms such as Google and two-sided 'share economy' platforms such as Uber and Airbnb, digital platforms have facilitated processes of decentralisation and network effects, but in more recent years have demonstrated the capacity for value capture and agglomeration.

Decentralisation and network effects

The concept of 'network effects' is well known and captures the interlocking impacts that multiple users of a network have on the underlying value and utility of a network. As one academic paper describes the role of network effects on platforms: "user benefits depend on participation and usage decisions of other uses, giving rise to network effects" (Belleflame and Peitz, 2016).

The perceived benefits of network effects played a critical role in shaping the uptake of sharing economy services for many years. Sharing economy advocate Rachael Botsman described the sharing economy as one that enables entrepreneurs, which she calls 'micro-preneurs', to create new service offerings via major (macro) platforms such as Airbnb or Uber (Botsman and Rodger, 2010).

Digital platforms have been celebrated for their capacity to decentralise value-creation by allowing others to generate new products and services within shared set of data protocols and frameworks. Iconic examples of this form of digital design include Apple's iPhone, and the launch of the App store, as well as Facebook's Social Graph. In both innovations, an underlying set of rules and protocols was put in place to facilitate data sharing and creation, underpinned by an application programming interface (API), encouraged external innovation and value-creation by developers.

This mode of data ecosystem design generated great value for network users (such as iPhone users or Facebook users, and advertisers), but even greater value for platform owners. The App Store generated billions of dollars in revenue for both software developers and Apple – while also extending the functionality of the iPhone for all users (Wingfield, 2018). Despite taking sizeable 30 per cent cut of app store sales, Apple in 2019 remains the largest income generator for developers amongst all players in the App Store space. This is why platforms can often be called 'catalytic value creators' (Evans, 2011).

From network effects to platform ecosystems

Today's digital platforms build integrated relationships between users, developers, advertisers and software infrastructure known as a 'platform ecosystem' (Tiwana, 2013). It is widely touted as a commercially-savvy business strategy in a world of connected devices – "a means of centralising expertise while decentralising innovation to the user" according to digital consultancy ThinkWorks. The iPhone software ecosystem – better known as the App Store – benefitted Apple immensely, and cemented its role as one of the world's leading digital companies, and by integrating platform ecosystems into its very hardware ensured the success of the iPhone product.

The unique strength of the platform-as-ecosystem model is that unlike more 'traditional' firms – and typified by legacy smartphones such as the Blackberry or Nokia offerings displaced by the iPhone – platforms aim to be extended and elaborated from outside, by other actors — provided that those actors follow certain rules (Simon, 2011). Platform analysts thus describe a shift 'from pipes to 'platforms' (Choudary, n.d.; Alstyne et al., 2016); from 'product and service competition' to 'platform-based competition' (Tiwana 2015); or from 'vertically integrated companies' to 'platform ecosystems' (Simon 2011). Platform business models also focus on integrating software services within products, sometimes known as a shift towards 'software-as-a-service'.

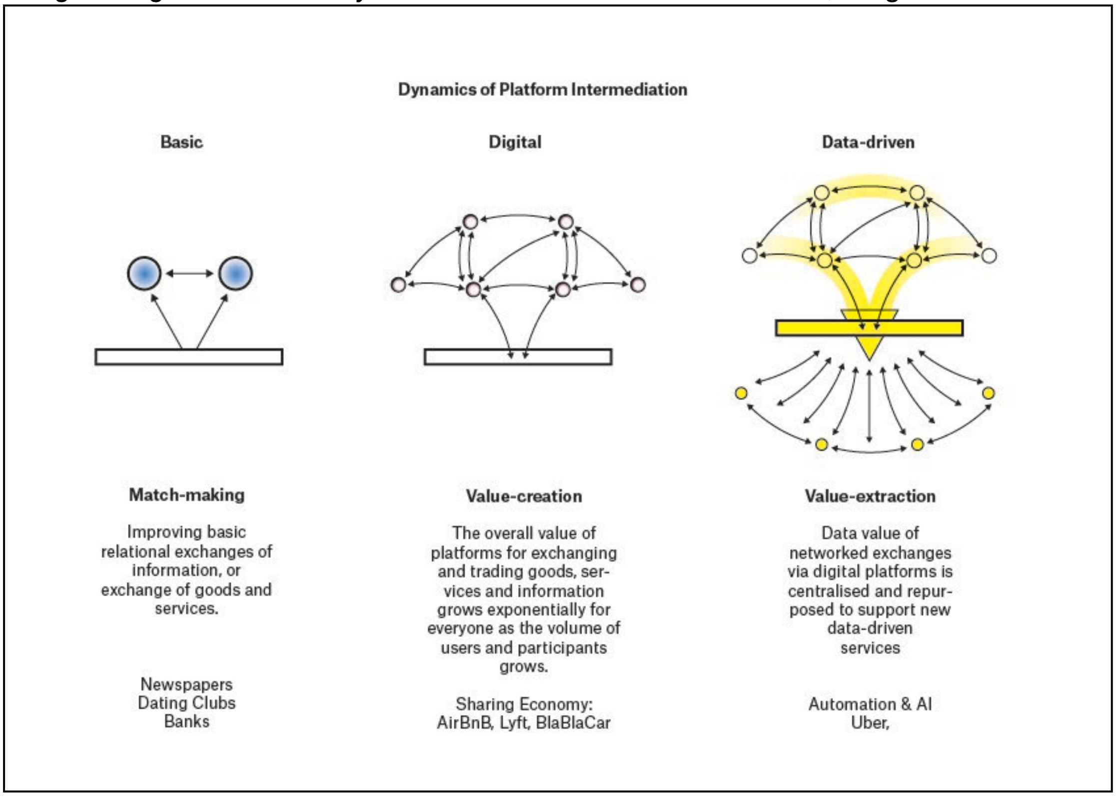
In recent years, it has become increasingly clear that one of the major features of the platform business model is reliance on centralised data governance, in ways that allow a company to benefit from the volume of digital interaction taking place across a platform environment or ecosystem.

While platforms will introduce APIs that facilitate external software innovation and inputs by diverse users (the ecosystem of 'micro-users' that use a platform), these concurrently introduce centralised protocols, standards and ownership structures that govern how user data is collected and processed. This enables platform owners to exert influence over how data assets can be used, creating asymmetries in the advance of data analytics capability that favour economies of scale. As financial geographers Langley and Leyshon (2017: 7) have written:

> *It appears that the key for the platform is to intermediate the ever-expanding value created by user interactions across their market network. This is because continually increasing numbers of users – understood as producers and creators of value and generators of data, and not as consumers – is crucial to a platform's capacity to cultivate and capture value, and to do so over time and on an ever-greater scale.*

These dynamics of platform businesses are captured in the visualisation below.

Figure 3: Three stages of platform intermediation. Source: Barns, S. Platform Urbanism : Negotiating Platform Ecosystems in Connected Cities. London, Palgrave Macmillan.



As visualised in Figure 3 above, a platform grows exponentially in value when it not only facilitates improved digital service delivery or ‘sharing’ between users, but also integrates more and more data feeds from more prolific and distributed devices (not just people, also things).

This is especially true when the service offering provided by a platform becomes fundamental to the operation of a distributed network, whether of communications, goods and services, or devices, or things. Google Search is a good example of how fundamental a digital platform can be to the operations of its users, as information seekers. This mode of platform intermediation also introduces new dependencies between distributed network infrastructures and centralised digital management systems.

This process – whereby a digital platform becomes fundamental to the widespread sharing and distribution of digital services across marketplaces – is particularly important in a digital economy. Platforms can essentially extract the data assets generated via digital exchanges, to be used in new intelligent or AI services (Langley and Leyshon, 2017; Evans, 2011). This places platforms in a position of competitive advantage, leveraging data assets to diversify into new marketplaces, or acquire competitors. Google was able to acquire smart home company Nest in 2014 for 3.2bn cash in 2014; it is also able to leverage the data assets generated via its digital search and other platforms for its Google AI services.

