National Infrastructure Commission

Study on international best practices in using technology to improve productivity

October 2017

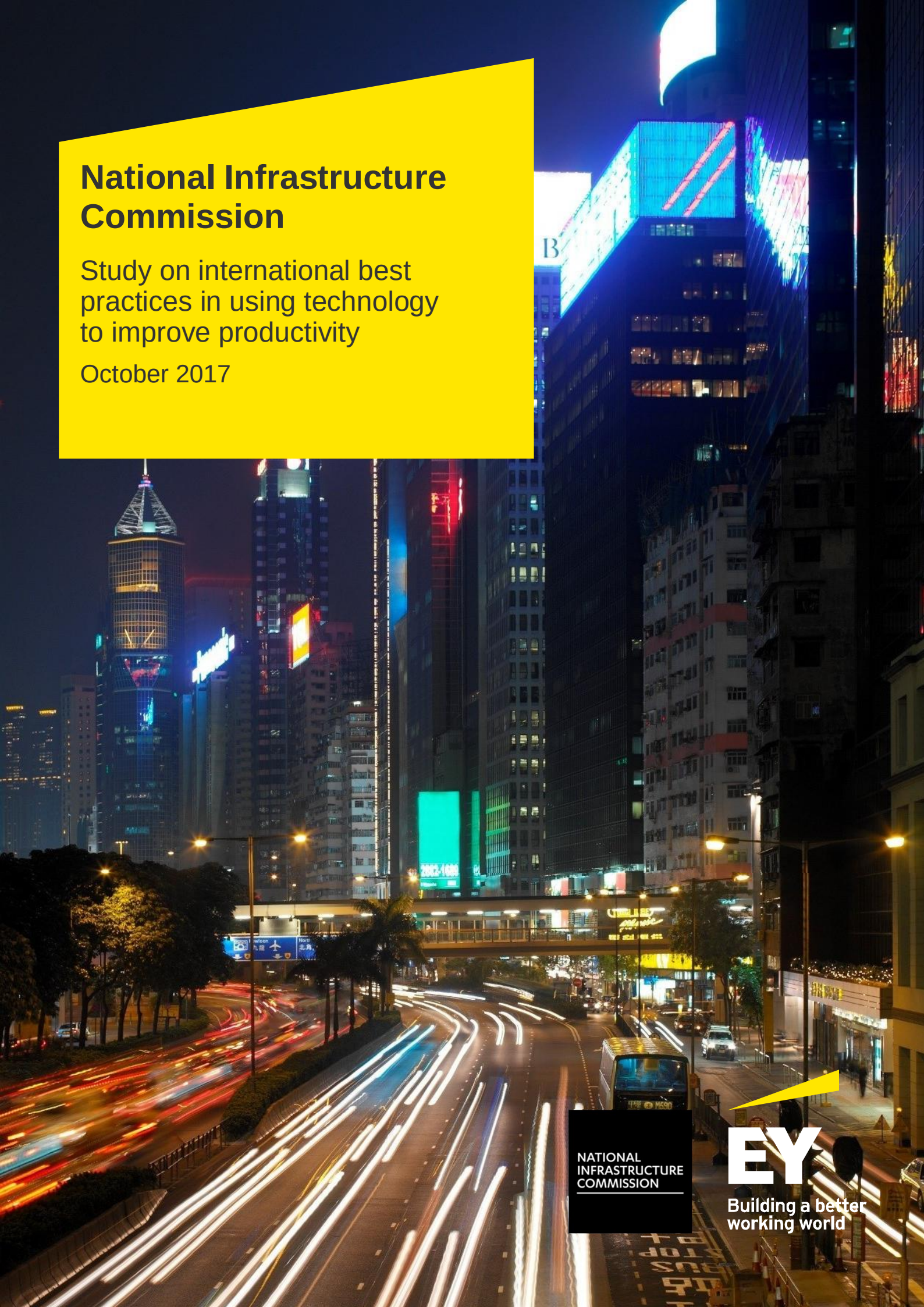

Table of Contents

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Executive summary

Background

Urbanisation and rapid population growth continue to put pressure on infrastructure management, alongside a growing demand for more efficient, reliable and safe services.

The cost of constructing and adding more infrastructure to a nation's asset base is substantial and drives a focus on the use of new and innovative technologies to contribute to a more productive management of existing infrastructure.

This report examines best practice examples of countries that have used technology to improve their infrastructure productivity. Research was conducted to generate a long list of projects across the in-scope technologies and countries. A smaller number of projects were then selected to be researched further and developed into case studies. This report focuses on the evaluation of these case studies and their relevance to the UK.

The aim of this report is to support the NIC's New Technology Study in identifying international best practices in using technology to increase infrastructure productivity. The countries in scope are: Estonia, France, Hong Kong, Japan, Singapore, South Korea, Sweden and the UAE.

Within these countries, our research focused on the use of eight technologies: distributed ledger systems, big data, digital twins, internet of things (IoT), machine learning, artificial intelligence (AI), sensing, and virtual and augmented reality. A sample of projects is provided below in Figure 1.

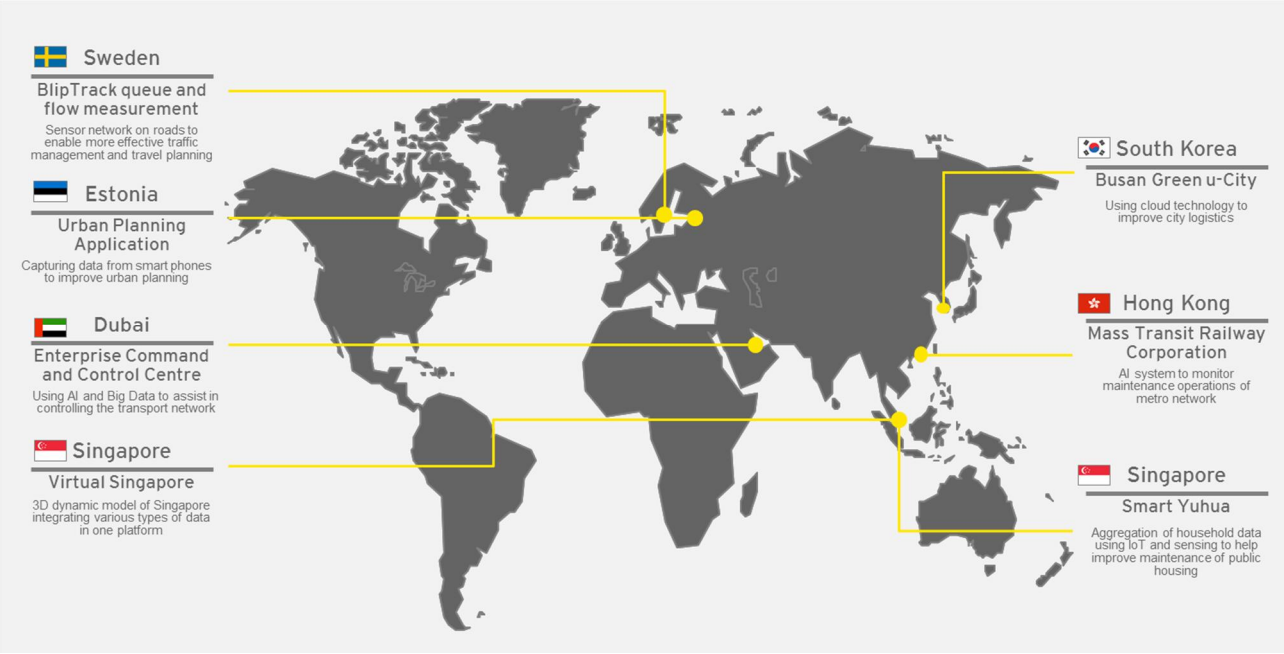

Figure 1: Sample of projects covered in the report

Many projects are in cities in Asia, where population growth has been, on average, faster than that in Europe, and where the major multinational technology organisations that have supported these programmes are located.

In addition to countries and technologies, the third frame of reference employed by this report is an economic lens on the infrastructure asset management life cycle, illustrated in Figure 2. Use of technology is referenced to the stage of the asset management life cycle from which the productivity benefits were realised. The four stages, depicted on separate levels, represent Capital Expenditure; Operational Expenditure; Economic return on invested capital; and Socio-economic return.

A sample of technologies researched are mapped out below in Figure 2, by way of example.

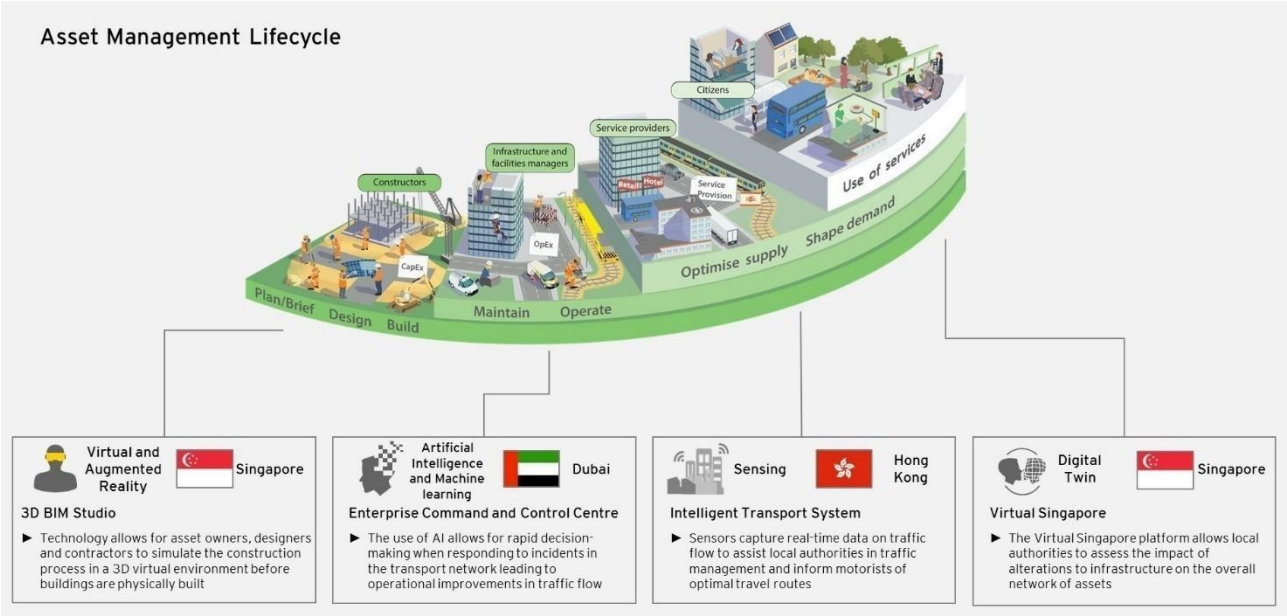

Figure 2: Sample of projects covered in the report

Summary of case studies

The table below provides an overview of the projects covered in this report and the benefits they delivered.

Type of Project	Country	Project	Technology	Benefits delivered									
				Improved Urban Planning	Reduced wastage	Reduced services disruption	Improved asset utilization	Improved operational efficiencies	Improved asset performance	Reduced operational expenditure	Improved construction productivity	Improved service delivery	Improved response to disaster management
Virtual models in Urban Planning		Virtual Singapore	Digital twin; Big data; IoT	✓			✓						✓
		SPINEX	Sensing; IoT; Digital Twin; Edge Computing					✓	✓	✓	✓		
		Urban Planning Application	Sensing; Analytics	✓		✓		✓				✓	
		Digital Transformation of DEWA	IoT; VR; Sensors; 3D Modelling		✓	✓		✓	✓	✓		✓	
Redeveloping public housing		Smart Yuhua, Singapore	IoT; Sensing; Big Data analytics		✓			✓	✓	✓		✓	
AI for asset maintenance		AI-based MTRC Project	AI; IoT; Sensing			✓		✓	✓	✓		✓	
Urban Transport and Traffic Control		Enterprise Command and Control Centre	AI; Big data; 3D Mapping			✓	✓	✓	✓			✓	✓
		BlipTrack	Sensing				✓	✓	✓			✓	
		Intelligent Transport System	Sensing; Automatic vehicle identification				✓	✓	✓			✓	
		Next-Generation Electronic Road Pricing	Big data; Sensing				✓	✓	✓			✓	
Smart City Complexes		Busan Green u-City	Sensing; IoT	✓	✓	✓		✓	✓				✓
		Songdo International Business District	Sensing; IoT	✓	✓	✓		✓	✓				✓
		Smart City Complex in Goyang	Sensing; IoT	✓	✓	✓		✓	✓				✓

Table 1: Summary of case studies

Conclusions

Consideration	Observations
Collaboration	• One of the objectives of this study is to examine the role of government in supporting the deployment of technologies to increase the productivity of infrastructure. • A common theme to the projects studied has been the collaboration between private, public and academic institutions. • This has enabled each of these groups of stakeholders to share their expertise, consider a broad range of interests and collaborate to develop innovative solutions. • The UK already has the ingredients for successful collaboration through Catapults and business incubators. The opportunity exists to establish a focused programme of innovation activity that explores opportunities for the use of crosscutting technologies to improve infrastructure productivity. Such an initiative could help encourage greater cross-sector partnership and collaboration, and define new ways of thinking. • This approach has proven successful in other countries and could provide a blueprint to help different organisations work together in the UK. • South Korea provides a good example of how collaboration has driven the innovation of new solutions to solve infrastructure problems.
People and change management	• A key theme among the examined case studies is the development of platforms that bring together a number of different stakeholders. • This is often performed under the umbrella of a national “Smart” scheme to facilitate communication and visibility. • For example, the ‘Virtual Singapore’ programme places a key emphasis on reducing silos between governmental departments by making data available to everyone who requires it; allowing for collaboration between the parties operating the built environment; and delivering significant efficiency gains. • Whilst the UK has much of the delivery vehicle required for innovation already in place, the British public is potentially less accepting than far-eastern nations of the benefits that new technology can bring. This is particularly so when detailed domestic and personal service usage data is required. A significant amount of change management and public education is required, led by government, to portray the benefits of data-driven infrastructure and the role the public has to play in making it happen.
Value of sharing data	• Another key observation is that significant benefit arises from the use of data across multiple life cycle stages. The value of data is increased through its accessibility, interoperability and application to different stakeholder groups and users. • The Smart Yuhua project in Singapore provides an example of data collection across a network, which is then used to inform better planning and design, better maintenance and operation, and better household cost management for citizens. • Virtual Singapore provides information on a whole network of assets, enabling more efficient planning and operation of a group of assets. • Accompanying the deployment of some of the programmes covered in this report, such as Virtual Singapore or the u-Cities in South Korea, is the establishment of data standards by these governments to enable interoperability between data and services. • Promotion of the benefits of data sharing have also supported these programmes.
Safety	• Technologies such as AI and virtual reality (VR) provide viable options in maintenance operations, improving the safety of maintenance operatives and reducing the likelihood of human error. • Dubai’s Digital transformation of DEWA provides an example of AI application within utility network maintenance. The use of AI has allowed DEWA to reduce the number of man-hours on site, ensure safer operation of assets and improve the cost-effectiveness of maintenance activities. • AI-based Mass Transit Railway Corporation (MTRC) project in Hong Kong employs AI to streamline and automate the planning of engineering works across the rail network. The use of AI eliminates the possibility of error from human manual processes. • Enterprise Command & Control Centre (EC3) in Dubai uses AI to manage traffic situations and enable faster decision-making and quicker accident response times.

Investment business model	• Blockchains and distributed ledgers have the potential to eliminate intermediaries across the asset management life cycle and, thereby, reduce administrative expenses. • Blockchain-based transaction platforms are applicable to the infrastructure sector in multiple areas, from enabling smart contracts to eliminating paperwork and creating payment transparency for provision of goods and services throughout the supply chain.

1. **Recommendation 1:** The UK has developed a set of initiatives to foster innovation in the infrastructure sector. These include the Infrastructure Challenge Fund, the Catapults programme and Manufacturing Technology Centres. In order to optimise the use of these initiatives there is opportunity to promote collaboration between innovative technology companies and public service providers.

   Developing focused programmes and initiatives, which highlight opportunities for the use of crosscutting technologies to improve infrastructure productivity, would help to encourage greater cross-sector partnership and collaboration and define new ways of thinking.

   For instance, a utility provider could collaborate with one of the Manufacturing Technology Centres in developing a new solution for one of its infrastructure challenges. It will be necessary to define the role of government and the NIC in fostering the cross-sector collaboration.

2. **Recommendation 2:** From the case studies outlined in this report, it is evident that public engagement and acceptance are key enablers to the success of technology programmes. It is necessary to consider the differences in public behaviour and political environment of Asian nations such as Singapore, when compared to that of the UK.

   Placing citizens at the centre of a programme and providing the opportunity for citizen participation in the development stages is a recognised enabler of success. The UK Government can support this engagement through promotion of benefits and success stories from programmes.

   In addition, it is important for the UK Government to have a proactive approach, helping set the stage for greater public support. For example, Singapore has been particularly successful in promoting Smart City projects through the use of roadshows and pilots. These initiatives were key to raise awareness about programmes prior to their deployment nationwide.

3. **Recommendation 3:** The Smart Nation programme in Singapore or the u-City programme in South Korea provide examples of initiatives that span across governmental departments. These programmes have been provided with budget certainty for a number of years, act as clear sponsors for innovation in cities and drive the programme forward across the government departments. An umbrella of “Smart” scheme can support promotion and visibility of UK projects, improving visibility of objectives and outcomes to the wider public.

4. **Recommendation 4:** A central theme across the case studies covered in this report is the collection of real-time data from infrastructure, service provision and citizen behaviour. Key points for the UK Government to consider are driving data standards and data integration across sectors and promote the value and benefits of data sharing. For some categories of data, the Government should also consider mandating data standards rather than just promoting.