This ‘renewal’ of data-value was acknowledged in the 2017 Productivity Commission report *Shifting the Dial* (2017: 166), which states: “Data (and its analytics) is the most significant renewable resource discovered this century”. The following passage also captures the scale of centralised intelligence this model of computational architecture facilitates:

> *The rise of AI inside Google resembles a journey billions of us are on collectively, hurtling into a digital future that few of us fully understand—and that we can't opt out of. One dominated in large part by Google (Brooker, 2019).*

As the growth of major sharing economy platforms has illustrated, these dynamics of platform intermediation may facilitate decentralised 'network effects' which many users may benefit from – in being able to access a more diverse array of services or market opportunities. But under conditions of centralised data processing, governance and analytics this model of digital service design can also lead to highly centralised commercial outcomes for a small number of very dominant platform owners (Evans, 2003).

In the Australian marketplace, IoT in 2019 is predominated by consumer uptake of smart speakers in the home. As a report by market research firm Telsyte identified, Google Home dominates this marketplace with 70 per cent market share 2018, followed by Amazon with 15 per cent. This demonstrates the way major digital platforms are able to leverage their data assets to gain a competitive (or dominant) position in the IoT marketplace.

1.6 Platform business models and IoT

Commercial opportunities associated with operating and managing IoT platforms reflect the extension of 'value-creating' nodes operating within a platform environment – from individuals connected to computers, or smartphones, for example, to the billions of 'things' connected via distributed devices.

These issues are becoming more pronounced in a world of more connected 'things', with potential implications for how services are being designed and delivered for consumers and citizens. Critical here are the rules and conditions that allow data from diverse users, nodes, and devices, to be owned, processed, aggregated and used in wider commercial and other service applications.

- *'SaaS-of-everything'*

IoT means 'Software as a service' (SaaS) offerings are integrated into more and more domains of life, displacing traditional notions of ownership. Just as we may no longer own music, but stream it via online streaming services for monthly fees, so IoT services enable traditional product sellers the opportunity to become 'SaaS providers'.

For example, a tyre seller could add sensing capabilities to the tyres its sells, which over time can be used to provide predictive analytics as a service to its tyre consumers.

While many contemporary technology journalists emphasise new commercial benefits associated with this shift towards 'software as an embedded service in everything', there are also major challenges around value-capture. Platform ecosystems have the potential to scale quickly and disrupt existing service models – and existing platform ecosystems, such as those developed by Google, Facebook, Amazon and Apple, have established sufficient scale to now be the subject of regulatory scrutiny across multiple jurisdictions.

Learnings from the establishment and global scaling of digital platforms in online and social media settings, as discussed in the recent Digital Platforms Inquiry and pertaining to the ownership, use and commercialisation of data via social media and online search, are critical to the future implications of IoT services. Also important are the implications of the EU's General Data Protection Regulation provisions, particularly in cases where digital supply chains include European customers or uses.

- *Digital service as loss leader*

The dynamics of platform ecosystems are critical to understanding the implications of the IoT. By connecting more and more 'things', technology companies create ongoing feedback loops between their users, whose data can be on-sold or utilised within their own software offerings, extending the functionality of this software in ways that continue to adapt to its users.

With Internet-connected heart-rate monitors and smart thermostats, for example, personal information becomes of value to the data-oriented information economy (van der Zeeuw et al., 2019: 1347). This allows existing, major technology companies to extend their reach into new service domains – allowing major companies such as Apple, Amazon and Google to quickly dominate the smart home marketplace.

Google's purchase of Nest is also illustrative of this process. When Google purchased the smart thermostat company in 2014, Nest had already opened up its API to external developers, but the purchase allowed the Nest ecosystem to contribute to the wider Google data ecosystem. Over the past five years, Nest has become more and more integrated into the Google ecosystem as a Google product, and as of 2019 requires Google Assistant as a central enabler of its suite of smart home products (Statt and Bonn, 2019).

This approach allows Google to better manage the data inputs it receives from consumer uses of its smart home products, in effect 'training' them to better respond to the personalised needs of its users.

Google executive Rishi Chandra describes this as a future of 'ambient computing' where smart home devices are in symbiotic relationship with their users, and where computing power is not limited to a device but an assemblage of connected devices.

- *The challenges of interoperability*

Platform business models are associated with the steady commercialisation of data assets and the growth of data silos. This limits the potential for true interoperability. While the need to extend environments for data collection can be seen as a commercial driver of IoT, lack of data sharing has also acted as an obstacle to many of the efficiencies proclaimed to result from IoT.

As an IBM report has emphasised: "IoT can be complex, with a large number of suppliers and ecosystem stakeholders needed for success. And the fact that an ecosystem of providers is needed sometimes becomes a stumbling block for many companies–putting IoT into the "too hard" pile" (Sendell, 2019). The importance of data as a valuable asset in the roll-out of IoT services is well recognised: an earlier IBM report highlighted the issues around the reliance of IoT services on business models that require the use of analytics to sell user data or targeted advertising (IBM, 2015: 7). This business model ultimately limits data sharing, connectivity across diverse 'IoT platform stacks' and, in turn, the capacity for interoperability.

High levels of heterogeneity operating within an 'IoT stack' reflects the operation of multiple vendors across levels of hardware or 'things', network connectivity, and data analytics and applications. As one paper has noted: "Interconnecting heterogeneous devices and services provided by different vendors and providing seamless interoperations across the available platforms still remain a big challenge" (Santofimia et al., 2018: 3). Or, put differently:

> *Imagine driving through dense city traffic using roads without any lane dividers, crosswalks, or signals. It would be utter chaos. That is the reality of the current state of IoT. There is a lack of holistic information design.* (Anonymous, 2018)

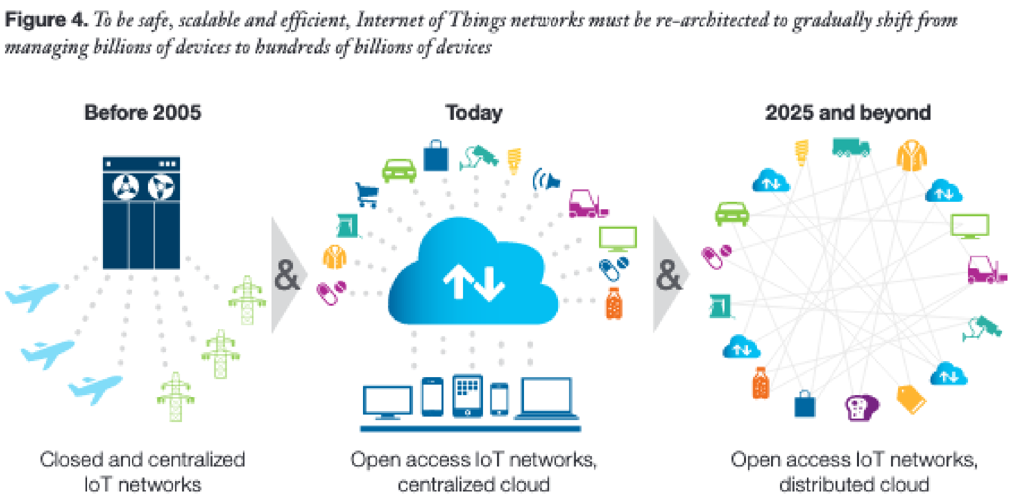
Lack of universal or open data standards and interoperability of IoT devices ultimately has limited the capacity for information sharing across devices, networks and platforms. This can lead to data silos, creating ‘walled gardens’ between different manufacturers of devices and their data outputs, which can also limit the available insights and efficiencies possible through the integration of data into analytics platforms (Nonnecke et al., 2016: 3). For this reason, IoT is considered to be at a relatively immature stage of development and integration (van der Zeeuw et al., 2019: 1358).

Addressing this need, a set of IoT platforms have developed which act as intermediary services to connect diverse IoT hardware (e.g. distributed sensors and devices) and application layers. These platforms are designed to act as the ‘plumbing’ that connects devices and applications. They are usually cloud based and facilitate the remote management and automation of distributed devices, as well as data management and integration.

A number of the leading IoT platforms today are provided by major technology and data commercialisation vendors, such as Amazon, Google, and Microsoft. These centralised cloud platforms are expensive as is the cost of server space for huge volumes of big data (IBM, 2015: 4). They can also lead to issues of latency in data processing. For this reason, IoT platforms increasingly offer not only cloud-based data integration but also ‘edge’ based computing services that facilitate data processing at the local level.

The visualisation below, sourced from a 2015 IBM paper *Device Democracy*, provides an idealistic vision of how IoT’s evolution from 2015. However, open access models for IoT continue to struggle against the IoT platform offerings by major commercial technology companies. This continues to entrench data asymmetries in marketplaces such as Australia.

Figure 4: A vision of open access IoT (IBM, 2015: 9)



- *Data hosting costs & GDPR compliance*

IoT services massively expand the volume of data being generated by everyday things, environments and objects. This increases the cost of cloud hosting services, but also introduces issues around latency when data is being hosted on the cloud.
For this reason, IoT is seeing an acceleration of 'edge' computing services, which focus on data analytics closer to the application area. This is also recommended as a

There is also a growing emphasis on designing data management platforms as data infrastructures, which perform critical functions in the management and delivery of a range of digitally-responsive services.

- *Security and interoperability*

Despite the demand for interoperability, achieving greater data sharing and integration to support the aspirations of IoT has many challenges. In short, with interoperability also comes the greater potential for security risks. Nonnecke et al (2016: 3) have argued that fully interoperable systems may be more vulnerable to failure, whether through accidental or malicious acts.

This reflects a broadly held view that a homogeneity of device structure can make connected IoT systems vulnerable to attacks that can spread rapidly throughout the system. As one technical study has found, "Most existing IoT platforms are highly centralized architectures, which suffer from various technical limitations, such as a cyber-attack and single point of failure" (Hang and Do-Hyeun, 2019).

It is increasingly recognised that blockchain technology can be used to manage secure transactions between different devices in a network, with particular applications to IoT (Park et al., 2018).

From a conceptual level, blockchain is a kind of secured, distributed database comprised by numerous peers that are able to track, verify, and execute transactions and store information from a large variety of entities.

Use of blockchain can enable data transmitted by IoT devices to essentially be ‘cryptographically proofed’ by the signature of the sender who holds a unique key pair. This approach, sometimes summarised as ‘smart contracts’ allows for the authentication and integrity of transmitted data.

There are, however, challenges to the use of this approach currently. Hang and Do-Hyeun (2019) have argued:

> *Although the blockchain may look like a panacea to solve IoT security of privacy issues that exist in the current centralized architectures, there are still many research challenges that prevent its incorporation into modern IoT networks. In fact, most consensus algorithms used by current blockchain-based systems are not designed to be run on devices with extreme limitations in computing resources [such as IoT devices].*

2. IoT and Services

2.1 Dynamics of IoT transformation

IoT has been predicted as a disruptor in key service delivery areas for some years now. It is worth noting that many of the predicted benefits and impacts are based on projected benefits, rather than evidence or long-term evaluations.

This section discusses some of the potential and identified service domains that IoT can be expected to transform.

Common dynamics of transformation are summarised below.

- ***Enhanced modelling and remote monitoring of infrastructures, environments, homes, supply-chains and properties*** through distributed sensors capable of transmitting and receiving data in a more fine-grained way. Lower cost sensors can be embedded into urban and regional environments to capture more detailed information about a location or infrastructure (pipe quality, air quality, people movements, temperature, water quality) than previously available.
- ***Enhanced automation:*** IoT facilitates greater automation of services and infrastructures, improving efficiencies and responsiveness to people movements, density, emergency situations or other events in a localised way.
- ***Increased vulnerability:*** Introducing connected devices within everyday environments and critical infrastructures increases the capacity for remote interference and hacking, highlighting critical security concerns commonly associated with IoT.
- ***Interoperability:*** As discussed, this remains a common challenge for IoT applications, with many of the key benefits of IoT requiring improved interoperability and data sharing protocols across devices, contexts and networks.

2.2 Key service domains and impacts

This section summaries key industry domains being impacted by IoT services.

Sustainability and the circular economy

- IoT technologies can yield increased capture of renewable energy (solar and wind) by provide real-time responses to the natural fluctuations in generation associated with renewables.
- IoT supports the delivery of a renewable energy through 'smart grid' technology, which uses IoT devices to ensure an energy grid can more responsively react to local changes in energy use and supply. This is sometimes described as the 'Internet of Energy' (IoE). IoE sensors optimise the efficiency of energy infrastructure and reduce wastage, and have various applications, such as power monitoring and demand-side energy management. For example, a consumer device such as a washing machine could, when connected to the internet, only operate when there is sufficient energy from solar power. IoE also helps power companies generate energy based on demand, thus reducing wastage.
- Smart water meters and sensors can be used to deliver more granular and real-time information on water leaks and high-water usages.
- IoT supports the development of the circular economy, reducing the amount of waste that goes to landfill, improving levels of recycling and the re-use and/or sharing of goods and services.

Urban planning and infrastructure management (smart cities)

- IoT systems are integral to the delivery of smart city services, which integrate real-time information services in the delivery of transport, urban planning, infrastructure and utilities management and citizen engagement by governments at local, state and federal levels. In Australia IoT has seen accelerated uptake in the past four years by local governments implementing smart city initiatives, particularly encouraged through the $50m Smart Cities and Suburbs initiative of the Australian Government, which co-invests in smart city trials in domains such as smart parking, smart waste, smart metering and digital engagement initiatives.

- Other applications of IoT include the use of digital dashboards by local governments to capture the functionality of urban services, whether traffic incidents, planning and property approvals, and the health and maintenance of street trees.

- Smart city initiatives rely on IoT to facilitate the more localised monitoring of urban activities and flows including energy, water, traffic and other dynamic conditions. IoT provides near-real-time asset monitoring and analytics capabilities which lead to better customer outcomes, higher operational efficiency and improved asset performance. For example, IoT can be used to detect vulnerabilities or faults in assets to prevent major interruptions to services. More information on smart cities and IoT is detailed below.

- IoT services are also used to develop ‘digital twin’ initiatives of properties, precincts and even whole states (or nation states), which can be used to support future infrastructure planning, or improve urban resilience by supporting emergence responses to extreme weather and/or terrorist attacks. More information about digital twins is included in section 3 below.

Rural and regional services

- IoT can be applied in the field to irrigate only when needed and in the precise quantity. This improves the efficiency of agricultural services, including precision agriculture, reducing waste and costs of water use, and also improving soil monitoring through more targeted monitoring of soil nutrients.

- IoT is recognised as having potentially major impacts on water management, including remote automated monitoring of water quality, and active drought monitoring systems. This reduces costs associated with physical inspections and improves knowledge about water quality and availability. IoT devices facilitate telemetry, or read-only data about an environment to support automated monitoring.

Health and social services

- IoT devices are widely used in smart health services. These services make use of context aware intelligent agents, which can include anything from computing devices, mobile phones, Fitbit smart bands, surgical devices, devices to measure your blood chemistry, or devices to measure brainwaves.