List of tables and figures

Abbreviations used in the report

Abbreviation	Full form
AI	Artificial intelligence
AR	Augmented reality
AV	Autonomous vehicle
AVI	Automatic vehicle identification
BCA	Building and Construction Authority, Singapore
BIM	Building Information Modelling
BMAC	Busan Mobile Application Centre
CDSI	Common Spatial Data Infrastructure
DEWA	Dubai Electricity and Water Authority
DRSS	Driving Route Search Service
EC3	Enterprise Command & Control Centre of Dubai
ETMS	Engineering Works and Traffic Information Management System
GIS	Geographic information systems
GNSS/CN	Global Navigation Satellite System/Cellular Network
GovTech	Government Technology Agency of Singapore
HDB	Housing & Development Board, Singapore
HEMS	Home energy management system
HKSAR	Hong Kong Special Administrative Region
ICT	Information and Communications Technology
IDA	Info-communications Media Development Authority, Singapore
IFEZ	Incheon Free Economic Zone, South Korea
IoT	Internet of Things
IOC	Integrated Operation Centre
ITS	Intelligent Transport System
IU	In-Vehicle Unit
LTA	Land Transport Authority, Singapore
MTRC	Mass Transit Railway Corporation, Hong Kong
NIA	National Infrastructure Assessment
NIC	National Infrastructure Commission
NRF	National Research Foundation, Singapore
OBU	On-Board Unit
PCU	Passenger car unit

Abbreviation	Full form
PUB	Public Utilities Board, Singapore
RFID	Radio-frequency identification
RTA	Roads and Transport Authority, Dubai
SLA	Singapore Land Authority
UAE	United Arab Emirates
UPA	Urban Planning Application, Estonia
VPP	Virtual power plant
VR	Virtual Reality
WCCD	World Council on City Data
WMS	Water management system
WOG	Whole-of-government

Section 1

Introduction

1. Introduction

1.1 NIC Technology Study

In November 2016, the UK Government, through HM Treasury, requested the National Infrastructure Commission (NIC) for the New Technology Study. One of the requirements of this study is to develop an understanding of international best practices in using technology to improve infrastructure productivity.[1,2]

The main objective of this report is to exemplify good policies and market practices of international projects or programmes that have the most potential in terms of management optimisation, performance and maintenance of existing and future infrastructure assets. The ultimate goal is to demonstrate "best practice" examples of technologies that the UK Government should consider deploying.

1.2 Infrastructure productivity challenge

Factors such as rapid urbanisation, population growth, congested transport links, natural disasters and ageing infrastructure are putting tremendous pressure on the UK's infrastructure. Such challenges bring significant social and economic costs to the UK's economy and management of the country's built environment, as highlighted below:

- In 2016, the UK ranked as the third most congested nation in Europe with traffic congestion costing £31 billion to the economy[3]
- In 2015, 2.6 million Britons were affected by power outages that lasted for 50 minutes on average[4]
- The National Health Service (NHS) spends £600 million per year for treating illnesses caused by the likes of poor housing conditions[5]

According to the World Bank, "more infrastructure is not always better."[6] Rather, making the most of what we already have can be a much more efficient approach. In the UK, the addition of new infrastructure adds less than 0.5% each year to the value of existing infrastructure.[7] Use of technology is key to unlock greater productivity and drive economic growth from infrastructure. Using innovative processes and technologies can be crucial to reducing the total expenditure from the built environment and ensuring that we can extract greater value from the services we provide from it.

Emerging technologies present an opportunity to solve some of the abovementioned issues. Recent developments such as the internet of things (IoT), big data analytics and connectivity have the potential to deliver significant improvements across the whole asset management life cycle.[8] The use of information and technology to digitalise infrastructure across the (1) plan, design, build, (2) maintain, operate, (3) service provision, and (4) strategic financial investment planning phases of the life cycle will allow to achieve impacts such as:

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[1] "New Technology Study," *National Infrastructure Commission*, www.nic.org.uk/our-work/tech-study, accessed September 2017

[2] "Using New Technology to Improve Infrastructure Productivity — Terms of reference," GOV.UK, www.gov.uk/government/uploads/system/uploads/attachment_data/file/571940/161120_-_letter_for_Cx_and_TORs_for_the_tech_study_fv__003_.pdf, accessed September 2017

[3] "Traffic Congestion Cost UK Motorists More Than £30 Billion in 2016," *INRIX*, 20 February 2017, © INRIX, 2017.

[4] "Blackout Tracker 2015 Annual Report," *Eaton*, powerquality.eaton.com/uk, accessed September 2017

[5] "The cost of poor housing to the NHS," *BRE*, www.bre.co.uk/filelibrary/pdf/87741-Cost-of-Poor-Housing-Briefing-Paper-v3.pdf, accessed September 2017

[6] "Five Misconceptions about Infrastructure," *The World Bank*, blogs.worldbank.org/psd/five-misconceptions-about-infrastructure, accessed September 2017

[7] "Smart Infrastructure: Getting more from strategic assets," *Cambridge Centre for Smart Infrastructure and Construction*, www-smartinfrastructure.eng.cam.ac.uk/files/the-smart-infrastructure-paper, accessed September 2017

[8] "How Infrastructure Will Benefit From the Internet of Things," *Bloomberg*, https://www.bloomberg.com/news/sponsors/siemens/how-infrastructure-will-benefit-from-the-internet-of-things/?adv=7051&prx_t=weECA-yERA0u0PA&ntv_idp=1, accessed September 2017

- Optimising resources through better information on the resource use cycle
- Using information to better manage utilities
- Enabling consumers to make more informed use of resources and lower their consumption, thereby reducing utility operating costs and extending operating life of existing infrastructure
- Providing opportunities for new services to citizens through smart technologies

To achieve the above, a standard to capture data and analyse information from multiple sectors in a consistent and interoperable format is currently being developed by Innovate UK and Digital Built Britain as an extension to the existing Building Information Modeling (BIM) standards mandated for use in construction programs funded by the Central Government.

While data is key to the improvement of infrastructure productivity, technology is crucial to the capture of this information. Technology provides the means by which the information can be used to inform decision-making or implement decision outcomes in the physical world. More and better information about the built environment and how it is used provides the opportunity to increase capacity, efficiency and resilience and improve the responsiveness of services provided through the asset base. This report will explore how the use of technology is delivering benefits to all users across the entire asset life cycle from constructors to facilities managers, service providers and citizens.

Importantly, improving infrastructure productivity will support the NIC's objectives of promoting sustainable economic growth across the UK, improve competitiveness and improve the quality of life.

1.3 Approach and structure of the report

Research: This report is the result of both primary and secondary research conducted from across different databases, governmental websites and interviews to gather relevant perspectives and insights.

Frames of reference: As the basis of our analysis, three frames of references were used to examine each project:

1. **Countries:** The study focuses on eight countries — Estonia, France, Hong Kong, Japan, Singapore, South Korea, Sweden and the UAE
2. **Technologies:** Research conducted focuses mainly on eight technologies — blockchains, distributed ledger systems, big data, digital twins, IoT, machine learning, artificial intelligence (AI), sensing, and virtual and augmented reality
3. **Asset management life cycle:** As part of the analysis of the impact of projects, the stage of the asset management life cycle that each programme influences is considered

A more detailed explanation of the frames of reference is provided in Section 2 of this report.

Taxonomy: The taxonomy of this study provides a common frame of reference for the process of long-listing and short-listing relevant projects. The baseline taxonomy includes:

- Country or city of the project
- Description or summary of what it entitled
- Technology components
- Sectors or segments of economic activity[9]
- Role of government intervention
- Benefits delivered
- Value of the project
- Costs and revenues
- Savings generated

[9] Note: The National Infrastructure Assessment (NIA) done by the NIC once in every parliament covers six infrastructure sectors — transport, energy, water and wastewater, digital communication, solid waste and flood risk management.

Long-listing and case study development: The initial remit of this report has been to develop a long list of projects for each of the eight countries. This list contains all of the elements of the taxonomy indicated above.

A workshop was held to identify the most relevant projects and decide on a short list for projects that were to be developed into case studies. The case studies place a particular emphasis on:

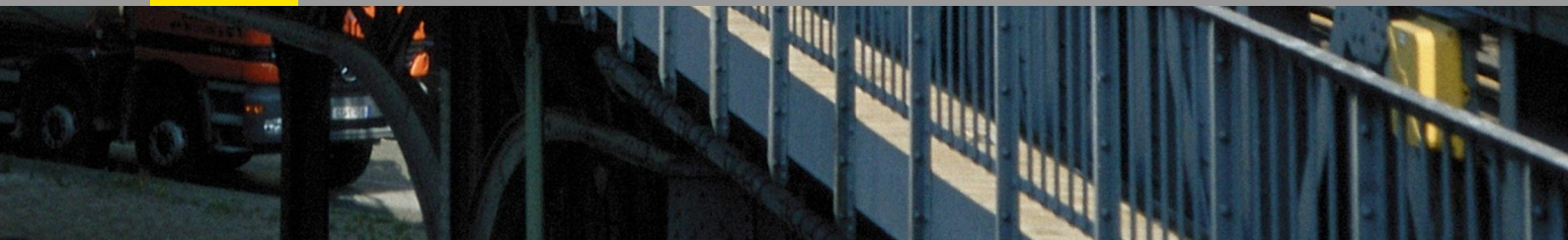
1. Cost or value of the project
2. Benefits delivered, including social and economic gains to the country
3. Role of government intervention in each project

The report contains five case studies with technologies that are delivering benefits in terms of optimising the management, performance and maintenance of infrastructure assets to support economic growth.

Note that this study is accompanied by a data set with the long list of projects.

Section 2

Frames of reference



2. Frames of reference

2.1 Asset management life cycle

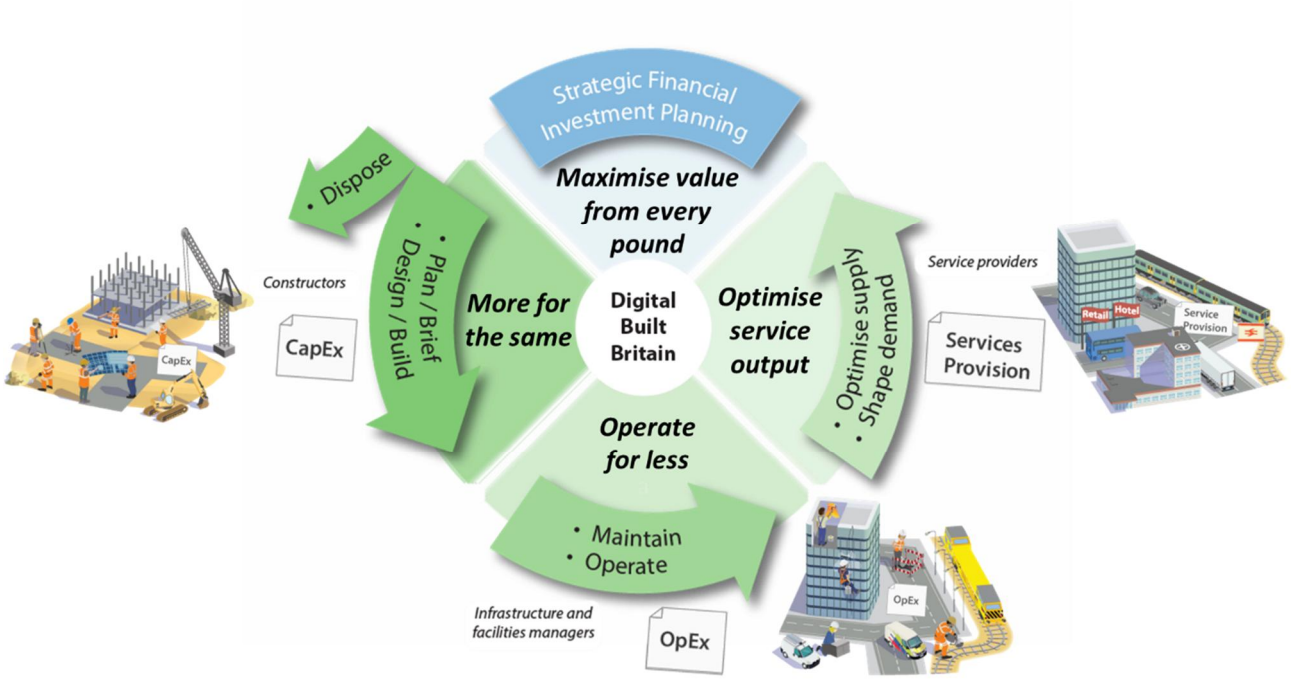


Figure 1: Asset Management Life Cycle.

The asset management life cycle describes a strategic approach to realising value from assets systems in the built environment.[10] Information collected about the asset system throughout its life cycle facilitates decision-making during the planning, design, construction, operations, maintenance, service provision and strategic financial investment planning phases, as illustrated above.

1. Plan, Design, Build

An asset's life cycle commences with constructors creating an asset — be it a hospital, a school or an office block. The cost of this activity is predominantly treated as CapEx (capital expenditure). BIM datasets, combined with technologies such as virtual reality (VR) and augmented reality (AR) deliver benefits around increasing productivity of the construction phase of assets as well as improving security. For example, with VR, one can test the operational functionality of a building before construction has begun and identify any required changes.

2. Maintain, Operate

Once the asset is constructed, it is operated to deliver value to users. This is typically regarded as the "facilities management" activity, but it often includes heavy refurbishment and periodic renewal of part or all of the asset. For example, large buildings are managed for faults and defects, railway tracks are maintained and roads are resurfaced. The cost of this activity is predominantly treated as OpEx (operating expenditure) quadrant. At this stage, technologies such as sensors and predictive analytics can provide accurate and live insights on infrastructure and its likelihood of failure. Such "rich" information allows for quick identification of any deficiencies in the asset network before any major problem occurs, mitigating potential service disruption.

3. Service provision

All of these assets are "used" by people, for example, taking the train to work or going to hospital for treatment. These costs are classified as "service provision." Data about asset usage and data about secondary services,

[10] Note: The asset management life cycle diagram was developed during the Strategic Outline Business Case for Digital Built Britain.

such as energy and waste, can provide information that enables service providers to optimise the capacity of their asset base, optimise configuration of supply, and — when supply has been exhausted — shape demand.

4. Strategic financial investment planning

Strategic financial investment planning entails understanding user and stakeholder needs alongside information about how the built environment works, to ensure the best possible outcome from investment in new infrastructure capability. The information required to optimise investment planning decisions is based on how infrastructure is utilised, how it performs, and the extent to which designed capability of existing infrastructure is being exploited to its full potential. The data models required to support strategic investment planning are typically network or whole system and models such as road networks and energy grids, representing the aggregate capability of different types of individual infrastructure assets. The sensing required to inform investment planning is typically linked to building a better understanding of demand, which is characteristically driven by operational volume data.

2.2 Technologies

As described in Section 1.3, “Approach and Structure of the Report,” the study focuses on eight focus technologies, which are considered to have the potential to enhance the productivity of infrastructure. The focus technologies are outlined below with some examples of how they have been applied across different stages of the asset life cycle within the countries in scope.

Technology	Overview	Examples	
1. Blockchains and distributed ledger systems 	• Blockchains and distributed digital ledger systems enable non-repudiation, transactional integrity and transparency through complex infrastructure supply chains. • Blockchain is applicable to facilitating benefits in the infrastructure sector in multiple areas, from enabling smart contracts to eliminating paperwork and creating payment transparency for provision of goods and services throughout the supply chain. • Blockchains and distributed ledgers are also potentially valuable in confirming the veracity of the underlying operational data used to optimise operations in the service provision phase of the asset management life cycle. • It has the potential to eliminate intermediaries across the asset management life cycle and, thereby, reduce administrative expenses.	**Project:**	Estcoin
		Asset management life cycle stage:	Service provision
		Location:	Estonia
		• Estonia is currently developing a digital currency that is expected to be used to raise funds for investments in technologies in the public sector. • This currency will be issued on top of blockchain, thus making it easy and convenient to be used inside smart contracts and other applications. • Estcoin is expected to attract investment in technologies for the public sector.	

Technology	Overview	Examples	
2. Big data 	• Big data technology is applicable primarily to the storage and analysis of huge volumes of operational data from the built environment from which insight can be derived to feed back into better construction and capital scheme design, predictive asset management and service optimisation. • It is required to support any large-scale deployment of blockchain — distributed ledger technology.	**Project:**	The Commuter Prognosis
		Asset management life cycle stage:	Maintain, Operate; Service provision
		Location:	Stockholm, Sweden
		• A commuter train operator in Stockholm developed a prediction model (algorithm) based on big data, to visualise the entire commuter train system and forecast disruptions and delays up to two hours in advance. • The system uses historical data from previous occurrences to forecast the likely impact on the entire train network.	
3. Digital twins 	• Digital twinning refers to the mapping of a physical asset into a digital platform. • Digital twins are applicable to spatial analysis and operational use of the built environment. • A digital twin for the future built environment enables visualisation of the infrastructure assets in its spatial operational context and also enables training of operational staff through simulation based on what the future environment will look like. Such processes have the potential of training and making staff more efficient in the operation/maintenance of assets. • They are useful in understanding how the built environment is used, which will enable better building as well as provide valuable insight for urban and transport designs.	**Project:**	Virtual Singapore
		Asset management life cycle stage:	Whole life
		Location:	Singapore
		• Virtual Singapore is developing a 3D dynamic virtual model that will incorporate static, real-time and semantic data on Singapore's built environment. • It will allow for benefits across the whole asset life cycle. This project will be explored in further detail in Section 4.1.	
4. Internet of things 	• IoT is a means of collecting data at high-frequency intervals from digital devices and embedded sensors. • It is not just about instrumenting fixed assets. Huge amounts of useful information can be captured from mobile devices also — phones or devices embedded in mobile assets such as vehicles, which include a spatial or positioning element within the data. • In application to infrastructure, IoT devices can capture and report a variety of inputs (such as energy consumption) and outputs (such as occupancy of a building) that can respectively be linked to cost and service elements of productivity.	Project:	Smart City Complex
		Asset management life cycle stage:	Maintain, Operate; Service Provision; Strategic Financial Investment Planning
		Location:	Goyang, South Korea
		• LG is using a combination of sensors and IoT to develop a smart city in Goyang. • It uses IoT to connect to a network of sensors to enable more efficient operation of assets as well as a better service to its citizens. • For instance, street lamps will have an automatic system to turn them on and off by detecting nearby pedestrians. • This case study is explored in further detail in Section 4.5.2.	