- These services support remote monitoring by health care professionals, improved self-management of chronic ongoing conditions, detection and diagnosis, and the delivery of patient treatments. Some care previously provided in hospitals may be transferred to the home. Wearables and other interactive devices can allow for remote monitoring of vital signs or even the administration of medicine. IoT can also be used in hospital settings to improve inventory management, and can aid in the management of chronic diseases through remote monitoring and analytics.

Public services and Cross-jurisdictional collaboration

IoT has the capacity to support greater cross-jurisdictional collaboration and improved data analytics, particularly when combined with more ambitious ‘Government as a Platform’ (GaaP) digital transformation initiatives. More on IoT and public services is detailed in Section 3.

Construction industry

It is widely recognised that the construction industry suffers from poor levels of productivity. IoT sensors can be integrated with other digital platforms including Building Information Management to facilitate more efficient construction management processes, while also improving on-site health and safety. Sensors monitor harmful onsite factors including noise, radiation and particulates, providing alerts when there is an emergency and automating OH&S reporting.

Creative and educational services

IoT facilitates new ways of interacting with collections and environments, supporting a variety of new approaches to curation, museum interpretation and public engagement.

- *Museums and galleries*

Distributed devices, including RFID-enabled objects and integration of near field communications (NFC) and Bluetooth beacons, have been with us for some time. As discussed in Section 1, locative media practices have explored creative ways to augment the experience of a location, often by layering historical, narrative, or visual information in affective or playful ways.

This multi-layered, affective approach to gallery curation and design is being further extended through the maturation of augmented reality (AR), virtual reality (VR) and other media innovations. The combination of IoT within these digital layers facilitates further potentials for creative engagement between visitors, interpretation designers and curators. Australian museums and galleries have been known to be leaders in this field.

The integration of IoT into museum experiences has encouraged the use of playful devices that facilitate more personalised tours and interactions with curated collections. The Cooper Hewitt Museum introduced a smart Pen that enabled visitors to collect objects they were interested in across museum displays, and then manipulate and discover more items related to these collected objects via screen interfaces throughout the museum.

The Cooper Hewitt Pen combines two main technologies. Its interface with the interactive tables employs the sort of conductive materials common to touchscreen styli. Its interface with the object labels employs near-field communication technology. A sensor in the end of the Pen reads the information on small NFC tags embedded in the object labels. This information is stored in the Pen’s onboard memory and can be read at the interactive tables.

NFC is widely used across the museum sector; what the Pen introduced was a new level of experience design between NFC, objects on display and user’s own creative level of engagement with collection objects.

IoT can also be expected to facilitate more diverse modes of audience engagement with collections. Presently, audiences are largely only able to view collection items on display within curated exhibits, which may represent only a small proportion of an overall collection held by a museum or gallery. IoT may facilitate greater use of ‘open storage’ by museum collections, which allows audiences and researchers to explore collections not currently on display. By enabling collections to be tracked and monitored remotely, IoT can reduce the need for physical security of objects and greater accessibility by the public, while also maintaining appropriate environmental controls.

It is worth noting that while relatively limited work has been undertaken on IoT and the arts sector to date, there is a history of engagement by artists on the potentials of responsive technology in creative practice.

From an audience perspective, IoT is also being used by the GLAM sector to better understand visitors and how visitors are engaging with exhibitions. Visitor interactions and movements can be tracked and monitored with a view to better understand how to plan, curate and design exhibitions, and understand how audiences are responding to different kinds of materials and media.

Art galleries are also using IoT to manage the environmental conditions in which their collections are stored, helping to monitor and analyse lighting, humidity and temperature control.

- *Creative, participatory and 'do it yourself' (DIY) media*

The use of IoT is widespread across many creative media fields. Many interactive art installations are generally computer-based and frequently rely on sensors, which gauge things such as temperature, motion and proximity that the artist has programmed in order to elicit responses based on the actions of the participants.

Relatively inexpensive technologies such as Raspberry Pi facilitate creative programming in ways that allow for touch and motion-based feedback, giving rise to new fields of creative media practice and audience interaction.

Audio practitioners, for example, use Raspberry Pi to program immersive sonic experiences for listeners that respond in real-time to motion and to touch, and can even be used to make new instruments. Programs such as Arduino are open source and can enable prototyping and development of interactive experiences that allow creative media to respond to user inputs, whether using lighting technology, sound, vision or other mediums.

These relatively inexpensive approaches to IoT facilitate an outpouring of creativity in relation to interaction design and creative storytelling. Audiences and technologies are intertwined in ways that facilitate different experiences of an artwork or performance by each member of the audience/participant (Abbasi et al., 2017: 52).

The availability of these relatively low-cost programs for IoT programming is also evidence of an outpouring of more participatory and DIY approaches to IoT. These facilitate more citizen and artist-centric approaches to measuring and monitoring conditions in an environment, with a view to advocating for changes in urban planning and management (Pritchard et al., 2018; Gabrys, 2014).

Citizen sensing is now a growing field of participatory media design, also relevant to smart cities, that seeks to empower citizens with the capacity to collect and monitor their own environments in ways that contribute to wider smart city goals (quality of life, air quality, heat, safety and so forth).

These initiatives are often positioned in resistance to more 'top down' technology initiatives associated with smart cities and large-scale IoT deployments (Coulson et al., 2018). Participatory sensing initiatives aim to improve scientific and policy literacy (particularly in relation to questions about how scientific information is used in decision making), but also align to initiatives to improve data and digital literacies in a world of connected devices (ibid).

- *Education and smart campuses*

IoT is being widely deployed across educational settings and university campuses. In a sense, the applications of IoT in these environments are similar to those across smart cities – integrating more responsive, environmentally efficient lighting, improved campus security, and more granular understanding of campus foot traffic dynamics, classroom uses and parking issues.

However, unlike many cities which incorporate multiple levels of governance and a range of private utilities and property developers, campuses are governed in much more uniform and centralised. This can accelerate the adoption of IoT by universities as a tool for campus management, as evidenced by the widespread adoption of 'smart campus' initiatives across the sector.

The Curtin University 'smart campus vision' for example, seeks to implement an IoT infrastructure to gather data on student movement and attendance to "provide analytics that support a smart campus" (McRae et al., 2018: 15). These approaches connect with the wider educational perspectives that champion the role of technology in enhancing student experience and learning. Analysis of this initiative by Curtin University researchers found there to be potential benefits of IoT for students with disabilities, allowing more personalised information and services. It did, however, see the benefits of these technologies being outweighed by privacy, security and interoperability concerns (McRae et al., 2018: 28).

A University of Melbourne smart campus initiative has captured attention with its implementation of over 700 applications and IoT devices that are used to measure "everything from "temperature, energy use, room capacity and to aid in wayfinding" (Johnston, 2019). These initiatives are described in terms of 'optimising student experiences' and also making the best use of campus real estate – essentially improving the performance of the university in property management terms, and improving resource use.

As a tool for data literacy and education, IoT also has the potential to support improved awareness of processes of data collection, and also the integration of evidence and data as part of scientific policy making (Coulson et al., 2018).

- *Libraries*

As with university campuses, libraries can adopt IoT to better manage the library experience for those using library facilities. This might include tracking room usage, temperature control, humidity levels and other environmental factors.

While libraries have been using RFID for some years, there are additional benefits to be had by integrating IoT into lending services One example of this is the 'Book-O-Mat' self-service lending service in Portland, Oregon, that provides a book lending facility in a high traffic area, with stock levels remotely monitored by library staff.

Libraries are also emerging as important locations for training around digital literacy and what IoT means for communities through hands-on training and workshops for diverse groups.

Speculative ideas about IoT and libraries also include the potential for more personalised book recommendations and alerts, including information about community events based on real-time patron data. However, this would also depend on libraries collating more and more data about their users over time. While personalised recommendations have become the norm for streaming services, which collect data on user preference and viewing history, this approach has not as yet extended to book recommendations by libraries.

As with art galleries, IoT can also be used to monitor the condition of historical manuscripts and the environments in which they are being stored, monitoring for humidity, temperature and other factors.

- *Philanthropy*

The impact of IoT on philanthropic services is as yet an under-developed area of study. It is understood that new IoT trials in the not for profit sector are attracting philanthropic investment and crowd funding. Contactless payment systems embedded with IoT are also being used by charities.

Environmental campaigners are also using IoT to monitor key issues such as plastics pollution, waste management and rainforest clearing. These initiatives use IoT sensors to monitor and track environmental conditions, helping to raise awareness, increase funding and generate impact.

3. IoT and Public Services

The breadth of applications of IoT in government service delivery is significant, spanning areas such as transport and logistics, utilities and resource management, health management and services, urban planning, traffic management, smart manufacturing, and precision farming, to name just a few examples.

As discussed, common across diverse applications of IoT is the capacity to embed digital intelligence into physical environments, things or even people, which allows for remote monitoring, improved data analytics, and more 'real-time' and responsive services that respond to local variations or weakness – whether health related, resource related or service-related. This might include faster response times to development and planning applications, reducing resource use, more accurate real-time monitoring of patient health, and ensuring regulatory compliance through smart contracts.

Nevertheless, across many different service domains, data governance and security considerations remain major obstacles to realising benefits. Arguably, the proliferation of IoT sensors, actuators and devices increases the need for greater policy attention towards issues of data governance and data sharing standards.

This is where governments have a clear role to play in facilitating the development of effective data infrastructure that is 'fit for purpose' for an intensively connected world of things, objects and environments. It is also important to contextualise the benefits of IoT for public service delivery within wider public sector digital transformation trends.

3.1 Government as a Platform and IoT

'Government as a Platform' (GaaP) represents a model for digital transformation of public services, which has been designed to extend platform business and service delivery models into the public service.

Many examples of GaaP in action today involve the development of common functionalities and standards that allow citizens to engage with government agencies in a more consistent way. GaaP approaches also aim to limit diverse agencies from 're-inventing the wheel' when developing new websites and service channels.

As the Australian Government Digital Transformation Agency states: "By adopting platforms, duplication across government is reduced, making services more efficient and quicker to build. When this happens, the people building services can be freed-up to focus on how user needs can be best met, instead of reinventing the wheel" (DTA, 2016).

This approach to GaaP represents a more limited interpretation of the original potentials of platform-based delivery models for government services. When the term was first introduced, GaaP was part of a wider movement towards 'opening' government services to allow for greater responsiveness and co-creation between governments, software entrepreneurs and citizens.

As noted by digital advocate and adviser Don Tapscott in his foreword to Open Government in 2010: "It is the next wave of innovation [based on data services] that presents an historic occasion to fundamentally redesign how government operates; how and what the public sector provide provides; and ultimately, how governments interact and engage with their citizens" (Lathrop and Ruma, 2010: xvi).

In 2010 Tim O' Reilly (O'Reilly, 2010: 11) labelled this next wave of innovation 'Government as a Platform', whereby government establishes a 'platform' for software innovators to access and recombine public data to drive new and innovative services for citizens, and to "better solve collective problems at a city, state, national, and international level". This model for data-driven government services aimed to build on approaches by Facebook, Apple and other technology providers, which, as discussed, essentially 'opened up' the capacity for external developers to extend the functionality of an underlying platform, building their own services on the back of a consistent, underlying data infrastructure.

In its original conception, GaaP was not only about building common websites and interfaces for citizens to engage with different agencies, but about putting in place internal systems, protocols and data management systems that allowed for more responsive services to be created by a wider 'ecosystem' of service providers. In this model, government is positioned as "a designer, manager and steward of systems, rather than a direct deliverer of services" (DPC, 2018; Hallsworth, 2011).

A true 'government as platform' model for digital service delivery implements data sharing protocols across agencies, and across jurisdictions, that facilitate more dynamic uses of data by a wider variety of service agencies (public and private) and respond more dynamically to user context.

As a recent 2017 Productivity Commission Inquiry on Data Availability and Use recommended: "Fundamental and systematic changes are needed to the way Australian governments, business and individuals handle data." These changes are needed before the applications of IoT in public services can have real impact. In particular, public agencies need to be empowered to incorporate a wider variety of data inputs and feedback loops (generated by more prolific connected devices) to inform decision making.

As stated by a recent *Data Reform Strategy* prepared by the Victorian Government:

> *Data can provide optimal system-level visibility, helping us move away from narrow, KPI-based indicators towards dynamic, real-time monitoring. This requires that we have maximum access to data generated through our service delivery supply chain, and the data capabilities to be able to dynamically interact with it (DPC, 2018: 10)*

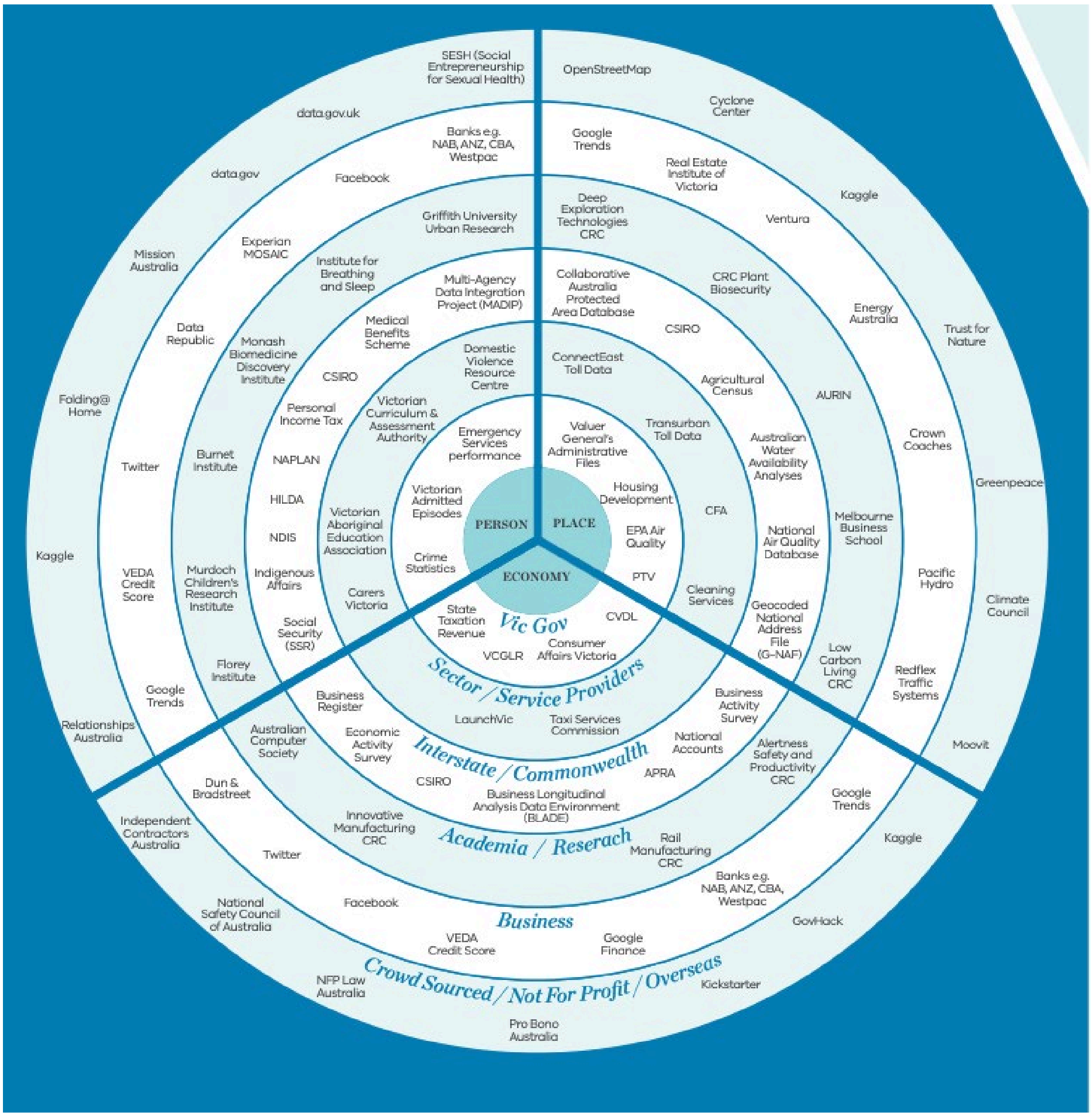
The same report notes that citizens increasingly expect government to deliver services that match the responsiveness and ease of use of private sector services, such as ride-sharing transport services, tasking platforms, and online shopping and banking. These expectations will only grow as technology advances.