Technology	Overview	Examples	
5. Machine learning and artificial intelligence 	• Machine learning and AI offer significant operational and reliability benefits to asset owners. • In the past, an engineer might have noticed an unusual “hum” from a piece of machinery that indicated the onset of a potential problem. Machine learning can take this to a different scale and level. • By analysing acoustic, power consumption, temperature, electromagnetic variation, bio-sensed and visual data captured from infrastructure assets, it is possible for machine learning algorithms to learn what represents “normal” and identify a deviation from normal, should it occur. • AI takes this further by building up knowledge of different deviation “signatures” linked to different potential failure modes. • In this way, potential infrastructure failures can be detected and mitigated at a very early stage, or the associated risk managed appropriately.	**Project:**	EC3
		Asset management life cycle stage:	Maintain, Operate
		Location:	Dubai, UAE
		• The Enterprise Command & Control Centre of Dubai (EC3) is using AI and big data analytics to assist in improving the city’s traffic management. • The use of AI allows for rapid decision-making when responding to incidents in the transport network, leading to operational efficiency improvements. • This project is explored in further detail on Section 4.4.	
6. Sensing 	• Sensing is a critical enabler to achieve higher productivity in managing infrastructure. • Using sensor technology provides the opportunity to understand assets at every stage of the life cycle. • It provides the ability to capture live data from the built environment. Nonetheless, it is crucial to then act upon the receipt of this information.	**Project:**	Connected Boulevard
		Asset management life cycle stage:	Maintain, Operate Service Provision
		Location:	Nice, France
		• The Urban Environment Monitoring project uses a network of 3,000 sensors to collect environmental data. This data is then used to support pollution control, traffic flow management and coordinate waste collection truck routes. • Some of the benefits achieved include the reduction of traffic congestion by 30% as well as reduced noise and air pollution levels by 25%. • Synchronising streetlights to pedestrian and traffic activities or changing weather conditions is expected to cut electricity consumption of city lighting by 20%–80%	

<table>
<tr><th>Technology</th><th>Overview</th><th colspan="2">Examples</th></tr>
<tr><td rowspan="4">7. Virtual reality and augmented reality
  </td><td rowspan="4">VR and AR provide a means of immersing a human into a virtual “digital twin” environment, allowing them to explore and interact with elements in the environment.
This has strong application in the following environments:
Safety-critical infrastructure environments: visualising the assets before their construction can help to better engineer safety considerations into the design.
Operational environments: It enables staff to familiarise themselves with the work site before entering the physical site, enhancing their understanding of hazards and increasing the likelihood of the work being completed in a safe way.
This application enables more productive working, resulting in a reduction of re-work and more reliable output.</td><td>Project:</td><td>3D BIM Studio</td></tr>
<tr><td>Asset management life cycle stage:</td><td>Plan, Design, Build</td></tr>
<tr><td>Location:</td><td>Singapore</td></tr>
<tr><td colspan="2">A state-of-the-art 3D BIM Studio at the Building and Construction Authority (BCA) in Singapore was developed by NETe2 Asia.
The studio allows owners, designers and contractors to simulate the construction process in a 3D virtual environment before buildings are physically built on site, as opposed to viewing conventional drawings and models on paper and screen.
It allows for a more efficient plan, design and build phase of assets. Having a virtual view of the asset when planning and designing allows for experimentation and reduces the margin of error in the construction phase.</td></tr>
</table>

Table 2: Overview of focus technologies

2.3 Countries

This report focuses on a group of countries that have invested in technologies and programs that aim to make their cities more competitive, sustainable and resilient. Table 3 provides a summarised overview by considering two sets of factors:[11]

1. **Geographic, political and economic context:** Sets some of the main challenges and drivers of infrastructure management in the country, for example, a densely populated nation will have an increased need to manage its resources more efficiently to serve all of its citizens
2. **Government intervention:** Provides an outline of the main policies and programs developed by governments to address their infrastructure challenges and support the adoption of smart technology

[11] Note: A detailed overview of each country is provided in Appendix 1.

Country	Geographic, political and economic context	Government intervention
1. Estonia 	• With limited resources to set up a new Government after its independence in 1991, Estonia decided to invest in innovation and technology to develop its public services.	• Estonia has implemented a series of policies that focus on the deployment of technology to connect people, generate data and manage public services and buildings.
2. France 	• With nearly 80% of its population living in urban areas, the Government has defined the development of smart solutions to manage its cities as a priority.	• France has benefited from both public and private programmes to drive the use of technology to manage infrastructure. • The EU identified 240 smart cities in Europe, 31 of which are located in France, compared with an average of 9.6 cities per EU member state.[12]
3. Hong Kong 	• As one of world's top financial centres, Hong Kong has a strong ambition to be "Asia's World City".[13] • Aligned to this goal is its purpose of being a competitive global city, a business hub, a top financial centre and an attractive tourist destination.	• Hong Kong 2030+ outlines a strategy to guide planning, land and infrastructure development. • In 2017, US$500 million will be invested in the Innovation and Technology Fund for Better Living to subsidise innovation and technology projects.[14]
4. Japan 	• Japan's geographical location is in an area characterised by mountains, restricted constructible land, an earthquake-prone region and limited natural resources. This means that its geography poses significant challenges to the efficiency of its infrastructure.	• The upcoming 2020 Olympic Games is considered as an opportunity for authorities to rethink on how the built environment is managed and operated, as well as bring a substantial number of new infrastructure projects to the country. • In 2015, the i-Japan Strategy was launched, which focuses on bringing digital technologies to several aspects of society and the economy, including the development of infrastructure and technologies to motivate the use of digital information.
5. Singapore 	• Singapore is one of the most densely populated countries in the world located in a small island with very limited natural resources. Hence, its geographic location poses significant challenges to its built environment and the efficiency of its infrastructure.	• In order to face its geographical challenges, productivity and technology enablement have been identified as two areas of investment by the Government. • A number of programmes have been developed in the last few years, including the Smart Nation program and the Building and Construction Authority's (BCA) construction and productivity R&D road map.

[12] "Doing Business in France: Smart grids and smart cities in France," *Business France*, October 2016.
[13] "Hong Kong 2030+: Towards a Planning Vision and Strategy Transcending 2030," *Hong Kong 2030+*, October 2016.
[14] "We Connect for Hope and Happiness," *Hong Kong Government — The Chief Executive's 2017 Policy Address*, October 2017.

Country	Geographic, political and economic context	Government intervention
6. South Korea 	• Over the last few decades, the fast growing ICT sector in Korea has been supported by a set of government policies to promote the use of technologies to manage its built environment.	• The Government's u-City (ubiquitous city) programme focuses on integrating next-generation technology with a city's built environment. • Circa 20 local administrations are working on u-City projects in conjunction with Korean telecommunication companies, the Korea Land Corporation and the National Housing Corporation.[15] • For instance, the Smart Seoul 2015 Plan focuses on areas such as given below: • ICT infrastructure: Including provision of smart devices for all, u-Seoul Safety Service and a smart metering project • Integrated city-management framework: Government or municipal-developed services such as online reservation system for public services and promotion of Open Governance 2.0
7. Sweden 	• The Swedish Government is making its largest investment to date on infrastructure. • Plans include investment of €64 billion on railways, roads and other major projects, and €150 billion on housing and offices until 2030. Part of these funds are directed toward improving the operation, maintenance and reinvestment on its current asset base.[16]	• A recent bill passed by the Government — "Infrastructure for the future" — focuses on innovations to strengthen the country's competitiveness and achieve sustainable development. • The Smart Built Environment program is another initiative that focuses on deploying applications including geographic information systems (GIS) and BIM.
8. UAE 	• Dubai has an aspiration to become one of the world's forefront cities with regards to resilience, sustainability and interaction with its citizens and has accordingly developed programmes to foster this development.	• The Dubai Plan 2021 addresses the urban environment, including built and natural assets as well as the quality of life of citizens. • Recently, Dubai has been appointed as one of the nine local data hubs for the World Council on City Data (WCCD). This commitment entitles gathering standardised and comparable city data. • Dubai Future Accelerators program has a US$275 million fund to bring 30 of the best start-ups around the world to work on its most significant public problems.[17]

Table 3: Overview of focus countries

[15] "U-City: New Trends of Urban Planning in Korea," *Urban and Regional Innovation Research*, www.urenio.org/2010/09/26/u-city-new-trends-of-urban-planning-in-korea, accessed September 2017.
[16] "Infrastructure & construction in Sweden," *Business Sweden*, www.business-sweden.se/en/Invest/industries/infrastructure-and-construction, accessed September 2017.
[17] "Dubai Has $300 Million To Entice The World's Best Start-ups To Its Accelerator," *Forbes*, www.forbes.com/sites/elizabethmacbride/2016/12/29/dubai-has-300-million-to-entice-the-best-startups-to-worlds-fastest-rising-city/#17a11ae758e4, accessed September 2017.

Section 3

Long list of projects

3. Long list of projects

Figure 2 provides an overview of the different technologies present in the long list of projects developed across the eight countries that were in scope of this study.

Some of the significant findings from the long list are highlighted below:

- Use of blockchain, analysis of big data, IoT implementation and use of sensing were key areas of focus across the geographies in scope.
- Nearly half of the projects involve the implementation of sensing technology as a part of smart infrastructure system.
- Very few projects used digital twins, VR and AR technologies.
- Projects in Estonia showed a prevalence of blockchain technology.
- Sensor-related initiatives in Hong Kong and Sweden have been successful in driving benefits.
- Projects in Japan, Singapore and South Korea show the benefits of using information from big data. South Korea, Sweden and UAE projects use IoT as a key technology for productivity improvements.

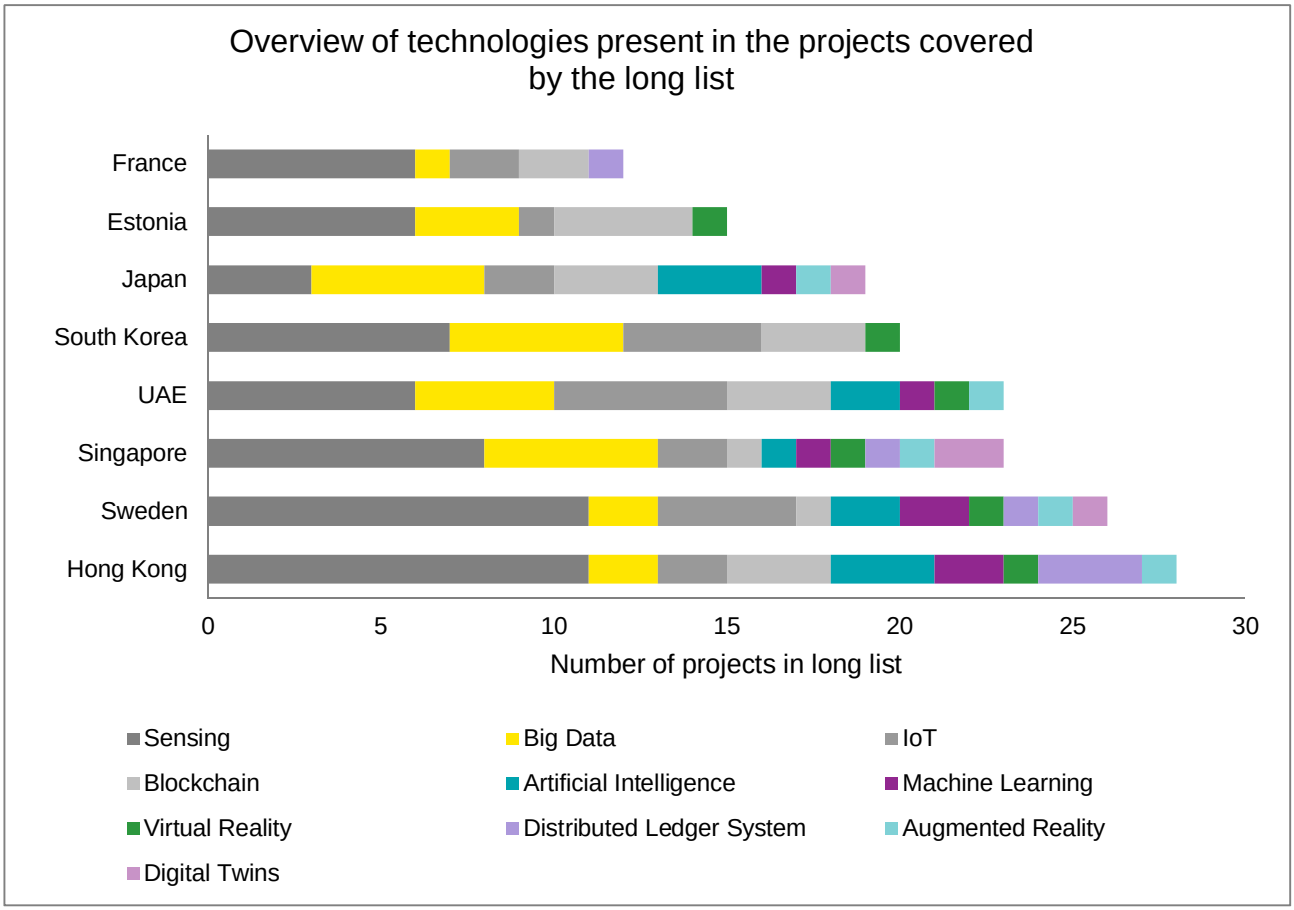


Figure 2: Overview of long list projects

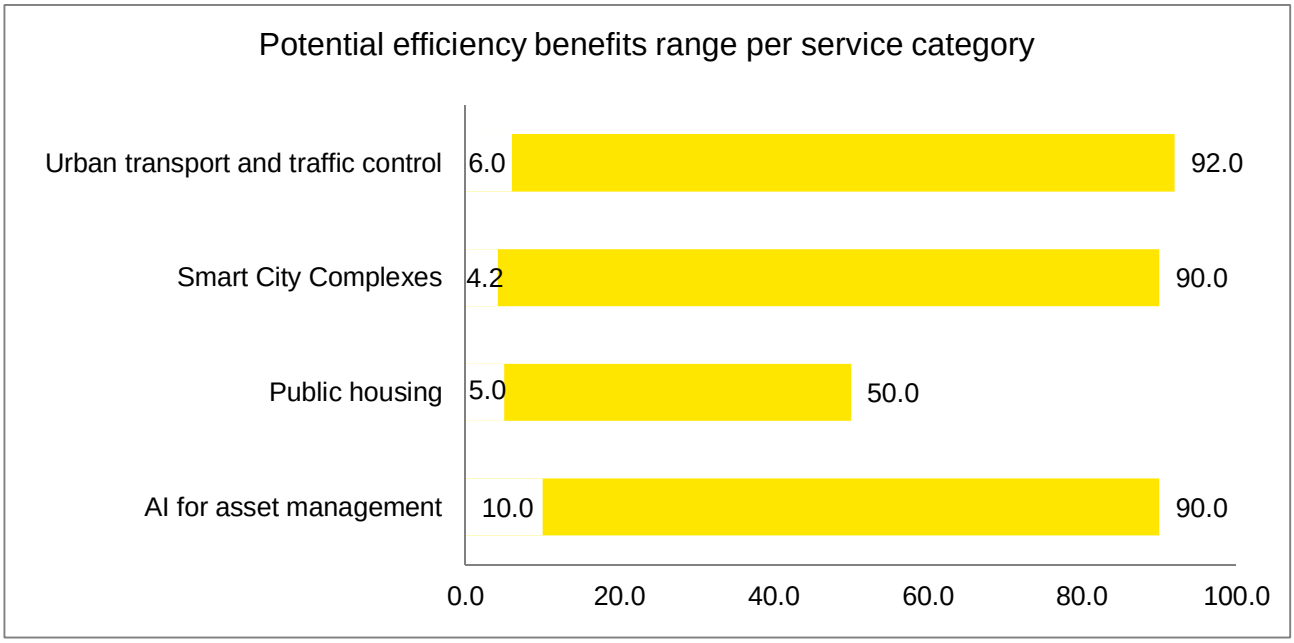


Table 4: Potential efficiency benefits range per service category

For the projects reviewed, we noted actual and predicted improvements in the following:

- Efficiencies, including reduced equipment and labour cost, of 10%–90% were gained as a result of AI for asset management
- Within public housing, the projects reviewed highlighted savings in costs and energy consumption ranging 5%–50%
- The smart city complexes reviewed showed energy savings and improvement in waste management of between 4.2% and 90%
- Finally, the urban transport and traffic control projects identified reduced air pollution, reduced public service waiting times, reduced congestion and reduced noise level ranging from 6% to 92%

Further detail regarding the actual and predicted benefits identified can be found in Appendix 2.

Section 4

Case studies

4. Case studies

4.1 Virtual models in urban planning

4.1.1 Virtual Singapore, Singapore

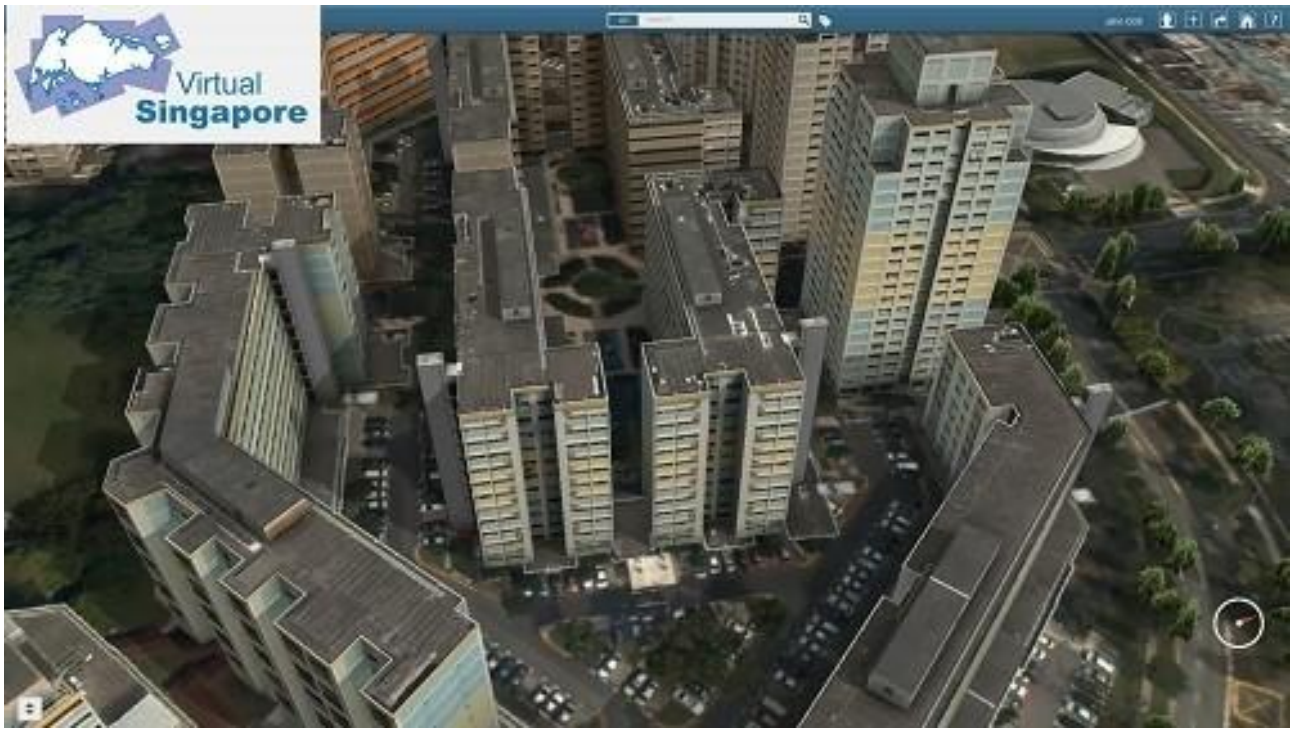


Figure 3: Screenshot of how the Virtual Singapore Platform will look like.