A model for how governments could better integrate and link more diverse data sources from IoT into decision making is outlined by the Victorian Government in its Data Reform Strategy (DPC, 2018: 28-29). Positioning the work of Victorian agencies as part of a wider data ecosystem, which includes both public and private organisations, the Strategy identifies the need for linked data and data partnerships that include a 'Data hub' that is able to draw from different layers of the data ecosystem, as well as facilitating greater sharing of de-identified data. Also integral to this approach is a re-evaluation of different points of service delivery, which are divided into 'Person', 'Place' and 'Economy'.

This strategic vision incorporates key advances generated by two Commonwealth Government projects: the Multi-Agency Data Integration Project (MADIP) and the Business Longitudinal Analysis Data Environment (BLADE).

A visualisation of the kinds of indicative data being considered as part of the Victorian Governments Data Reform Strategy is detailed below.

Figure 5: Victorian Government data ecosystem, visualised through the themes of People, Place and Economy (DPC, 2018: 29).



The above visualisation provides a useful schematic for understanding how IoT has the potential to reshape government services. While IoT facilitates the extension of data analytics into more diverse dimensions of service delivery, a revaluation of underlying infrastructures and protocols for sharing and using data across government agencies and jurisdictions is needed before major impacts can be realised.

3.2 Smart cities and local government services

As discussed, smart cities are a key domain in which the IoT can impact on the way governments deliver urban and regional services.

As is widely recognised, the use of IoT can improve the capacity for city governments to monitor a wide range of infrastructures and services, from traffic infrastructure to water utilities; from urban heat to crime. Smart city initiatives also target reductions in resource use (water, energy) and adaption to climate change (through urban heat monitoring, tree canopy mapping, and flood management, as examples). IoT and smart cities has particular applications in the field of smart energy, smart water, and smart utilities management. While the majority of investment in IoT and smart city services is expected to be in urban environments, smart city applications are also evident in regional areas as well.

Investments in smart city services to date have experienced challenges relating to the lack of interoperability and cross-sectoral integration of smart city data. It is increasingly recognised that the implementation of IoT sensors across a city will lack transformative impact without a concurrent rethink of data governance. This is sometimes described as ‘vendor lock in’ and also involves the reliance on ‘point solutions’ such as smart parking, or smart lighting, that fail to scale learnings or impacts at a city-wide scale (IOTA, 2017; Robinson, 2016; cohen, 2015; Barns et al., 2017).

While these initiatives can generate some relatively straightforward benefits, such as a reduction in the energy consumed by streetscape lighting in a smart parking trial, the activity data that is being collected to support the operation of a smart light is not being used in any other way. NNNCo, a technology vendor working across smart cities projects in Australia has described the issue in the following way:

> *During the past 24 months we have regularly encountered customers who have a device, the means for transmission and a platform but the protocols and their platform will not talk to each other.*

A more integrated or interoperable approach to data and device management would see activity data generated by smart lighting services published in a harmonised or standardised format, for use in other software services. At present, middleware companies in Australia like NNNCo, as well as Meshed Network, are positioning themselves as suppliers to local governments to support in data harmonisation and normalisation.

However, arguably the process of data integration needs to also include more connected decision-making processes, which draw from broader sources of data and intelligence. As put by engineering and planning firm Arup in relation to the smart city: “[It is] so different in essence to the twentieth century city that the governance models and organisational frameworks themselves must evolve”. Importantly, the authors argue that the ideals of the smart city, in seeking to leverage the benefits of digital services and data to improve the way a city works, can't simply be realised by investing in distributed sensors and technology solutions alone.

Such shifts necessitate a ‘reinvention of governance’, which involves “transforming the way they work internally and together with outside partners and citizens” (Arup, 2014: 32).
As recognised by the Committee for Sydney in its 2017 #wethecity3 Report on smart cities in Australia: “This coming era of responsive government will depend as much on new forms of collaboration as much as they'll rely on advances in data analytics. Collaborations across public, private and community sectors will be vital in enabling data-driven services, addressing data gaps, building data partnerships and building solutions, rather than replicating existing siloed agency structures.” It is worth noting that cross jurisdictional collaboration is particularly important for Australian cities where three levels of government overlap (Barns et al., 2017).

Smart cities are also a domain that is seeking the extension of data-driven business models by major technology companies. This has led to the association of smart city initiatives with ‘top down’ technology vendor strategies, such as those associated with the extension of

IBM, Cisco and Siemens operating systems into urban management domains (Sadowski and Bendor, 2019; McNeill, 2015; Wiig, 2015).

More recently, Google sister company Sidewalk Labs has also sought to enter the urban innovation space by seeking to build a city 'from the internet up' using IoT and other smart city technologies. This has attracted widespread criticism from local residents concerned about the capacity for Google to further extend its reach in order to advance its data commercialisation and AI, or deep learning, strategies (Lorinc, 2018).

This shift towards 'platform urbanism' – whereby technology companies utilise advances in IoT and data analytics to extend the reach of their existing platform ecosystems into urban domains – has led to a growing politicisation of urban governance, data privacy and data surveillance concerns alongside smart city investments (van der Graaf and Ballon, 2018; Barns, 2019).

Key practical initiatives being implemented to address present shortcomings in wider the implementation of smart city initiatives include the implementation of City APIs, city data marketplaces and data collaboratives or 'trusts' that seek to create common protocols and frameworks for data sharing across vendors, public private agencies and citizens.

Examples include the Copenhagen Data Marketplace, the European DECODE Project underway in Amsterdam and Barcelona and the X-Road initiative implemented in Finland and Estonia (Raetzsch et al., 2019).

3.3 Smart city experimentation for citizen engagement

The integration of IoT is also associated with a more 'experimental' and bottom up approach to urban management and design, which sees urban interventions and innovation initiatives developed under the rubric of urban living labs and other temporary initiatives. Drawing from earlier approaches in urban sensing initiatives, such as those advanced by university laboratories such as the MIT SENSEable Cities Lab, these initiatives introduce 'test beds' and experimental infrastructures and interventions that point to how an urban environment might be reformed by more powerful urban actors.

For example, one of the first SENSEable City Lab project, Real-time Copenhagen, used mobile devices to track people's movements through the city, displaying the pulse of Copenhagen's Kulturnatten (culture night) as it unfolded in real-time. These early projects encouraged users to think of themselves as actively 'participating' in the production of new 'urban interfaces': interfaces not of physical surfaces, but of informational use. These ideas were part of a wider movement that saw the potential for more ubiquitous technologies and sensors to facilitate a new kind of 'architecture of participation' (Williams, 2008: 4) in which traditional urban, social structures and governance methods could be radically reconstituted.

In more recent years, these experimental approaches have also been accompanied by citizen sensing initiatives (Gabrys, 2014) and 'urban living labs' which have incorporated experimental uses of IoT to explore the potential for improved data collection in areas such as water use, air quality monitoring temperature mapping, and citizen engagement (Bulkeley, 2016).
These experimental approaches in citizen science are also associated with the urban transitions movement which seeks to accelerate the adoption of low-carbon and other urban sustainability initiatives.

In Australian cities such as Perth, IoT investments are being paired with new trials by the City of Perth in citizen sensing initiatives, which involve high school students partnering with universities and urban planners to examine how data sourced from IoT sensors can be used to facilitate new collaborations. Launched in August 2018, schools are being offered the ability to monitor environmental indicators such as temperature, humidity, air and water quality readings in their local area, and can collaborate with other participants on this data to understand local environmental conditions. This project was funded by the Australian Government's Smart Cities and Suburbs Program.

3.4 Australian urban and regional impacts

IoT impacts across local government can be expected across urban, regional and rural areas. While the majority of smart city investments underpinned by IoT are being driven by local governments in metropolitan areas, 'mid-sized cities' such as Newcastle, Gold Coast and Wollongong have also seen significant investments to date, as has the City of Darwin.

Many IoT investments by local government have been matched by Australian Government Smart Cities funding, with specific domains of investment reflecting local demand drivers.

Some examples are detailed below.

IoT investment examples: Australian cities

- City of Darwin: Smart city investments include microclimate sensors and IoT devices to enable a range of data to be collected about the city such as rain, humidity, air quality and CO2 among others.
- City of Newcastle: This mid-sized city has focused smart city investment in the area of smart transport and start-up hubs. The 'smart moves' program was awarded $5m in funding by the Australian Government and includes a city-scale transport, energy and digital infrastructure network. IoT data sourced from intelligent infrastructure will be integrated into a
- City of Perth: IoT investments have been in the area of smart irrigation, utilise new irrigation sensors to use predicted weather forecasts and soil moisture readings to automatically adjust watering. Perth is also using water and air quality sensors across Perth.
- City of Gold Coast: IoT investments focused on digital water metering, waste management, and support for parks and fields
- Within major metropolitan areas such as the Greater Metropolitan Region of Sydney, smart city projects have also facilitated IoT experimentation in a range of diverse domains of urban management. This includes smart waste management (Canterbury-Bankstown, NSW) and smart furniture capable of monitoring micro-climates (Georges River). The City of Melbourne's smart city investments use IoT to improve customer input into asset management and public space amenity.

As these examples demonstrate, local governments see the opportunity to use IoT to improve environmental and asset management, reduce resource use and improve customer responsiveness. Details about these initiatives can be accessed via the Smart Cities and Suburbs Collaboration Platform.

IoT investment examples: rural and regional services

IoT has an important role to play in supporting more efficient environmental management practices. Rural and regional areas can be expected to benefit from IoT through precision agriculture, smart water sensing and telemetry. IoT integration into farming (as part of precision farming) allow farmers to better observe and record data in order to improve production output while also minimising cost and preserving resources.

The IoT company NNNCo is rolling out a 3 million-hectare IoT network for cotton farmers in 2019. The network will provide data on soil moisture through the use of sensors including soil probes, rain gauges, local weather data, water and fuel tank monitors, and satellite imagery, in turn enabling better scheduling of irrigation.

Another project running in 2019 is an IoT trial sponsored by the City of Bundaberg, via the Smart Cities Program, that is using IoT to measure the level of urban glow generated along the Bundaberg coast and its impact on turtle populations.
IoT-enabled remote health care can be expected to have particular benefits for remote communities.

National cities performance management indicators

The Australian Government has also introduced a National Cities Performance Framework (NCPF) to better monitor the relative performance of Australia's urban areas. Data is collected across a range of standardised indicators and published in a common dashboard online. The dashboard uses two kinds of indicators: those that measure progress of cities across key indicators, and those that provide contextual information about a city and why it performs the way it does.

The initial launch of the NCPF in 2017 was based primarily on data assets accessed via the ABS Census. This data is collected every 5 years and is therefore relatively limited in demonstrating changes to cities that occur between census dates. The incorporation of data from IoT provides an opportunity for the Australian Government to co-ordinate the delivery of improved data assets to inform decision making across three levels of government.

This could include more granular, location specific data assets relevant to changing heat, water access, transport and mobility, crime and other dynamic features of urban living. Data accessed via IoT could also be used to improve the monitoring of cities' performance against Sustainable Development Goals (SDGs) and other sustainability indicators.

Digital twin technology

Broadly speaking, a digital twin represents the digital replication of physical assets, processes and systems. While virtual models have been with us for some time, the use of IoT sensors within physical environments is now allowing these models to offer a far more detailed and real-time digital representation of a set of physical dynamics, components and systems in action at any given time.

While existing forms of digital modelling, such as Building Information Modelling (BIM) software, focus on the design and construction of a building, a digital twin aims to capture a much broader array of interactions between people, infrastructure and environmental services, and to do so in 'real-time'. It is the presence of IoT sensors, feeding and transmitting data into complex information models, that allows digital twins to perform as relatively accurate replicas of their physical counterpart.

Digital twins represent a step-change in infrastructure and asset management. A more accurate and real time digital replica of an asset or property enables much faster modelling of an asset lifecycle, improving diagnostics and maintenance, and building new tools through which to optimise workplace experiences. The best-known example to date is the Singapore Government's 'Virtual Singapore' initiative.

The quality of applications of these 'digital twins' is dependent on the quality of data integration, visualisation and apps, which allow for diverse data streams to be visualised v accompanied by a number of new digital twin platforms that offer data integration and visualisation services.

Digital twin is seeing strong uptake in the property and asset management space, and has been used extensively in mining and manufacturing services. This technology depends on the capacity for a single ‘owner’ of a space to manage multiple real-time data feeds simultaneously through a central interface.

Government agencies across Australia are now also building digital twins to support improved service delivery. For example, in NSW, the Department of Finance, Services and Innovation (DFSI) has an ambitious program of work underway to create a digital twin for the entire state.

Data

A Victorian Digital Twin project developed by Land Use Victoria and the University of Melbourne Centre for Spatial Data Infrastructures and Land Administration (CSDILA) will allow 4D modelling of the design and condition of physical infrastructure in real world locations both above and below ground, including legal boundaries, to enable better decision making about how to manage current and future infrastructure and planning. A major digital twin initiative is underway at Fisherman’s Bend.

Open access initiatives

Open access initiatives

Organisations such as The Things Network, Meshed and the LoRa Alliance are advancing open standards for IoT wireless networks. In Australia, Meshed uses LoRaWAN as an open standard technology to facilitate IoT applications across diverse sectors including smart cities, smart agriculture, smart university campuses and smart water domains.