Source: NRF — Virtual Singapore.

What is the project?

The Virtual Singapore programme consists of building a platform that provides a 3D dynamic virtual model — **a digital twin** — of the urban areas of Singapore. It will incorporate both static and real-time data on factors such as climate, demographics, terrain attributes, energy consumption or building elevation. It will also contain semantic information such as the composition and materials of buildings. In forming this virtual model, it will incorporate data from sensors on physical assets, which will allow monitoring of asset efficiency, their real-time condition and scenario-testing.[18]

The main objective of this platform is to build a collaborative tool where a range of scenarios can be virtually simulated through layering different kinds of data in a 3D model. It provides the capability for city planners to have a holistic view of the island's built environment. It allows access to the far-reaching impacts of any changes to Singapore's infrastructure base. For example, a city planner will be able to assess the impact the construction of a new building will have on traffic or pollution.

Virtual Singapore will be used by government agencies, private entities, citizens and researchers. It also aims to be collaborative and, hence, brings together different stakeholders in addressing complex urban problems. It considers the whole network of assets in a certain area, enabling urban planners, local service providers, governmental authorities and citizens to interact and make decisions, improving service provision and livability

[18] "Digital twinning explained," *Raconteur*, www.raconteur.net/business/digital-twinning-explained?utm_source=pardot&utm_medium=email&utm_campaign=thurs220617, accessed September 2017.

of that area or region. This is especially relevant in a nation that is so densely populated and is the home of six million people in an area half the size of Greater London.[19]

Virtual Singapore started development in 2014 and deployment is planned to start in 2018. To date, the areas of Yuhua and Teck Ghee have already been mapped and modelled.

Role of Government

The project is part of an R&D programme initiated by the National Research Foundation (NRF) that funded the US$73 required for the platform development as well as research into relevant technologies. Other organisations involved in the programme include the following:

- The NRF is working with a French multinational company, Dassault Systèmes, to develop the platform[20]
- The project is led by the NRF in collaboration with the Prime Minister's Office, the Singapore Land Authority (SLA) and the Government Technology Agency of Singapore (GovTech)
- The SLA is providing 3D topographical mapping data and will own and operate the project once it is completed

Asset management capabilities

The development of Virtual Singapore will enable the development of a set of capabilities in managing the country's built environment. The main capabilities identified by the NRF are outlined below:[21]

- **Virtual experimentation and test-bedding:** The platform enables organisations to test and experiment new projects prior to their deployment. The possibility of visually seeing how a new building will impact a certain area in terms of traffic, pollution, energy consumption among other factors makes this tool particularly powerful
- **Simulation:** The tool allows for testing the built environment under extenuating circumstances such as disaster management. For instance, if a fire erupts in a stadium, how the crowd would be managed; or how modeling could be used to predict the impact of flooding. This enables Singapore to be better prepared for when such events occur
- **Planning and decision-making:** The collaborative nature of the platform with a holistic and integrated view of Singapore provides information to make 'better' decisions around asset management
- **Research and development:** Making this tool available to start-ups and academia, as well as private and public entities, provides the opportunities for these to collaborate, innovate and develop new technologies and tools that tackle pertinent urban problems

What benefits will it deliver?

Importantly, with Virtual Singapore, the Government will be able to improve city experiences of residents, businesses and government departments.

A major benefit which is expected to be delivered by Virtual Singapore derives from the fact it will encourage collaboration across all parties that have an interest in the country's built environment. The platform will provide the opportunity for all stakeholders to share data and collaborate to make decisions that allow for a more efficient running of infrastructure. Digital twins are key to reducing or eliminating silos by making data available to everyone who requires it.[22] It is estimated that it will deliver significant cost savings from this collaboration as different parties operating the built environment can coordinate their decisions across the asset life cycle.

The NRF has also identified a number of beneficiary stakeholders:

- **The Government:** Virtual Singapore is aligned to various Whole-of-Government (WOG) initiatives such as Smart Nation, Municipal Services, nationwide Sensor Network, GeoSpace and OneMap. It is a key step

[19] "London can learn from Singapore's approach to high-rise living," *Financial Times*, www.ft.com/content/49955844-6563-11e7-9a66-93fb352ba1fe, accessed September 2017.
[20] Dassault Systèmes is a software company specialising in the development of 3D software applications.
[21] "Virtual Singapore," *National Research Foundation*, www.nrf.gov.sg/programmes/virtual-singapore, accessed September 2017.
[22] "Digital Twins — The Business Imperative You Might Not Know About," *Forbes*, www.forbes.com/sites/danielnewman/2017/05/30/digital-twins-the-business-imperative-you-might-not-know-about/#25ca48e5693c, accessed September 2017.

in the Government's intentions in developing a truly "Smart" nation by developing and managing its infrastructure to improve the quality of life of its citizens. Additionally, the platform provides data for various agencies in the areas such as utilities, urban planning, climate change, telecommunications or heritage preservation

- **Citizens and residents:** Ultimately, the main objective of Virtual Singapore is to improve the quality of life of its citizens. By having a tool that enables a more effective management of Singapore's built environment — through, for example, being better prepared for disaster management or being able to improve traffic flow in the city — the city's livability will improve. Also, the tool provides access to an array of information to citizens including traffic information, or health and weather updates
- **Businesses:** The Government is planning to collaborate with business in the sectors such as financial, architecture, engineering, transportation and energy. Furthermore, the platform will provide an array of information for business analytics and resource planning that can be accessed and used by any private entity
- **Research community:** As outlined above, the research community will benefit from having access to information and a platform to test business ideas and solutions

Challenges to the success of the programme

One of the major areas of concern is **data security**. Virtual Singapore consists of a collaborative data platform where public authorities, researchers, citizens and businesses would share and access data. Therefore, there are privacy and security concerns over sensitive data being handled by a third-party vendor. The NRF has indicated that individuals will not be identified and all data will be anonymised. In addition, all organisations in possession of this data will be required to take measures against unauthorised access.

Though Singapore has a strong ambition in developing a "Smart" nation, the adoption of new technologies by many government agencies that have their own tools, habits and processes may pose some challenges in switching to a less "siloed" and more collaborative approach. Thereby, there will be a considerable amount of time dedicated to **change management** over the next few years. It will be essential for the Government to delineate a thorough stakeholder engagement plan to ensure that key stakeholders are engaged with Virtual Singapore, understand how it can positively impact their day-to-day life and provide any training that may be required. Overall, there will have to be a cultural change, as those who typically operate assets will have to collaborate with data scientists and IT professionals.[23]

Data standards

Accompanying Singapore's Smart Nation program is the need for a set of standards that allow for the data generated between different systems to be interoperable. The Info-communications Media Development Authority (IDA) has been working with more than 20 organisations over the last couple of years to establish guidelines on IoT standards for interoperability, security and data privacy. These organisations include both public and private parties such as academic institutions, technology providers, multinational organisations and industry alliances.[24]

[23] "Gartner's Top 10 Strategic Technology Trends for 2017," *Gartner*, www.gartner.com/smarterwithgartner/gartners-top-10-technology-trends-2017, accessed September 2017.
[24] "Singapore is surveying the various IoT standards out there, and adopting them where applicable for the Smart Nation," *Infocomm Media Development Authority*, www.imda.gov.sg/infocomm-and-media-news/buzz-central/2015/5/gearing-up-for-the-smart-nation, accessed September 2017.

The objective is to ensure that the various technologies being deployed as part of the Smart Nation programme will remain open and form an interoperable ecosystem. This has been defined as a crucial step to ensure the success of the Smart Nation programme.

Two standards, TR 38 and TR 40, have already been developed for sensor networks in public areas and homes. Another standard with regards to a reference architecture for the IoT — IoT Information and Services Interoperability — is under development.[25]

4.1.2 SPINEX, Japan

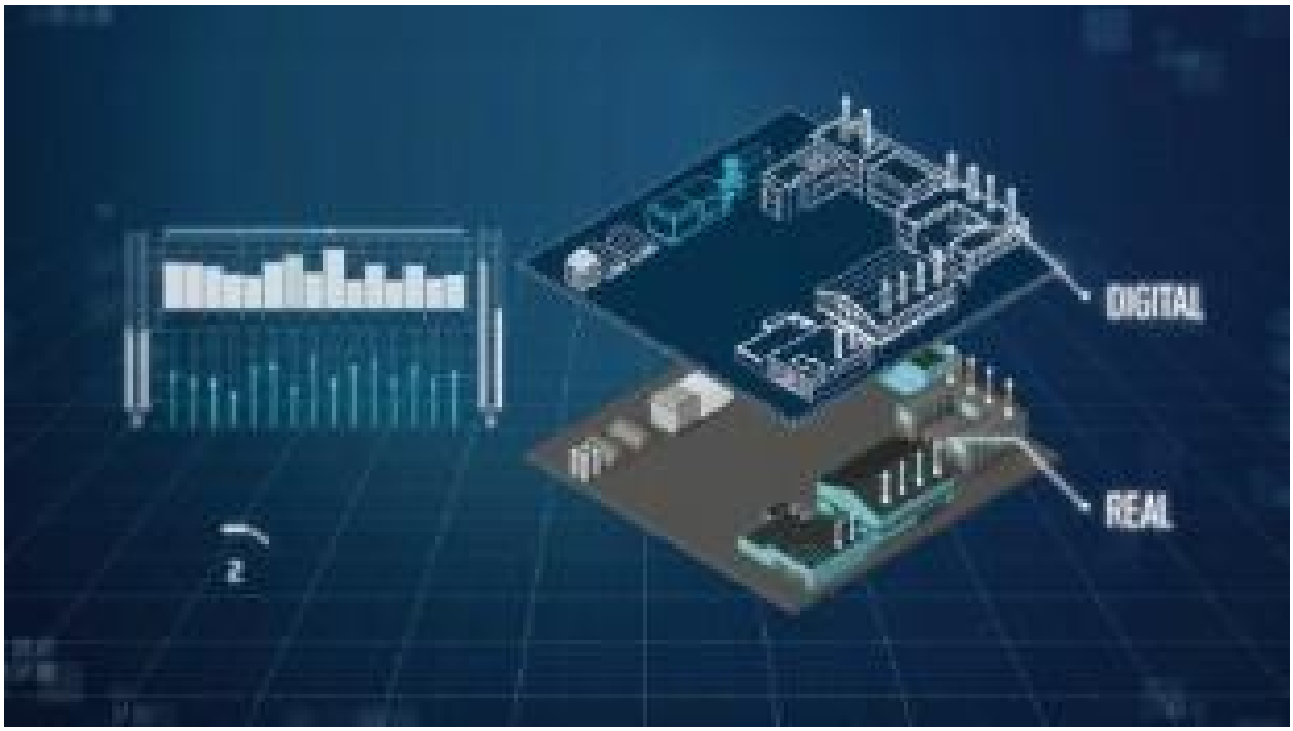


Figure 4: SPINEX, seeing the real-world digitally.

Source: Toshiba — SPINEX

In late 2016, Japan's Toshiba announced the launch of SPINEX, a technology that leverages IoT, edge computing and data analytics to enable improvements in control of equipment and operational performance. SPINEX will use digital twin technology to visualise and examine constantly changing worksite conditions. Its primary focus will be directed toward manufacturing plants; but it plans to expand to be used in other locations and sectors.

SPINEX enables detailed visualisation and real-time assessment of assets' conditions as well as quality information on asset performance to improve decision-making. It enables one to connect different pieces of equipment, collect data and perform advanced analysis on that information. It uses an open architecture and is capable of multi-cloud and device connectivity. It offers three features as outlined below:

- **Edge computing:** This feature integrates information at source, allowing for time gains. It allows for the collection and processing of large amounts of sensor data in addition to audio, image, video, vibration and other data. The main benefit derived from this feature is the reduced network lag time and contribution toward worksite environment capable of sophisticated data processing. This data can feed into AI systems, enable error detection, perform autonomous control of devices and provide a rapid response in case of asset failure
- **Digital twin:** It is a digital representation of an asset. Benefits generated include failure prevention strategies and improving the performance of the asset

[25] "Standards ensure that Smart Nation technologies will remain open and interoperable as an ecosystem," *Infocomm Media Development Authority*, www.imda.gov.sg/infocomm-and-media-news/whats-trending/2015/9/raising-the-standards-for-smart-nation, accessed September 2017.

- **Media intelligence:** This feature uses AI with facial and speech recognition to integrate human intentions and activities in asset operations

Some of the use cases outlined by Toshiba include:[26]

- **Buildings and asset management:** This includes preventive maintenance of elevators; energy saving of air conditioning and lighting; and building energy management
- **IoT:** IoT systems built with SPINEX have been used to improve the quality and productivity of the Yokkaichi Plant, which manufactures NAND flash memory, and has achieved positive results
- Yokohama City and Tokyo Electric Power Energy Partner Company collaborated to use IoT architecture feature of SPINEX solution, for the development of the Smart Resilience virtual power plant (VPP) as a part of Yokohama Smart City Project. The VPP combines the solar power and storage batteries that are distributed throughout the area and integrates them to control as a single power plant

4.1.3 Urban Planning Application, Estonia

The Urban Planning Application (UPA) in Estonia is a smart governance solution for city and transportation planning that is currently under development. The application intends to use smart phones as sensors. Phones can provide a substantial amount of data. For example, in a city with 1 million people, 0.25 billion location updates can be generated per day.[27] In contrast with static sensors, this provides more data which is of better quality. The application will then combine it with other spatial datasets and extensive data analysis tools. With such data, the benefits generated include the following:

- Data mining and different algorithms enable identification of correlations between different phenomena, evaluating citizens' mobility in various aspects and spatial resolutions
- It helps to identify the reasons behind different problems and bottlenecks in the urban space. It will help analyse the origin-destination matrix in a better way and provide insights to cater to the challenges faced in the smart city
- From a transport planning perspective, being able to answer where people come from, where they head to and why are they travelling are essential pieces of insight to improve public services. Essentially, simply counting people leaves many questions unanswered. In contrast, the ability to analyse indications such as aggregation, trajectory, intensity, circadian and seasonal variability are of great importance in the urban planning sphere

UPA is the result of a public-private-people partnership for establishing new ways to improve the inclusion of various public sector bodies, private entities, residents, NGOs and other civil agencies in planning processes. Importantly, the application aims to involve more stakeholders in the process of urban planning through improved digital participation and a more transparent urban planning process. The users would have fast and easy access to information about the ongoing planning processes and the possibility to comment and provide their own suggestions or proposals. The urban planners in Tallinn regard the new inclusive application as a valuable tool for getting feedback to redesign new public spaces.

A challenge for the UPA will be to provide sufficient assurance to citizens on data privacy and security. It will be crucial to enable the appropriate levels of trust so that citizens feel assured they can share their location and travel information, and that this data will be used for the benefit of the overall population while maintaining the anonymity of individuals.

[26] "SPINEX," *Toshiba*, www.toshiba.co.jp/iot/en/spinex, accessed September 2017.
[27] "Urban Planning Application," *ReachU*, www.reach-u.com/urban-planning-application.html, accessed September 2017.

4.1.4 Digital transformation of DEWA, Dubai

Figure 5: Using Microsoft HoloLens

Source: Dewa.

Microsoft HoloLens in power plants

The Dubai Electricity and Water Authority (DEWA) has adopted Microsoft HoloLens — the world's first self-contained holographic computer — for maintenance and operation of its power plants. With this project, DEWA aims to strengthen its position as one of the most innovative and efficient utility companies in the world. The program highlights DEWA's recent efforts to implement technology in its operations with the objective of having a more efficient cost control, reducing energy consumption and decreasing likelihood of incidents in its utility network.

The Microsoft HoloLens is a mixed reality technology that allows the user to engage with digital content while interacting with the hologram.[28] The user will be able to "fix" a hologram to a particular object or component of an asset while interacting with data using gesture, gaze and voice.[29] It is a relatively "easy-to-use" technology and should not take long for a new user to become competent in operating with it. Importantly, this technology will foster collaboration between different teams involved in the operation of assets. Even if the teams are in different locations, they are able to view and hold a discussion on a particular 3D model as if everyone is in the same location.

At DEWA, Microsoft HoloLens allows for the visualisation of the Smart Power Plant, providing an interactive 3D model for the plants' equipment and remote expert assistance, including access to maintenance job cards, equipment, training manuals and other operating procedures. It works just like an independent computer displaying information (such as graphs and statistics) on the assets while the user gets a 3D vision of its surroundings.

[28] "Microsoft HoloLens," *Microsoft*, www.microsoft.com/en-gb/hololens, accessed September 2017.
[29] "Microsoft HoloLens: Harnessing Mixed Reality," *CDM Smith*, cdmsmith.com/-/media/White-Papers/hololens-(1).docx, accessed September 2017.

Through virtual estimation relating to the remote maintenance of power plants, DEWA will be able to have faster technical decision-making and manage future demand, while improving energy efficiency and reducing power consumption. Furthermore, it can be used in confined spaces, such as combustion chambers, while continuously communicating with the entire team. The facility of communication will allow for easier and faster decision-making while carrying out maintenance and operation works.

The scenario visualisation, data-gathering and remote maintenance of DEWA's Smart Power Plant increased efficiency of the operate and maintain phase in this asset, culminating with a reduction in power consumption by as much as 30%.

Virtual reality for remote inspection

DEWA launched, in late 2016, a pilot project for the world's first VR remote inspection for utility maintenance. The project consists of remotely inspecting the electricity and water networks, making the inspection process faster, safe and more cost-effective. The project is aligned to the National Innovation Strategy and supports DEWA's vision to become a sustainable and innovative world-class utility organisation.

The robots will carry scanners and sensors while patrolling electricity lines and the data will be uploaded to SAP's cloud for analysis. The main advantage is that it eliminates the need for full-area visual inspection by a human expert, who can do the in-depth qualification remotely by using the technology, thus saving time and effort in the maintenance of high-voltage cables compared to conventional methods.

DEWA won the Smart City Initiative of the Year Award for a pilot project that combines autonomous robots with VR and IoT to remotely inspect high-voltage cables.