4. Summary of challenges and opportunities

Key Challenges

- **Data governance and interoperability**

The need for improved data governance and platform interoperability is a common issue across sectors and service domains grappling with IoT. As one commentator argues in relation to IoT and the connected health sector:

> *..Some people say this is the number one problem of expanding the connected health system, is that we have so many different platforms and so many different types of data that it's very difficult to integrate them.*
>
> *In the U.S. just with the electronic health records, we have at least five major vendors of electronic health record systems that are being used — and they don't share data. […]*
>
> *These different data platforms are a problem for trying to do some of that big data analytics kind of thinking with our healthcare data. (Russo, 2016)*

In the smart cities' domain, vendors, analysts and governments all claim the need for improved platform and data interoperability. As the project lead for the NSW Government 'digital twin' initiative has stated:

> *The only thing that makes this success is everybody working together from a government perspective in terms of information management frameworks and being able to collaborate with industry partners in terms of making the data available in a delivery platform that's easy, accessible, and that allows other people to expand upon that to meet their own individual requirements.*

Lack of interoperability is particularly evident in areas where there are multiple government agencies and overlapping jurisdictions. For example, while IoT devices and telemetry is improving in relation to water monitoring, there numerous government agencies that each have a role to play in managing water outcomes and many of these agencies employ separate data management systems.[2]

- **Privacy and security**

Cyber security

The integration of IoT into critical areas of infrastructure and services introduces new vulnerabilities in the form of cyber-hacks, phishing, and data breaches. Growing investment in smart city services has already led to increased security and privacy breaches.

Security vulnerabilities reflect a set of specific dynamics unique to IoT sensors, which are often sold separately to security services. In a 2018 study, an IBM security identified the most common vulnerabilities across 17 major security flaws discovered by an 'ethical hacking project' into major IoT-backed smart city initiatives (IBM 2018), as outlined below.

- *Public default passwords*

[2] This was identified as a major obstacle to the impact of IoT on water sensing at the NSW Smart Sensing Network (NSSN) Water Workshop held 2 October 2019.

IoT devices can be placed into operation without requiring users to create a secure password, providing easy access to devices by hackers.

- *Authentication bypass*

These flaws allow attackers to skip a login page and call up an internal administrative menu page that shouldn't be accessible to them, allowing an outsider the same control as a legitimate administrator would have.

- *SQL Injection*

This involves sending data that looks like part of the communication between the application and the database, confusing the database into performing actions it shouldn't, such as disclosing usernames and passwords.

IoT security breaches have been identified in relation to smart city initiatives, with impacts on public safety and amenity. In particular, the interconnected nature of devices poses risks to infrastructure of smart cities. For example, a cyber-attack on the industrial control networks of critical infrastructure providers could result in major disruption, such as citywide blackouts and traffic control outages.

Privacy

A review of Internet of Things products in 2016 by the Office of the Australian Information Commissioner (OAIC) found that 71 per cent of devices and services used by Australians did not provide a privacy policy or any notices to adequately explain how personal information is collected, used and disclosed (OAIC 2016).
With IoT devices now integrated into smart toys, furniture, fitness trackers and other digital services, the OAIC found customers are not always aware of how these devices collect, store and share user information.

The *Australian Privacy Act* (1988) also offers relatively low levels of privacy protection in the context of IoT services. In 2018 mandatory data breach notification legislation was introduced which requires eligible entities to report eligible data breaches to Federal Privacy Commissioner. However, this scheme is limited to breaches of 'personal information' only, and does not necessarily take into account data collected by IoT devices (Daly 2018). It also does not take into account breaches that affect commercially sensitive information.

As they navigate more and more connected environments and services, the issue of data rights and data privacy is becoming more significant to citizens. The data management policies of platforms like Facebook, which were widely criticised in the wake of the Cambridge Analytica data scandal, have raised critical consumer and regulatory attention towards data use and data privacy policies. Smart home companies such as Nest, owned by Google, have highlighted the data-vulnerabilities within many IoT devices by introducing a stricter set of permissions and partners approved to interconnect with its devices.

Key implications

Data ecosystems, business models and governance

- IoT cannot be considered in isolation from wider challenges associated with the global data economy. An overly 'device centric' approach limits the many overlaps between IoT and broader social, economic and cultural disruptions associated with the advance of AI, automation and platform business models.
- IoT evidences the extension of data analytics, data commercialisation, and data governance frameworks into more diverse environmental and industry contexts and supply chains. Recent studies suggest there are to be significant productivity and efficiency benefits as a result. Arguably, these also need to be balanced against the potential for new asymmetries in data access and re-use by major platform companies as compared to smaller Australian companies and consumers.
- Existing commercial platforms are seeking to extend their existing platform ecosystems into IoT environments, through smart home devices and smart city initiatives, as examples. Other service providers are also seeking to use IoT to generate and commercialise data assets. Existing business models around data use are leading to stubborn obstacles in interoperability.
- While interoperability and data sharing are both ideals underpinning IoT, these also come with security and privacy challenges.
- There is an important role for governments at all levels to play in supporting 'fit for purpose' data governance models that respond to the significance of data analytics in shaping wider models of service design.
- This requires more ambitious adoption of GaaP frameworks that address citizen- and user-centric approaches to service design, which may require moving away from existing, legacy agency structures. The Victorian Government's Data Reform Strategy provides an example of work that could be extended to other jurisdictions.
- 'Fit for purpose' data governance models should also include consideration of the implications of data commercialisation and use (and data surveillance) being extended into domestic home settings and broader urban management settings. Alternate approaches, including the potential for 'data commons' and 'data collaboratives' should be considered.
- In this respect, it is also important that Digital Platforms Inquiry recommendations be considered in relation to the future impact of platform business models on the dynamics of IoT. Resourcing of the Office of the Australian Information Commissioner (OAIC) needs to improve in line with growing issues around consumer data privacy.

Cities and regions

- Australia faces particular complexities around data governance and smart cities, due to the different levels of government overlapping in many metropolitan areas. Many major cities lack a single government champion capable of implementing city wide data initiatives at the metropolitan scale.
- Initiatives such as the National Cities Performance Framework provide opportunities for experimentation in the use of IoT data to support more dynamic monitoring of urban settings, beyond 5-year data inputs from Census data.
- The Australian Government's Smart Cities and Suburbs Program has accelerated investment in IoT technology by local governments across urban, regional and rural areas. Many of the programs funded are rolled out over a one-year period, with relatively limited opportunity for scaling or integration into business processes. The coming years will need to see consistent focus on the impact and integration of learning from these short-term trials and pilots on ongoing local government services.

Citizen engagement and data literacy

- Greater investment in growing citizen awareness around digital value and digital economy value chains is needed. While consumers benefit from many data-driven services, they are often lacking awareness about how their data is being used and what value is being derived from it.
- In recent years, this has led to growing mistrust of digital platforms and their data policies. We may see these issues migrate to the IoT domain, in the form of growing politicisation of data-driven services in everyday domains such as transport and smart cities.
- It is recognised that participatory citizen sensing can support greater data literacy and provides an important context for more experimental and participatory urban engagement initiatives.

Smart campuses

- Smart campus initiatives are an area of significant investment across the higher education sector. Many smart campus initiatives are currently focused on improving efficiencies in real-estate management and resource use, positioning their campuses as 'living labs' to support sustainability initiatives.

Creative futures

- There are many creative applications of IoT, leading to new artistic modes of expression, curatorial design methods and audience experiences. Historically, the arts and creative industries have been highly engaged with sensing and responsive technology to creatively explore and expand relationships between audiences and context or place.
- It is anticipated that galleries and museums, particularly larger museums, adopt IoT technology to improve their knowledge of audience experiences. GLAM organisations are also using IoT to manage their storage collection facilities. Over time, IoT may be used to support more 'open storage' which allows researchers and interested audiences to access greater volumes of a collection than what can be put on display at any one time. IoT could enable improved monitoring of collection items to ensure they are tracked and remain secure but are nevertheless more accessible to audiences.

Government services, including social services

- IoT has the potential to transform the delivery of many government services, including health and social services, particularly by facilitating a more customer-centric approach. However, the capacity for transformative impacts is linked as much to a 'reinvention of governance' around GaaP models of service delivery, as it is to the integration of IoT technology.
- Not for profits are using contactless payments to raise funds.
- Health and aged care services are identified as areas where IoT is generating major impacts currently, facilitating preventative care and remote care and improving efficiencies in health care settings.

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