4.1.5 Virtual models in urban planning: case study comparison

Case study comparison

Project	Technology	Asset management life cycle				Benefits delivered
		Plan, Design, Build	Maintain, Operate	Service Provision	SFIP	
Virtual Singapore	Digital twin; big data; IoT	P	P	P	P	• More efficient and integrated urban planning • Preparation on how to respond to extreme scenarios (e.g., disaster management) • Public-private-academic collaboration to solve infrastructure problems
SPINEX	Sensing; analytics; IoT; edge computing	P	P			• Efficiency gains in operation and maintenance of assets • Reduced likelihood of human error
Urban Planning Application	Digital twin; IoT		P	P		• Collaboration between the Government and citizens to address infrastructure problems • High-quality data on city mobility
DEWA Digital Transformation	IoT; VR; sensors; mixed reality; 3D modeling		P			• Quicker maintenance of utility assets • More cost-effectiveness • Reduced likelihood of human error • Collaboration between different parties involved in operation and maintenance of assets

Table 5: Case study comparison on virtual models in urban planning

A key common benefit of the projects outlined in Section 4.1 has been the combination of different technologies to facilitate more efficient collaboration between different organisations and stakeholders that participate in planning, designing, building, operating, maintaining and using these assets. Historically, the management of infrastructure has suffered from the operation of different parties in silos and they not collaborating to ensure extraction of greater value from the existing asset base. Nonetheless, all of the abovementioned projects provide examples of how technology can support in increasing the availability and capacity, and improving the performance of the built environment.

Lessons learned and relevance to the UK

From the case studies described in Section 4.1, Virtual Singapore is the best far-reaching program that will most likely deliver significant benefits in terms of managing infrastructure more efficiently. There are a couple of points that are important to retain:

- **Main government sponsor:** Virtual Singapore is part of the Smart Nation initiative. This programme was established in 2014 with the objective of bringing together information and communication technologies, networks and data to address urban challenges such as ageing population, energy sustainability and urban density.[30] There is a clear sponsor that is promoting "Smart" projects throughout different governmental departments and allows for a coordinated approach in addressing urban challenges. In addition, there is a central budget dedicated to developing these initiatives throughout government departments. For instance, the 2017 government budget contains US$1.7 billion to be invested over four years in the development of information and communication technology tenders. These include a focus on data analytics, data centres and IoT sensors[31]. Having a clear sponsor and budget certainty over a number of years are important factors for the UK to have in consideration
- **Promotion of data sharing:** The Government of Singapore aims to agree on rules and standards for data sharing, and integration of data between government agencies. Achieving an integration of different information and communications technology (ICT) systems is expected to facilitate management of resources across different systems
- **Citizen engagement:** A common feature of Virtual Singapore and UPA in Estonia has been the involvement of citizens in the programs. Citizens have been given access to data on local services and an opportunity to provide feedback on government initiatives. By involving citizens in infrastructure projects from an early stage, it is possible to raise public awareness and acceptance of the programmes

[30] Sang Keon Lee, Heeseo Rain Kwon, HeeAh Cho, Jongbok Kim, Donju Lee, *International Case Studies of Smart Cities — Singapore* (Inter-American Development Bank, 2016).
[31] "Singapore government to partner industry to spark innovation and build capabilities in a Smart Nation," *Digital News Asia*, www.digitalnewsasia.com/digital-economy/singapore-government-partner-industry-spark-innovation-and-build-capabilities-smart, accessed September 2017.

4.2 Redeveloping public housing

4.2.1 Smart Yuhua, Singapore

What is the project?

In Singapore, with approximately 80% of households living in public housing, there is a strong need for the Government to manage its housing infrastructure in an efficient manner.

The Smart Yuhua project is part of Singapore's Smart Nation Program.[32] The Housing & Development Board (HDB) and IDA have been working on a pilot project for 9,000 residents in more than 3,000 flats of HBD's estate in Yuhua. The projects consist of introducing several "Smart" features to residents with the objective of improving quality of life. It aims to make the area more livable, efficient, sustainable and safe.

Once the pilot period is terminated, HBD aims to extend the smart solutions elsewhere, to more residents in more estates. The pilot should provide key insights on how citizens perceive these technologies and how they could be improved when deployed nationwide.

The technologies and solutions deployed focus on both flats and neighbourhoods, and include:

- **Home energy management system (HEMS) and water management systems (WMS):** These solutions aim to help residents save energy and water and lower their utility bills. It provides real-time information on energy and water usage. Further, it provides energy- and water-saving tips as well as alerts whenever there is some form of incident, such as a leakage. The table below provides a description of the price and services included in the utilities management systems

System	Price	Description
Utilities management system	~US$5.10 per month	Provides information for residents to make more informed decisions on their utilities management

Table 6: Product, price and description of the utilities management systems provided by M1 in Yuhua[33]

- **Smart electrical sub-meter and remote water meters:** The collection of water and energy usage and consumption patterns allow the local council to manage its resources more efficiently. It will also alert the local authorities in the event of an incident
- **Smart solar energy monitoring system:** This system monitors the performance of solar panels remotely and ensures they are functioning with no problem

Role of Government

The HDB is the statutory board of the Ministry of National Development responsible for this project. The pilot project falls under Smart HDB Town Framework, which aims to assess feasibility and cost–benefit of utilising smart home technologies before being implemented in other HDB estates. The project supports the Smart Nation program of Singapore.

Asset management capabilities

The installation of IoT-enabled sensors allows for a proactive, not reactive, maintenance and operation of city infrastructure assets. It enables utility operators and local authorities to focus efforts on ensuring that the assets are in optimal condition — through, for example, preventive maintenance — and provides for a "smoother" operation of infrastructure that results in a better service to citizens.

The Smart Yuhua project delivers benefits across the whole asset management life cycle:

[32] "Yuhua the First Existing HDB Estate to Go Smart," *Housing & Development Board*, www.hdb.gov.sg/cs/infoweb/press-release/yuhua-the-first-existing-hdb-estate-to-go-smart, accessed September 2017.
[33] "M1 supports Smart HDB Home programme with affordable Elderly Care and Utilities Management services for Yuhua residents," *M1*, www.m1.com.sg/AboutM1/NewsReleases/2016/M1%20supports%20Smart%20HDB%20Home%20programme%20with%20affordable%20Elderly%20Care%20and%20Utilities%20Mgt.aspx, accessed September 2017.
Note: M1 is a leading communications provider in Singapore.

- The Government is able to improve the planning, design and maintenance of public housing estates by aggregating household data, using analytics and computer simulation. Authorities are able to accurately measure energy consumption, waste production and water usage in real time. This data then allows for a better understanding of the built environment and, consequently, provides the ability to make better investment decisions going forward. These decisions will consider the impact that a change to an asset will have on the network of assets
- Smart applications and sensors contribute to more efficient management of utilities. These benefits are outlined below

What benefits will it deliver?

Smart Yuhua has delivered benefits across multiple areas as highlighted below:

- **Improved efficiency of utility distribution network:** A key benefit delivered by the IoT-enabled sensors has been the reduction of unaccounted (lost) water rates. Unaccounted water refers to clean water that is produced and then lost before reaching end-users. Sensors are capable of measuring the water flow rate and pressure of water, and identifying leakages by detecting noise made through leaks. Currently, Singapore's unaccounted water rate is circa 5%. As a matter of comparison, London, for example, has a 20% unaccounted water rate. Nonetheless, Singapore wants to achieve improved rates alike cities such as Tokyo, which has a rate of 3.2%.[34] In addition, the Public Utilities Board (PUB) has been replacing water pipes with more robust iron and steel pipes, which should reduce leaks and also contribute in making the water distribution network more efficient. The PUB plans to replace 75km of pipes over the next two years
- **More responsive to incidents in the network:** Greater availability of real-time data provides monitoring capabilities as the operator is able to react quicker to adverse conditions. Local authorities are now capable of detecting incidents more rapidly and respond to these immediately, thereby reducing any downtime or major water leaks
- **"Citizen-friendly" technology:** An initial trial of 10 households in Yuhua from October 2015 to April 2016 yielded positive responses and showed that the devices were "easy to use" and "non-intrusive." As a result, this will be a technology that is positively received by citizens
- **Greater cost control:** One in 10 households responded that the utilities management systems helped them track their utility bills more closely and led to cost savings of 10%–15%
- **Reduction of imported water:** Singapore imports approximately 10 billion gallons of water from Malaysia each year. By managing the network more efficiently, Singapore will be able to reduce the amount of water imported
- **Benefit across WOG:** Government agencies, including HDB, PUB, MOH/H, NEA and IDA, are working with industry players to develop and test smart home solutions in HDB estates. Therefore, the success of HDB-led projects is likely to have a scalable impact

Challenges to the success of the programme

While the Smart Home solutions were extended to all households in Yuhua at discounted rates, some of the participating households raised concerns over the possible high costs of implementing these solutions after the trial period. The Government has indicated that the pilot period serves to assess the usefulness of the services and determines at what point residents will be willing to pay for these technologies.

Also, HDB considers it challenging to explain the functional aspects and value of the systems to elderly residents and get their acceptance. Their acceptance is essential for the success of the initiative.

Lessons learned and relevance to the UK

- **Interdepartmental coordination:** Similar to Virtual Singapore, Smart Yuhua is part of the Smart Nation initiative, bringing together different governmental departments to work together on the development of "smart estates." Some of the departments working on Smart Yuhua include the Ministry of Communications and Information, PUB, Jurong Town Council, Ministry of Health, National Environment Agency and the IDA
- **Singapore as a "living lab":** Organisations such as technology providers and entrepreneurs have been invited to be part of the Smart Nation programme and use Singapore as a "living lab" to test innovative

[34] "More sensors to be installed in pipes to reduce water loss," *Channel NewsAsia*, www.channelnewsasia.com/news/singapore/more-sensors-to-be-installed-in-pipes-to-reduce-water-loss-9181986, accessed September 2017.

services and products. This has created an innovative and entrepreneurial environment for new ideas to be tested

- **Effective use of pilot projects:** Singapore seems to be particularly effective in using pilot projects before establishing a programme nationwide. Pilot projects provide the opportunity for authorities to examine the cost of implementation, the openness of citizens to new technologies and services, and to assess how useful these projects are. In addition, by examining these factors, it is possible to reduce the risk of the program being unsuccessful
- **Citizen engagement:** The Singaporean Government has used pilots, hackathons and conferences among other events to raise awareness on Smart Nation initiatives. Citizens have been able to experiment technologies and provide feedback prior to their nationwide deployment, which has been particularly important for new technologies to be positively received and adopted

4.3 Using AI for asset maintenance

4.3.1 AI-based MTRC Project, Hong Kong

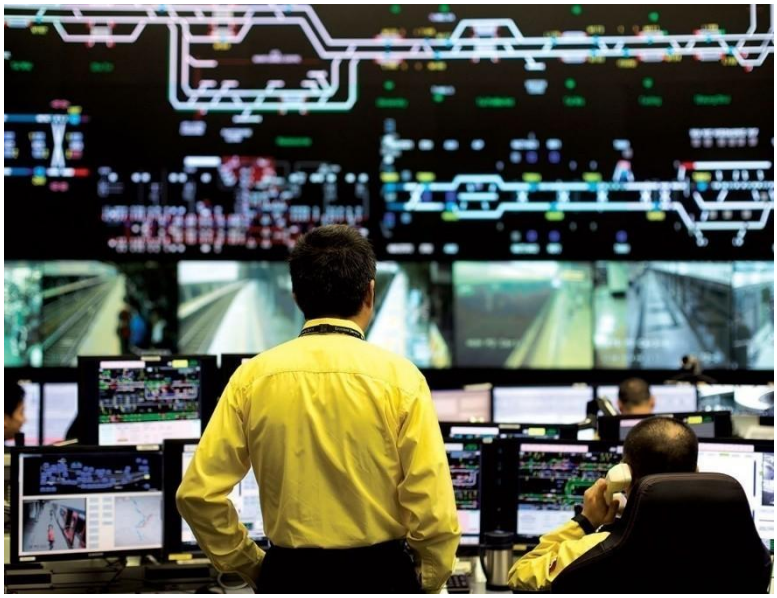


Figure 6: MTRC Control Centre

Source: New Scientist, The AI boss that deploys Hong Kong's subway engineers

What is the project?

The MTRC owns and operates the metro system of Hong Kong. Its total route length consists of 231km[35] and had 1.95 billion passenger journeys in 2016.[36] Hong Kong's metro is one of the busiest in the world and is regarded as one of the safest, most reliable and efficient metro systems.

Despite the number of passengers it transports on a daily basis, MTRC has been able to maintain a notable punctuality record, achieving 99.9% on-time trains in the three million trips made in 2016. The ability to maintain these high standards heavily depends on the capacity to perform engineering and maintenance works in an extremely efficient manner. This consists of maintenance of the lines, inspection and repair or installation works that take place in a very short period of time while trains are not operating at night. The time frame allowed for these tasks is typically four or five hours a day. Due to the short time frame, it is essential to schedule and plan these works to ensure safety and reliability of the metro service.

Previously, the scheduling of works was a manual process in which engineers would have to submit requests and meet with experts within other departments before making a decision on when to do the works. Consequently, this process was time-consuming and had significant exposure to human error.

In 2004, these works started to be planned and scheduled by the Engineering Works and Traffic Information Management System (ETMS) application. The ETMS system uses AI technology and is recognised as one of the most advanced systems in the world. It streamlines and automates quarterly planning and weekly scheduling of all engineering works across subway stations, making the process significantly more efficient. The algorithm-driven AI system typically ensures the coordination of 10,000 personnel and 2,600 weekly engineering projects. It monitors the entire subway line to determine critical maintenance tasks and directs the workforce according to the priority. Sensors along the tracks, switches and signals generate real-time data to assist in informed decision-making with effective IoT application.

An important fact to consider in the development of this AI system was that the knowledge of experts, who were responsible for the operations and maintenance of the subway network, was considered. The algorithm reflects a vast number of factors that are considered by experts in making a decision and formulating a set of rules.

[35] Note: Rail route length includes MTR, Airport Express and Light Rail services.
[36] "Business Overview," *MTR Corporation Limited*, July 2017.

In addition, MTRC's efforts in using technologies to improve their services do not stop here. In its Asset Strategy 2030, the company clearly states that it plans to use cloud computing, smart sensor technology and sophisticated analytics on its rail network.[37]

Role of Government

MTRC is a listed company in the Hong Kong stock exchange with the Government having a majority stake. The project was jointly led by MTRC and the City University of Hong Kong, who designed the AI system and helped MTRC build it into their network.

Moreover, the research conducted by the City University was partially supported by a grant from the Research Grants Council of Hong Kong Special Administrative Region, China and from the City University of Hong Kong.

Each year, the MTRC invests US$645 million in maintenance, upgrades and renewals of the metro network.[38]

Further, it is important to note that the Hong Kong Government has been investing in AI in a number of its governmental departments and services.[39] For instance, in hospitals, nurses' schedules are not created by AI.

Asset management capabilities

The AI technology used by the MTRC plays a key role in planning the operation and maintenance works of the metro network. It is a good example of the power AI may have in driving productivity in asset management making it a more efficient service with a reduced number of operational incidents.

In addition, the improvement in maintenance works and the reduction in incidents have helped enhance the condition of the rail lines and extend asset life.

What benefits did it deliver?

The AI engine has delivered several benefits as detailed below:

- **Efficiency gains:** MTR realized an improvement of more than 50% in overall maintenance efficiency contributing to the 99.9% on-time record of trains. Also, it eliminated preparation time (two days per week) of repair schedule, saving US$800 thousand a year. It also provided repair teams with an additional 30 minutes to complete nocturnal shifts. The system helped MRTC in optimal use of non-traffic hours, streamlined workflows, fastened amendments and track access[40]
- **ROI gains:** Effective maintenance and engineering works helped enhance asset conditions and extend asset life, providing a better ROI in assets
- **Long-term planning:** The ETMS helps in long-term planning, using up to one year ahead of the time of execution of the engineering works
- **Agility and scalability:** Since the AI technology is data-driven, it has the capability of adding new stations, new lines and new rules to the system. MTRC can rapidly adapt its maintenance operations when expanding the network. Hence, the AI system provides greater agility to cope with growth and scale its operations
- **Customer satisfaction:** With an impressive on-time record, a more efficient maintenance and operation of assets have resulted in a better service to its passengers
- **Safety:** The algorithm eliminates the possibility of error from human manual processes
- **Maximised resource allocation:** Streamlined workflows and more efficient processes provide MTRC with oversight of what tasks will be done and when. As a result, it gives room to more efficient resource allocation

[37] "Investing for the Future," *MTRC*, www.mtr.com.hk/en/corporate/sustainability/2014rpt/beyond-moving.php, accessed September 2017.
[38] "Hong Kong's MTR — Taking a ride on the world's most envied metro system," *CNN*, edition.cnn.com/travel/article/hong-kong-mtr-success-story/index.html, accessed September 2017.
[39] "Exclusive: Hong Kong's vision for Artificial Intelligence," *GovInsider*, govinsider.asia/smart-gov/exclusive-hong-kongs-vision-for-artificial-intelligence, accessed September 2017.
[40] "A.I. Controls Hong Kong's Subway Engineers," *Sourceable*, https://sourceable.net/a-i-controls-hong-kongs-subway-engineers, accessed September 2017.

Challenges to the success of the programme

There were several challenges faced by MTRC in the initial design of the AI system. It is important to acknowledge the complexity of the job of engineering works and how this role is "highly knowledge-intensive."[41] For instance, certain types of maintenance work may require the work to be done on or near the track, others may require supporting resources, such as wagons. Like this, there is an extremely vast number of factors that come into play when formulating the set of rules to be reflected in the AI system.

In 2007, MTRC merged with Kowloon-Canton Railway and took control of all railway lines in Hong Kong. With an increase in the number of trains, lines, stations and maintenance personnel, there was a need to redesign the AI system to ensure adaptation to these changes. Another redesign of the network was performed in 2011.

One of the challenges of the redesign was the integration of commuter lines, which were quite different in the manner they were operated and maintained. Differences that needed to be accounted by the AI engine include:

- **Power:** There is a need to allocate the overhead power lines. For the metro network, power is normally off during maintenance. On the other hand, for commuter lines, power is normally on
- **Permits:** A different set of permits were required to perform works in commuter rail lines. Therefore, the AI engine needed to ensure the availability of required level of resources to manage the power lines
- **Train paths:** With an extended number of trains and train lines, the AI engine will need to reflect any potential conflicts between train paths and engineering works to be performed on them
- **Scalability:** Considering MTRC's growing international presence, the company will have to consider the best way to scale this AI solution to other tracks around the globe

Lessons learned and relevance to the UK

- **Collaboration with academia:** MTRC's AI system is an example of where the Government of Hong Kong provided a research grant to the City University of Hong Kong. The collaboration between a transport operator and a university has proved to be highly successful with the development of a solution that has provided significant efficiency gains
- **Growing AI industry in the UK:** A recent UK Government report has estimated that AI could add an additional US$814 billion (£630 billion) to the UK economy by 2035[42]. It also identified a number of areas within infrastructure where it can be applied to deliver the following benefits:
    - More responsive and adaptive scheduling of transport
    - Better predictive maintenance of infrastructure
    - Better predictive rostering and responsive scheduling of staff resources
    - Better demand management in networks
    - Management of pay, payments and invoices

MTRC's use of AI highlights how this technology can be an important tool to provide solutions to manage infrastructure more productively. Importantly, it seems like the UK Government is focused on supporting the deployment of AI.

[41] Andy Hon Wai Chun, Ted Yiu Tat Suen, *Engineering Works Scheduling for Hong Kong's Rail Network. (Twenty-Sixth Annual Conference on Innovative Applications of Artificial Intelligence, 2014).*
[42] Professor Dame Wendy Hall and Jérôme Pesenti, *Growing the Artificial Intelligence Industry in the UK (GOV.UK, 2017).*

4.4 Urban transport and traffic control

4.4.1 Enterprise Command & Control Centre, Dubai

Figure 7: EC3 Control Room in Dubai

Source: The National — Dubai Ruler inaugurates RTA's Enterprise Command and Control Centre

What is the project?

Dubai's mass transit systems are on track to achieve 16% ridership of metro and buses in 2017 as opposed to only 6% in 2016. The Government's objective is for 30% of Dubai's residents to use public transport for their daily travel by 2030.[43] Dubai is committed to drive increased use of public transportation and has invested heavily in expanding the transport network and the services that come with it. The Enterprise Command & Control Centre (EC3), opened in May 2017, is one of the largest and most advanced urban control centres in the world. It costs around US$90 million, of which US$39 million was directed toward the development of technological systems and infrastructure.[44]

It was launched with the objective of monitoring Dubai's mass transit systems, including the Dubai metro, Dubai tram, marine transit, public buses and taxis. The centre uses "smart technologies" including AI and big data to monitor various traffic-related situations across the city — from accidents to crowd control — and links the Roads and Transport Authority's (RTA) operational agencies with a central, integrated system. The centre collects surveillance data from more than 11 thousand CCTV cameras that support in planning and coordinating the transportation network. It allows for direct, real-time access to the transport network and contains features such as 3D maps that allow one to zoom in to specific parts of the city, identify a vehicle and access if it's running late.

[43] "16% of Dubai residents will use public transport by the end of this year," Gulf News, gulfnews.com/news/uae/transport/16-of-dubai-residents-will-use-public-transport-by-the-end-of-this-year-1.1870711, accessed September 2017.
[44] "RTA's futuristic new command hub starts operations in Dubai," Khaleej Times, http://www.khaleejtimes.com/news/transport/rtas-news-command-centre-starts-operation-in-dubai, accessed September 2017.

The EC3 Control Room is linked with 34 other technological systems that are controlled by the RTA, and is capable of integrating with these in real time.[45] AI is used in automated identification of population density and provides appropriate directions in transit control. It also has the capability of reading movement behaviour from mobile phones using GSM technology. This enables the detection of human movements and identifies the spread of people, including locations with high density.

Further, EC3 acknowledges the challenges associated with collecting an array of data on the city's transport systems and has formed a cybersecurity team dedicated to ensure the security of data and operation systems. The system is capable of receiving 55 million data records per day.

Role of Government

RTA, an independent government transportation authority, has funded the development and operations of the EC3, and is being operated by them in Dubai.

This project is aligned with the Smart Dubai's vision of improving the quality of life of its citizens. Also, EC3 will be important in managing large crowds in major events in Dubai over the next few years (e.g., Dubai Expo 2020).

Asset management capabilities

The technologies used by the EC3 provide a vast amount of static and real-time data on the metro, tram, public bus, taxis and road network of Dubai. The Centre will provide capabilities that will deliver benefits across the maintain, operate and service provision phases of the asset management life cycle. Some of these capabilities are outlined below:

- **Decision-making:** The collection of data from an array of sensors, cameras and mobile devices as well as its processing through the use of big data analytics provides more information to support better decision-making. It is expected to enable operational decision-making that favours improved asset performance (e.g., reduced traffic and faster public transportation), improved asset utilisation and reduced service disruption
- **Planning:** It is expected that the EC3 will play an important role in the planning and organisation of mega events as well as planning for emergency and crisis situations

What benefits will it deliver?

Through establishing a centre to coordinate, plan and operate all transport systems in Dubai, the RTA has gained a capability in managing mobility of its citizens and addressing transportation challenges. The main benefits are outlined below:

- **Efficiency and operational gains:** The centre will help ease traffic congestions, reduce transit time and cost, fend off traffic accidents, and curb environmental pollution through adopting smart planning in addressing transport challenges of the Emirate
- **Faster response to emergencies:** The use of AI allows for faster decision-making. This is especially important under circumstances such as accidents and crises where fast response is crucial. AI and machine learning provide the capability of receiving voice commands and instantly entering these on the system, rather than the traditional way of printing commands. Machine learning will also reduce the likelihood of human error in coordinating an emergency situation
- **Origin-destination data:** The collection of information from citizens' mobile phones allows for the identification of the origin and destination of their journeys. This is particularly useful in understanding citizen journeys and combining it with transport planning
- **Better prepared for the future of transport:** With the emergence of autonomous vehicles (AVs) seen to occur in a nearby future, the technology capability of this centre makes it better prepared to adapt and empower self-driving transportation
- **Customer satisfaction:** Through better mobility and transport planning, citizens will experience more efficient transportation. By using live data, the Centre can communicate and interact with citizens

[45] "Sheikh Mohammed opens RTA's Enterprise Command and Control Centre," Emirates 24/7, www.emirates247.com/sheikh-mohammed-opens-rta-s-enterprise-command-and-control-centre-2017-05-23-1.653337, accessed September 2017.

Challenges to the success of the programme

The Government has a clear ambition of increasing ridership of public transport. Alongside, it has plans to extend and develop its current public transportation network. For instance, it aims to have a quarter of all cars driverless by 2030. In addition, it has in place a €2.6 billion plan for a 15km extension and seven stations for Dubai metro. These plans exemplify how major change and innovation will occur in Dubai over the next few years. The main challenge will be to understand how EC3 will be able to cope with this change.[46]

4.4.2 BlipTrack queue and flow measurement technology, Sweden

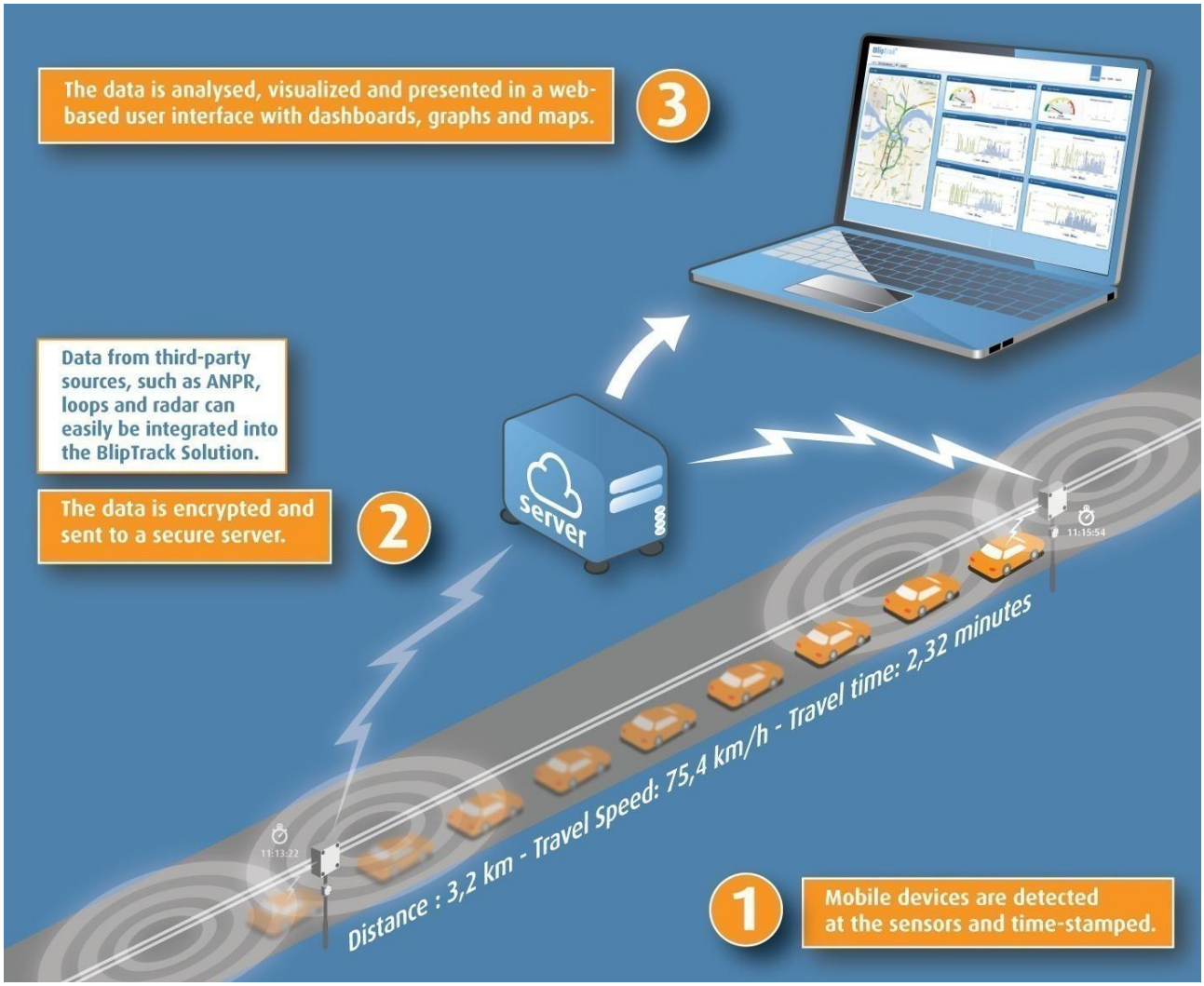


Figure 8: BlipTrack queue and flow measurement technology

Source: BLIP systems)

BlipTrack queue and flow measurement is a technology provided by the Danish company, BLIP Systems. BlipTrack sensors are installed along strategic road points of the Swedish capital, which then detect and connect with Bluetooth and Wi-Fi devices in phones and car communication systems. The technology detects and collects data from approximately 50% of all mobile devices in areas with slow-moving traffic, bicycles and pedestrians. Its implementation started in 2017 and is currently being deployed to more points around the city. BlipTrack can easily be integrated with other systems that are in current use by local authorities by using the various data output facilities.

Data generated provides detailed information on travel times, average speed and movement patterns. Importantly, it allows for live updates on the road network and provides the capability to examine the impact of

[46] "Major extension upgrade for Dubai metro," Khaleej Times, www.khaleejtimes.com/news/transport/major-extension-upgrade-for-dubai-metro, accessed September 2017

traffic control, weather-related patterns, congestion patterns during roadworks, accidents and events, and driving behaviours.

Both local authorities, who control the road network, and commuters can benefit from data generated by BlipTrack. Information is accessible to any individual on the web and allows for more efficient journey planning. Live updates are also placed on electronic signs placed around the city.

Figure 9 below depicts how the platform is "user-friendly" and allows each user to customise the analysis platform with the type of data that is most adequately suited for the purpose.

Figure 9: BlipTrack analysis platform

Source: BLIP Systems

Moreover, it is important to note that this technology has already been deployed in certain locations in the UK:

- **The Port of Dover**, Europe's busiest ferry port, has BlipTrack installed to reduce bottlenecks and improve vehicle movements by predicting potential traffic congestion areas. BlipTrack provides the port authority with live data while vehicles are boarding ferries, helping improve traffic flow, and also identifies eventual incidents during the boarding process[47]
- **UK airports of Bristol, Edinburgh, Manchester and Birmingham** are implementing BlipTrack for queue management. The technology accurately measures queues and waiting times.[48] This data is then used to support the airports with resource planning and inform passengers of current waiting times. BlipTrack provides important data to airport authorities by informing of when passengers arrive, where they travel within the airport and when they leave. This piece of data provides important insight to the authorities in understanding their passengers' behaviours in detail and improving the service provided

4.4.3 Intelligent Transport System, Hong Kong

Hong Kong's ambition to be "Asia's World City" has driven government support on several programmes to boost its competitiveness, such as a leading transport system. Hong Kong's roads are built on hilly terrains and are among the busiest road networks in the world. Also, it is not economically and environmentally viable to continue expanding the road and railway transport infrastructure. Therefore, there is a strong need and focus to maximise capacity and enhance the performance of the existing transport system.[49]

The project was initiated by the Transport Department of Hong Kong Special Administrative Region (HKSAR) in partnership and collaboration with the private sector, academia and professional institutions. The systems are being operated and owned by the Transport Department.

[47] "Mobile technology helps streamline Europe's busiest passenger port," Port of Dover, www.doverport.co.uk/about/news/mobile-technology-helps-streamline-europes-busie/13095, accessed September 2017.
[48] "Birmingham joins UK airports using sensors," ADS Group, www.adsgroup.org.uk/news/member-news/birmingham-joins-uk-airports-using-sensors, accessed September 2017.
[49] "Intelligent Transport Systems," Transport Department, www.td.gov.hk/en/transport_in_hong_kong/its/introduction/index.html, accessed September 2017.

Intelligent Transport System (ITS) is a multi-phased programme that started in 2001 with an initial investment of around US$420 million and further US$380 million in traffic control systems in 2006 to be invested over 10 years.[50]

Various sensor-based equipment supports the Transport Department in traffic management, and commuters with their journey planning. The programme includes several advanced technologies such as Speed Map Panel Displays, Journey Time Indication System and Driving Route Search Service (DRSS) supporting the Transport Department in managing traffic and providing value-added transport services to citizens. The system is built on technologies including spot speed detector, automatic vehicle identification (AVI) detector and Radio-frequency identification (RFID)-based detectors:

- **Speed Map Panel Displays:** Each panel comprises a series of schematic speed map display and journey time indicators, established at critical diversion points of strategic routes. Panels are updated every two minutes and the routes are represented with different colours defining traffic congestion
- **Journey Time Indication System:** This system provides journey time information of different cross harbour routes and assists motorists to make informed route decisions beforehand
- **DRSS:** The eRouting provides driving route, real-time traffic condition and parking information for pre-trip planning

4.4.4 Next-Generation Electronic Road Pricing (GNSS/CN) System, Singapore

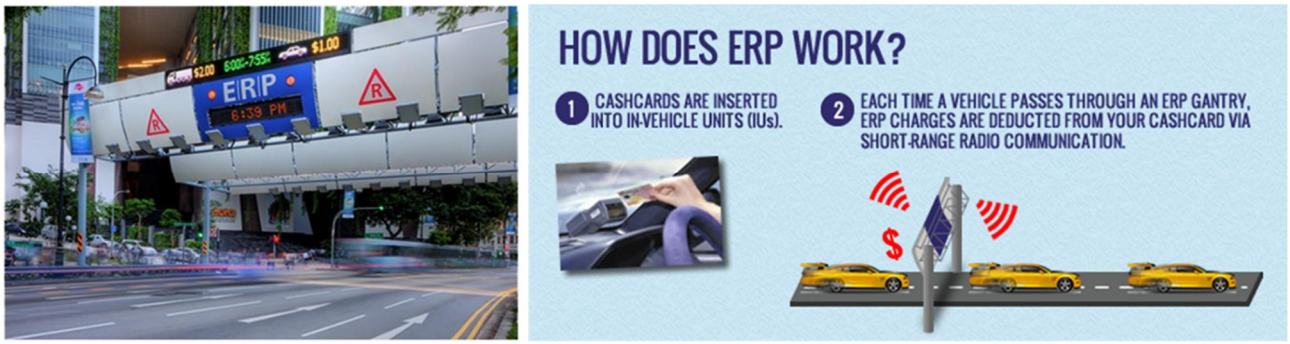


Figure 10: Illustration of how the current ERP system works

Source: Land Transport Authority

Singapore's Transport Minister recently highlighted the country's objective to increase trips made by public transport from 65%–70% today to 75% by 2030 and 85% by 2050.[51] The Government's ambition emphasises its intentions to limit car usage and incentivise the use of public transport.

The Electronic Road Pricing system was first deployed in 1998 and is used to manage traffic. It is based on a pay-as-you-use principle in which motorists will be charged when using roads during peak hours. The rates charged will vary across different roads and according to the time of the day. The rates are adjusted according to traffic conditions. The pay-as-you-use principle acts as an incentive for citizens to change their mode of transport, travel route or time of travel according to current congestion conditions.

Initial implementation cost	US$147 million
Initial operation and maintenance cost	US$12 million
Initial revenue per year	US$59 million

Table 7: Cost and revenue data for the ERP system in 1998[52]

[50] "Hong Kong Intelligent Transport System," Road Traffic Technology, www.roadtraffic-technology.com/projects/hong-kong/, accessed September 2017.
[51] "To be car-lite, be road-lite too," Straits Times, www.straitstimes.com/singapore/transport/to-be-car-lite-be-road-lite-too, accessed September 2017.
[52] "The Case for Electronic Road Pricing," ASIA Development, www.development.asia/case-study/case-electronic-road-pricing, accessed September 2017.

The price charged to each vehicle will depend on the passenger car unit (PCU) equivalent, location of the gantry and time of entry into a particular restricted zone. Those vehicles that are bigger and take up more road space are charged higher rates as detailed in the table below.

Prior to the deployment of the ERP system, research by the Nanyang Technological University concluded that optimal traffic throughput would be achieved through a range of speeds where traffic flow more efficiently, and not necessarily in higher average speeds. These optimal speeds vary according to the type of road. As a result, the ERP system is very adaptive and has 30-minute charging periods that will be updated every quarter. The rates will be changed according to average speed in a particular area. For instance, if the average traffic speed in an area has increased and is higher than optimal speed, then the rate is lowered.

Vehicle type	PCU equivalent
Cars, taxis and light goods vehicles	1.0
Motorcycles	0.5
Heavy goods vehicles and small buses	1.5
Very heavy goods vehicles and big buses	2.0

Table 8: PCU equivalent for each vehicle type

The benefits delivered by this system include the following:

- **Reduction of traffic in highly congested roads** by charging during peak hours
- **Optimisation of road network** by encouraging motorists to use alternative routes
- **Provision of a fair price:** This price reflects the usage of every motorist. Those who use the roads more frequently will be charged more. Further, those who travel during non-peak hours will be charged less or not charged at all. Fares will be reviewed on a quarterly basis after a thorough review of average traffic speed on ERP roads
- **Elimination of licences:** Previously, motorists had to buy licences to be authorised to travel in highly congested areas
- **Elimination of exposure to human error:** The ERP system is extremely reliable and operates on a 24/7 basis. The system ensures that gantries are always operating

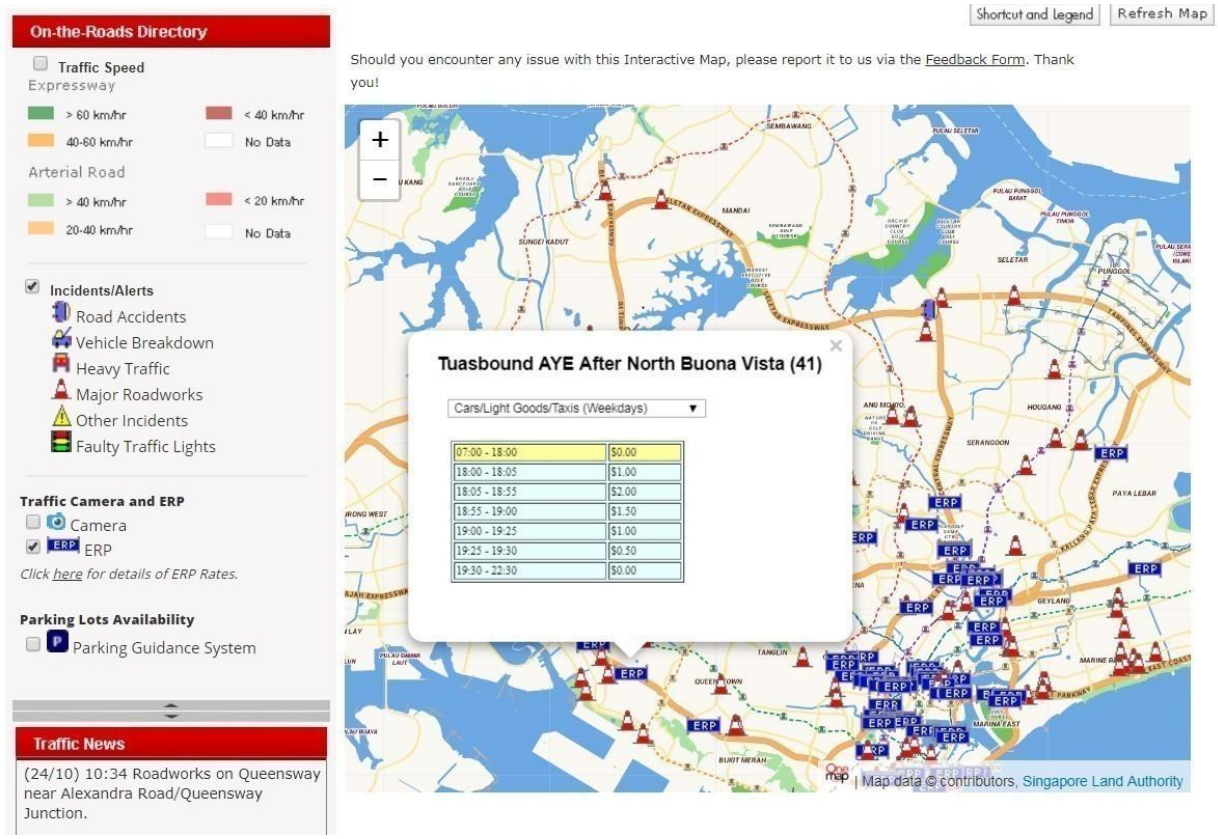


Figure 11: Prices for cars at set times at one Singapore ERP charging point.

Source: screenshot taken from the One.Motoring portal

ERP system based on Global Navigation Satellite System

Global Navigation Satellite System (GNSS) is the next-generation ERP system and will be operating from 2020. Singapore's Land Transport Authority (LTA) appointed NCS Pte and Mitsubishi Heavy Industries as the providers of the new system in 2016. The new system will gradually substitute the previous ERP technology that was first deployed in 1998. Operating and maintaining the previous ERP system was expensive. The GNSS ERP will allow for improvement from the previous system and is planning to offer additional services to citizens.

The existing In-Vehicle Unit (IU) will be replaced with a new On-Board Unit (OBU). The new OBU is yet to be designed but it will most likely look like a smartphone. Its features include the following:

- The OBU will send positioning and transaction details to the central system administered by the LTA via GNSS
- Motorists will be charged according to the distance travelled on congested roads
- It removes the need for physical gantries
- It will allow for the provision of services such as traffic information according to driver's location and offer the possibility to pay for parking or tools

This project is directed by the LTA, a statutory board under the Ministry of Transport of Government of Singapore. Alongside the project cost of around US$400 million, the Government will also bear the one-time IU replacement costs for Singapore-registered vehicles. Moreover, the project supports Singapore's Smart Nation plan.

4.4.5 Urban transport and traffic control: case study comparison

Case Study Comparison						
Project	**Technology**	**Asset management life cycle**				**Benefits delivered**
		Plan, Design, Build	**Maintain, Operate**	**Service Provision**	**SFIP**	
EC3	AI; big data; 3D mapping		ü	ü		• Operational efficiencies • Faster decision-making • Preparation for future of transport (e.g., AVs)
BlipTrack queue and flow measurement	Sensing		ü	ü		• Availability of more data to both citizens and local authorities • Better understanding of traffic patterns
ITS	Sensing; AVI		ü	ü		• Live information for citizens to choose optimal route
ERP GNSS System	Big data; Sensing		ü	ü		• Reduced traffic • Incentivising motorists to use alternative routes • Provision of information to motorists and services (e.g., parking payments)

Table 9: Case study comparison on urban transport and traffic control

When examining urban traffic congestion, it is important to acknowledge its costs to each individual citizen and society:

- Loss of productive hours due to time spent in congested roads or transport routes
- Environmental pollution and adjacent health effects as well as fuel wastage

Often, the construction of more roads is potentially not the most beneficial option for a country's economy and society. Rather, the solution passes through operating the current road network more efficiently. The case studies discussed in Section 4.4 provide alternatives on how cities are managing their traffic flow. These include:

- Creating incentives for motorists to use public transport or alternative routes
- Informing citizens of the most efficient travel plan
- Responding quickly to incidents on the road network through the use of real-time data
- Connecting vehicles and citizens to a central management system
- Interacting with citizens to provide a better public service

" Behavioural change is a significant challenge area and one of the main barriers to smart transport. How do you get people to accept technology? How do you get people to use it?"

Senior Member — Connected Transport, Innovate UK

Lessons learned and relevance to the UK

- **Growing congestion in the UK cities:** This is giving rise to the consideration of initiatives to reduce car use, such as pay per mile schemes, city centre parking bans, vehicle-free days and car-free zones, all of which have been successfully implemented in other countries
- **Congestion pricing tends to be politically unpopular:** Motorists typically dislike any policies that limit the usage of their cars and will not readily accept these initiatives. However, provision of data to inform citizens and incentives for change behaviour can help achieve congestion reduction and result in better use of public transport
- **Health and well-being:** Encouraging walking and cycling to improve health and activity levels also improve air pollution through reduced car use

4.5 Smart city complexes

4.5.1 Busan Green u-City, South Korea

What is the project?

Busan is the second largest city in South Korea with a population of 3.4 million people, and is home to the country's largest port. In 2005, Busan started its journey toward becoming a "Smart City" with the Government's u-City (ubiquitous city) programme. The programme focussed on integrating next-generation technology with the city's built environment, including the port, transportation network, tourist sites and convention centres. The total investment in the program comprises US$320 million and is currently on its multi-stage implementation phase.[53]

Busan Green u-City has benefited from a successful collaboration with the local government, KT (one of South Korea's leading telecommunications provider), and Cisco (the technology provider). Each of these organisations has contributed their expertise in their respective fields to develop innovative solutions.

The programme has allowed for the development of technology and innovate services for the benefit of urban planning and management. The main components that sit at the centre of the Busan u-City are described below:

- **Mobile broadband:** KT's mobile broadband coverage has been a key enabler of the new cloud-based model. KT has allowed for a high-speed broadband coverage and bandwidth throughout Busan
- **Blueprint ecosystem:**[54]Cisco supported the Busan Metropolitan City in integrating ICT and services into existing city infrastructures with pervasive network connectivity. Both Cisco and the local government worked on developing the blueprint and business architecture. The blueprint ecosystem provides a means by which different stakeholders have easy access to a shared platform containing municipal data. It is based on a pervasive IP network combining next-generation broadband technologies. This network then supports a cloud infrastructure made up of an intelligent city management system called Integrated Operation Centre (IOC) and an application development platform called the Busan Mobile Application Centre (BMAC)
- **Integrated Operation Centre:** The IOC consists of a back-office centre that integrates city data. It integrates both private and public data collected from different sources. This includes traffic, facilities, offices and residential buildings and disaster prevention information. The IOC provides essential insight to operation managers and city planners
- **Busan Mobile Application Centre:** BMAC is an incubator of smart city services where organisations seeking to develop products or services for the city can apply to obtain support in terms of training, consultancy services and other resources. This has been a means to incentivise private entity involvement as well as innovation. The BMAC has turned into an important source of revenue for the city of Busan. In its first year of operation, 13 new businesses were established and the revenue of these businesses operating from the BMAC was US$2.2 million[24]
- **Data interoperability:** One of the essential aspects in the implementation of a u-City is data harmonisation and interoperability among data, services and service components

Role of Government

The Busan Green u-City programme is a successful example of public-private partnerships.

In the partnership between Busan Metropolitan City, Cisco and KT, all parties share both the costs and the risks of the project. The Busan Metropolitan Government provides financing for Busan Green u-City, and plans to recover its costs from both operational savings and new revenue streams.

[53] "Busan Green u-City — A successful example of a Smart City in South Korea," GSMA, www.gsma.com/iot/busan-green-u-city-a-successful-example-of-a-smart-city-in-south-korea, accessed September 2017.

[54] Tony Kim, Shane Mitchell, Nicola Villa, Smart+Connected City Services: Cloud-Based Services Infrastructure Enables Transformation of Busan Metropolitan City (Cisco, 2011).

Asset management capabilities

An important aspect of the Busan u-City is the fact that the IOC brings together city data from both public and private entities in an integrated platform. This allows local authorities to make coordinated decisions that can benefit the city in general. The benefits delivered are not only in the management of public assets but also private assets, as both types of entities have access to this information. It allows for more efficient planning of transportation enhancements, utilities planning and other social services.

What benefits will it deliver?

The programme has delivered a set of benefits across different areas. The most important ones are described below:

- **Public-private collaboration and innovation:** The provision of city data and having BMAC provide incentives and support for private entities to attempt to solve pertaining urban challenges. As a result, private entities are now providing a range of services that contribute to the well-being of citizens and sustainable management of Busan. Some of the services provided by private entities include digital signage and smart bus shelters or energy management services for commercial and residential businesses
- **Improved cost control:** The collection of city data and management of services in an integrated manner provides the means to have greater oversight on cost and, thus, have greater control over costs
- **Efficiency gains:** Through the use of extensive public data, the Green u-City operating centre (IOC) is expected to help the Busan city management to improve the use of resources, city logistics and waste management, thus reducing the operating costs for the city

Challenges to the success of the programme

There are two main challenge areas:

- Busan will need to continue developing innovative business models to ensure that new city services are profitable
- The initial focus on the business sector will need to be broadened in order to stimulate sufficient public support and ensure that new cloud-based services are adopted by the entire community

4.5.2 Songdo International Business District, South Korea

Figure 12: Aerial View of Songdo

Source: Business Korea

Songdo International Business district started development in 2003. It is a US$35 billion smart and sustainable city built from scratch in the region of Incheon.[55] It is an example of a large-scale city constructed with the objective of containing low-carbon infrastructure, having green areas to absorb carbon emissions and low-energy consumption infrastructure.[56] The project, developed by Gale International, aims to build an international business district over an area of more than 1,000 acres. City planners partnered with several technology companies, local service providers and government organisations in order to implement next-generation smart city solutions. The city has implemented sensors and IoT technology to gather data and analyse citizens' requirements.

Though Songdo is managed by a government authority, the Incheon Free Economic Zone (IFEZ), it is 100% privately owned and funded. Gale International owns a 60% share of the project while the large Korean steel company, POSCO, has a 30% stake, and the remaining belongs to Morgan Stanley Real Estate.

Songdo was built to attract foreign organisations to Korea and become a global competitive city. It has played a vital role in sustainable growth and is expected to become the centre of economic activity for the Northeast Asia region. This project has given developers the opportunity to invest heavily in technologies that are yet to debut in conventional cities. The city aims to be a hub for global companies, with employees from all over the world.

Some of the technologies deployed include:

- Using sensors to monitor temperature, energy use and traffic flow, thus facilitating the city functions
- Using IoT to deliver solutions directly to the people of the city

Some of the developments in Songdo are outlined below:

- **Transport:** Songdo uses technologies to provide innovative services throughout its transport network. These include, for example, a nighttime automatic power-saving function in which street and bus stop

[55] Songdo International Business District, www.songdoibd.com/about, accessed September 2017.
[56] Paul D. Mullins, The Ubiquitous-Eco-City of Songdo: An Urban Systems Perspective on South Korea's Green City Approach, Volume 2, Issue 2, pages 4–12 (Urban Planning, 2017).

lights will turn on and off according to the detection of movement. Songdo also has a traffic signal system that operates differently during peak and off-peak hours. During peak hours, the signals operate on a regular basis, while during off-peak times, they will vary according to the detection of traffic flow

Figure 13: Transport services provided in Songdo

Source: Inter-American Development Bank, International Case Studies of Smart Cities — Songdo)

- **Energy:** IoT sensors installed in houses and other buildings inform users of energy usage levels through a mobile application. The provision of this information enables users to benefit from energy savings. For example, citizens are able to switch their lights or heating on and off using their smart phones
- **Citizen interaction:** A mobile application allows local authorities to provide tailored information to each citizen
- **Emergency and response:** The collection of real-time data allows local authorities to rapidly respond to any emergency or disaster. Data collected is provided to emergency services including the Incheon Fire Department or the National Emergency Management agency
- **IoT cube:** The city has developed an IoT cube in collaboration with Cisco. It is being used by businesses and start-ups to pilot their developing solutions to the public on the street. This lab then gathers real-time data, feedback and analytics from citizens. The user feedback allows solutions to be placed back into the real environment
- **Waste disposal system:** The city has installed an underground waste disposal system that removes waste directly from citizen's kitchens and delivers directly to a processing centre via an underground network of tunnels
- The network that is being deployed in Songdo IBD is connecting all of the building subsystems together to save energy and is expected to help bring down the energy consumption in each building by 30%
- **Integrated systems:** The systems that are being developed will collect and store data through an integrated platform. This platform allows for distinct services such as administration, traffic, crime prevention, utilities or transport to be interconnected

Figure 14: Map of Songdo

Source: Songdo International Business District

4.5.3 Smart City Complex, Goyang, South Korea

Figure 15: Smart waste management system in Goyang

Source: Pulse News — LG Uplus starts internet of garbage in Goyang City

LG, the leading electronic and telecom multinational from South Korea, is working to develop a smart city complex in Goyang. This project will be based on IoT technologies. The project is aimed at building a model complex to contribute to the nationwide environment of IoT services. LG was appointed by the Ministry of Science, ICT and Future Planning.

Under the project, the city government is expected to cooperate with private businesses to address urban problems such as waste, security, environment, energy and transport. LG will source diverse sensors and devices designed for public services and apply them to urban problems. LG and the Government will open the public data collected from this initiative to support other similar projects elsewhere in South Korea.

Some of the developments of this complex include:

- **Bus stops:** More than 200 bus stops in Goyang will be equipped with environmental sensors that detect fine dust, exhaust emissions and noise in streets. Information collected will be communicated through a mobile network
- **Waste management system:** IoT sensors will be installed on the inside of the lid of trash cans on the city's main streets and in densely populated residential areas. These devices will be capable of recording the amount of trash held in each trash can. This data is expected to be shared with a control centre located in Goyang. Waste management operators will be able to access this information on their smartphones. Some of the important benefits are outlined below:
    - Reduced operational costs by eliminating unnecessary pick-ups, providing dynamic collection routes and schedules for a complete optimisation of collection operations
    - Transparency and increased operational effectiveness in the waste collection chain, reducing costs and labour associated with such services
- **Smart meters:** IoT technology is expected to be installed in water gas and electricity meters as a part of the smart meter initiative.

4.5.4 Smart city complexes: case study comparison

Case Study Comparison						
Project	**Technology**	**Asset management life cycle**				**Benefits delivered**
		Plan, Design, Build	**Maintain, Operate**	**Service Provision**	**SFIP**	
Busan Green u-City	Sensing; IoT		ü	ü	ü	• Provided means for private investment and innovation to address city problems
Songdo International Business District	Sensing; IoT		ü	ü	ü	• Use of sensors for optimal management of public services
Smart City Complex	Sensing; IoT		ü	ü	ü	• Use of sensors for optimal management of public services

Table 10: Case study comparison on smart city complexes

As outlined at the start of this report, the growth of urbanisation poses significant challenges in managing cities' infrastructure. Citizens increasingly demand for timely, accurate and accessible public services. With an ageing and saturated built environment, the emergence of new technologies provides an opportunity to address some of these problems.

The case studies outlined in Section 4.5 provide examples of how cities, citizens and public services can become increasingly connected and, most importantly, can interact to ensure that citizens and their quality of life is at the heart of urban infrastructure management. Sensors and IoT can provide the means to capture data that can be used by local authorities to improve the provision of services from their local or regional infrastructure, and serve to inform citizens. These technologies enable the optimisation of people, transport and logistics flows; help lower pollutant gas emissions; and improve return on investment.

> " We have a lot more bureaucracy in countries such as the UK when compared to others like Japan. In the UK, there is often a big gap between business and the Government.
>
> **Senior Member, Connected Transport, Innovate UK**

Lessons learned and relevance to the UK

Some of the interesting developments of the abovementioned case studies are the following:

- **Private-public-academic collaborations:** Local governments incentivising collaborations among private-public-academic institutions. This has been a way by which all parties can work together in solving an infrastructure problem by bringing in their expertise in their respective fields. For example, telecommunications and electronics companies Cisco, LG and KT provide their know-how in IoT and sensing, and leverage these technologies by developing solutions with local governments
- **Entrepreneurship and innovation:** Busan's BMAC has been a catalyst to attract innovation and start-ups. Importantly, this created businesses that provide services to local citizens and acts a source of revenue to the city. The collaboration between local authorities and service providers (e.g., utilities) with start-ups is an example of a process that could be taken to the Catapult program or the manufacturing technology Centres. While these might sometimes operate in isolation from local service providers, linking these up can be an important facilitator of innovation to improve infrastructure management and public service provision
- **Use of data:** All programs advocated the use of sensors and IoT to capture data on their built environment. This has allowed for precise and real-time monitoring of energy consumption and traffic flows. An essential point to acknowledge is how to motivate different service providers to share data among them. While some may have competitive concerns, the South Korea examples highlight that all parties may benefit from more data on the consumer as well as the built environment

Section 5

Conclusions and recommendations

5. Conclusions and recommendations

The table below provides an overview of the projects covered in this report.

Type of Project	Country	Project	Technology	Benefits and relevance to the UK
Virtual models in urban planning		**Virtual Singapore**	Digital twin; big data; IoT	• This platform provides information on a whole network of assets enabling more efficient planning and operation of a group of assets • It provides an understanding of the impact a change in one asset will have on the whole city or region • The benefits it enables are leveraged across the whole network
		**SPINEX**	Sensing; IoT; digital twin; edge computing	• SPINEX technology demonstrates how technology companies are developing digital twin technologies that enable more efficient asset management • It can potentially be a viable solution for large assets such as power plants
		**Urban Planning Application**	Digital twin; IoT	• It is an example of a public-private-citizen collaboration that can generate important data to help in transport planning
		**Digital Transformation of DEWA**	IoT; VR; sensors; 3D modeling	• The technologies demonstrated that it is a viable option to perform the maintenance of utility networks • Importantly, the technologies bring safety to the operators who carry out the maintenance works and they reduce the likelihood of human error
Redeveloping public housing		**Smart Yuhua, Singapore**	IoT; sensing; big data analytics	• Yuhua is an example of a regeneration of public housing by installing devices in flats and connecting the whole network • This project is an example relevant to solving some of the UK's public housing deficiencies
AI for asset maintenance		**AI-based MTRC Project**	AI; IoT; sensing	• MTR is already operating in the UK (and wasrecently awarded Elizabeth Line Concession)[57] • The efficiency gains from using AI in rail maintenance operations demonstrate that it is a viable option that can be applied throughout the UK rail network
Urban transport and traffic control		**Enterprise Command and Control Centre**	AI; big data; 3D mapping	• The technology that perhaps stands out the most in EC3 is the use of AI to manage different traffic situations • This has allowed for fast decision-making and a quicker response to incidents in order to ease traffic flow
		**BlipTrack**	Sensing	• It is a means of generating data by connecting to citizens' mobile devices • Data generated provides useful insights to both local authorities and motorists

[57] MTR: Europe Operations, www.mtreurope.com, accessed September 2017.

Type of Project	Country	Project	Technology	Benefits and relevance to the UK
		**Intelligent Transport System**	Sensing; AVI	• Similar to BlipTrack, the sensor network provides useful real-time data on the road network
		**Next-Generation Electronic Road Pricing**	Big data; sensing	• The most innovative piece of technology in this program is the OBU that is under development. • This will be a means to support traffic control as well as to provide services to motorists
Smart city complexes		**Busan Green u-City**	Sensing; IoT	• These South Korean examples have been successful in demonstrating how they have incentivized private-public-academic institutions • This collaboration has facilitated the application of innovative solutions to solve infrastructure problems
		**Songdo International Business District**	Sensing; IoT	
		**Smart City Complex in Goyang**	Sensing; IoT	

Table 11: Summary of short-list case studies and their relevance to the UK

Key considerations

Consideration	Observations
Collaboration	• One of the objectives of this study is to examine the role of government in supporting the deployment of technologies to increase the productivity of infrastructure. • A common theme to the projects studied has been the collaboration between private, public and academic institutions. • This has enabled each of these groups of stakeholders to share their expertise, consider a broad range of interests and collaborate to develop innovative solutions. • The UK already has the ingredients for successful collaboration through Catapults and business incubators. The opportunity exists to establish a focused programme of innovation activity that explores opportunities for the use of crosscutting technologies to improve infrastructure productivity. Such an initiative could help encourage greater cross-sector partnership and collaboration, and define new ways of thinking. • This approach has proven successful in other countries and could provide a blueprint to help different organisations work together in the UK. • South Korea provides a good example of how collaboration has driven the innovation of new solutions to solve infrastructure problems.
People and change management	• A key theme among the examined case studies is the development of platforms that bring together a number of different stakeholders. • This is often performed under the umbrella of a national “Smart” scheme to facilitate communication and visibility. • For example, the ‘Virtual Singapore’ programme places a key emphasis on reducing silos between governmental departments by making data available to everyone who requires it; allowing for collaboration between the parties operating the built environment; and delivering significant efficiency gains. • Whilst the UK has much of the delivery vehicle required for innovation already in place, the British public is potentially less accepting than far-eastern nations of the benefits that new technology can bring. This is particularly so when detailed domestic and personal service usage data is required. A significant amount of change management and public education is required, led by government, to portray the benefits of data-driven infrastructure and the role the public has to play in making it happen.

Value of sharing data	• Another key observation is that significant benefit arises from the use of data across multiple life cycle stages. The value of data is increased through its accessibility, interoperability and application to different stakeholder groups and users. • The Smart Yuhua project in Singapore provides an example of data collection across a network, which is then used to inform better planning and design, better maintenance and operation, and better household cost management for citizens. • Virtual Singapore provides information on a whole network of assets, enabling more efficient planning and operation of a group of assets. • Accompanying the deployment of some of the programmes covered in this report, such as Virtual Singapore or the u-Cities in South Korea, is the establishment of data standards by these governments to enable interoperability between data and services. • Promotion of the benefits of data sharing have also supported these programmes.
Safety	• Technologies such as AI and virtual reality (VR) provide viable options in maintenance operations, improving the safety of maintenance operatives and reducing the likelihood of human error. • Dubai's Digital transformation of DEWA provides an example of AI application within utility network maintenance. The use of AI has allowed DEWA to reduce the number of man-hours on site, ensure safer operation of assets and improve the cost-effectiveness of maintenance activities. • AI-based Mass Transit Railway Corporation (MTRC) project in Hong Kong employs AI to streamline and automate the planning of engineering works across the rail network. The use of AI eliminates the possibility of error from human manual processes. • Enterprise Command & Control Centre (EC3) in Dubai uses AI to manage traffic situations and enable faster decision-making and quicker accident response times.
Investment business model	• Blockchains and distributed ledgers have the potential to eliminate intermediaries across the asset management life cycle and, thereby, reduce administrative expenses. • Blockchain-based transaction platforms are applicable to the infrastructure sector in multiple areas, from enabling smart contracts to eliminating paperwork and creating payment transparency for provision of goods and services throughout the supply chain.

Recommendations

1. **Recommendation 1:** The UK has developed a set of initiatives to foster innovation in the infrastructure sector. These include the Infrastructure Challenge Fund, the Catapults programme and Manufacturing Technology Centres. In order to optimise the use of these initiatives there is opportunity to promote collaboration between innovative technology companies and public service providers.

   Developing focused programmes and initiatives, which highlight opportunities for the use of crosscutting technologies to improve infrastructure productivity, would help to encourage greater cross-sector partnership and collaboration and define new ways of thinking.

   For instance, a utility provider could collaborate with one of the Manufacturing Technology Centres in developing a new solution for one of its infrastructure challenges. It will be necessary to define the role of government and the NIC in fostering the cross-sector collaboration.

2. **Recommendation 2:** From the case studies outlined in this report, it is evident that public engagement and acceptance are key enablers to the success of technology programmes. It is necessary to consider the differences in public behaviour and political environment of Asian nations such as Singapore, when compared to that of the UK.

   Placing citizens at the centre of a programme and providing the opportunity for citizen participation in the development stages is a recognised enabler of success. The UK Government can support this engagement through promotion of benefits and success stories from programmes.

   In addition, it is important for the UK Government to have a proactive approach, helping set the stage for greater public support. For example, Singapore has been particularly successful in promoting Smart City projects through the use of roadshows and pilots. These initiatives were key to raise awareness about programmes prior to their deployment nationwide.

3. **Recommendation 3:** The Smart Nation programme in Singapore or the u-City programme in South Korea provide examples of initiatives that span across governmental departments. These programmes have been provided with budget certainty for a number of years, act as clear sponsors for innovation in cities and drive the programme forward across the government departments. An umbrella of “Smart” scheme can support promotion and visibility of UK projects, improving visibility of objectives and outcomes to the wider public.
4. **Recommendation 4:** A central theme across the case studies covered in this report is the collection of real-time data from infrastructure, service provision and citizen behaviour. Key points for the UK Government to consider are driving data standards and data integration across sectors and promote the value and benefits of data sharing. For some categories of data, the Government should also consider mandating data standards rather than just promoting.

Section 6

Appendix

6. Appendix

6.1 Appendix 1: List of countries

Country	Geographic, political and economic context	Government intervention
1. Estonia 	• Since Estonia's independence from the Soviet Union in 1991, the country has moved to become one of the "most internet-dependent countries in the world."[58] • With limited resources to set up a new government, Estonia decided to invest in innovation and technology to develop its public services • The use of ICT was seen as a way to connect people as well as to save time and resources	• Estonia has implemented a series of policies that focus on the deployment of technology to connect people, generate data and manage public services and buildings • The Estonian Cluster initiative brings together private and public entities to work together in a specific idea within various fields. Examples include the Digital Construction and the Smart City Cluster[59] • The Smart City Cluster brings together businesses, citizens, public authorities, R&D institutes and structures that support innovation and the use of technology in Estonian cities.[60] It provides the means to pilot new technologies and then deploy and scale them (if successful) in towns and cities of Estonia
2. France 	• Nearly 80% of France's population lives in urban areas and, hence, the Government has defined the development of smart solutions to manage its cities as a priority[61] • Being one of the world's most advanced economies, France invests heavily in innovation and technology to manage its infrastructure.[62] For example, France is a leading nation in terms of R&D expenditure in smart grids — €505 million investment ahead of €490 million in the UK and €360 million in Germany	• France has benefited from both public and private programs to drive the use of technology to manage infrastructure • For years, the French Government has promoted programs around Smart Grids and Smart Cities • The EU identified 240 smart cities in Europe in which 31 are located in France, compared with an average of 9.6 cities per EU member state • Several French companies are pioneers in the smart city industry (e.g., Veolia, Suez Environment, EDF, Engie, Vinci, Atos, Schneider Electric)

[58] "How Estonia became E-stonia," BBC News, www.bbc.com/news/business-22317297, accessed September 2017.
[59] "A cluster — why and for whom?" Estonian Clusters, www.estonianclusters.ee/textpage, accessed September 2017.
[60] "Smart City Cluster," Estonian Clusters, www.estonianclusters.ee/estonian-clusters-2/smart-city-e-and-m-services-cluster-2, accessed September 2017.
[61] "Urban Population," The World Bank, www.data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS, accessed September 2017.
[62] "Doing Business in France: Smart grids and smart cities in France," Business France, October 2016.

Country	Geographic, political and economic context	Government intervention

3. Hong Kong 	• As one of world's top financial centres, Hong Kong has a strong ambition to be "Asia's World City."[63]
	• Aligned to this goal is its purpose of being a competitive global city, a business hub, a top financial centre and an attractive tourist destination in the region
	• The Government acknowledges the need to have a world-class infrastructure to fulfill the following:
	  • The requirement of developable land to meet the needs of a growing population
	  • Establishment of effective transportation links through air, rail, road and water
	  • Improvement of quality of life to its citizens
	  • Increased environmental challenges
		• Hong Kong 2030+ outlines a strategy to guide planning, land and infrastructure development
		• In 2017, US$500 million will be invested in the Innovation and Technology Fund for Better Living in 2017 to subsidise innovation and technology projects, which will bring more convenient, comfortable and safer living to its citizens[64]
		• There are works to develop a Common Spatial Data Infrastructure (CDSI) to provide both public and private entities with spatial data on the built environment
		• Hong Kong is using the district of Kowloon as a pilot area to experiment various new developments. Technologies such as sensors and IoT are being used for trails around pedestrian and vehicle traffic management[65]

4. Japan 	• Japan's geographical location is in an area characterised by mountains, restricted constructible land, an earthquake-prone region and limited natural resources. This means that its geography poses significant challenges to its economy
	• Nonetheless, Japan is globally recognized for its high level of modernisation, which has been achieved by making efficient use of its limited resources, developing infrastructure that is resilient enough to cope with events such as earthquakes, and developing significant technological expertise
		• The Japanese Government initiated its investment in Smart City projects in 2010. These include, for example, deployment of the following:[66]
		  • Smart Energy Grid that has provided greater stability and reduced power outages
		  • Sensors and GPS data to monitor risks against disasters
		• In 2015, the i-Japan Strategy was launched, which focuses on bringing digital technologies to several aspects of society and the economy. The program considers areas such as the development of infrastructure and technologies to motivate the use of digital information[67]
		• Additionally, the upcoming 2020 Olympic Games is considered as an opportunity for authorities to rethink on how the built environment is managed and operated, as well as bring a substantial number of new infrastructure projects

[63] "Hong Kong 2030+: Towards a Planning Vision and Strategy Transcending 2030," Hong Kong 2030+, October 2016.
[64] "We Connect for Hope and Happiness," Hong Kong Government — The Chief Executive's 2017 Policy Address, 2017.
[65] "Research Report on Smart City," Government of the Hong Kong Special Administrative Region, Central Policy Unit, September 2015.
[66] "Smart Cities in Japan," EU-Japan Centre for Industrial Cooperation, October 2014.
[67] "i-Japan Strategy 2015: Striving to Create a Citizen-Driven, Reassuring & Vibrant Digital Society," IT Strategic Headquarters, July 2009.

Country	Geographic, political and economic context	Government intervention

5. Singapore 	• Singapore is one of the most densely populated countries in the world and has limited natural resources (e.g., no energy deposits). Therefore, its geographic location poses significant challenges to its built environment[68]
	• Singapore has become one of the main financial centres in the world. To sustain this status, it has been forced to continually revisit its policies to ensure that they meet livability, environmental sustainability and economic competitiveness standards
	• Its small island location has forced authorities to take measures to manage its infrastructure through, for example, imposing traffic restrictions and rethinking where to locate services such as waste treatment plants and power stations
		• In order to face its geographical challenges, productivity and technology enablement have been identified as two areas of investment by the Government
		• A number of programmes have been developed in the last few years:
		  • Smart Nation program was launched in 2014 in which technology developers have been invited to use Singapore as a "living lab" to try out new ideas
		  • The Building and Construction Authority (BCA) has developed a construction and productivity R&D road map that aims to develop and deploy new technologies in the sector

6. South Korea 	• Over the last few decades, the fast-growing information and communication technologies sector in Korea was accompanied by a set of governmental policies to use technologies to manage its built environment
	• The Korean Government brought together ganisations from distinct sectors to work together on some of the country's infrastructure challenges[69]
		• The Government's u-City (ubiquitous city) programme focusses on integrating next-generation technology with a city's built environment
		• Circa 20 local administrations are working on u-City projects in conjunction with Korean telecommunication companies, the Korea Land Corporation and the National Housing Corporation[70]
		• Almost every aspect of public life in Seoul is guided by technology — from its integrated public transport system to the Government's emergency warning system
		• The city has transformed itself with its Smart Seoul 2015 Plan that focuses on areas such as:
		  • ICT infrastructure: Including Smart devices for all, u-Seoul Safety Service and smart metering project
		  • Integrated city management framework: Government- or municipal-developed services such as online reservation system for public services, promoting Open Governance 2.0, etc.

[68] Sang Keon Lee, Heeseo Rain Kwon, HeeAh Cho, Jongbok Kim, Donju Lee, International Case Studies of Smart Cities — Singapore (Inter-American Development Bank, 2016).
[69] Yeon Mee Kim, Hyun Soo Kim, Soo Young Moon, So-Yeon Bae, "Ubiquitous Eco-City Planning in Korea. A Project for the Realization of Ecological City Planning and Ubiquitous Network Society," REAL CORP 2009.
[70] "U-City — New Trends of Urban Planning in Korea," Urban and Regional Innovation Research, www.urenio.org/2010/09/26/u-city-new-trends-of-urban-planning-in-korea, accessed September 2017.

Country	Geographic, political and economic context	Government intervention
7. Sweden 	• The Swedish Government is making its largest investment to date on infrastructure • Plans include €64 billion on railways, roads and other major projects, and €150 billion on housing and offices until 2030. Part of these funds are directed toward improving the operation, maintenance and reinvestment on its current asset base[71]	• A recent bill passed by the Government — "Infrastructure for the future" — focuses on innovations to strengthen the country's competitiveness and achieve sustainable development[72] • It considers sectors such as transport, where it aims to deploy new technologies such as digitization and automation to achieve a more intelligent use of its assets and decrease the burden on the transport system • The Smart Built Environment program is another initiative that focuses on deploying applications including GIS and BIM. The program's objectives are to: reduce the environmental impact by 40%; reduce planning and construction time by 33%; reduce total construction costs by 33%; and enable new business logic in the built environment sector
8. UAE 	• Dubai has an aspiration to become one of the world's forefront cities in regards to resilience, sustainability and interaction with its citizens and has, accordingly, developed programmes to foster this development	• The Dubai Plan 2021 addresses the urban environment, including built and natural assets as well as the quality of life of citizens. Its initiatives focus on six areas including the development of a "Smart and Sustainable City," in which it aims to deploy technology for the development of an integrated and connected cities where its infrastructure can achieve "world-class levels of efficiency."[73] • Recently, Dubai has been appointed as one of the nine local data hubs for the WCCD.[74] This commitment entitles gathering standardised and comparable city data • Joining this initiative from the WCCD is aligned with Dubai's ambition to develop a "smart city" with technologies that can improve how the city functions • Dubai Future Accelerators program has a US$ 275 million fund to bring 30 of the best start-ups around the world to work on its most significant public problems.[75] This initiative highlights Dubai's efforts in fostering innovation to solve challenges in its public infrastructure

[71] "Infrastructure & construction in Sweden," Business Sweden, www.business-sweden.se/en/Invest/industries/infrastructure-and-construction, accessed September 2017.
[72] "The right investments in transport infrastructure build a strong and sustainable Sweden for the future," Government Offices of Sweden, http://www.government.se/articles/2016/12/the-right-investments-in-transport-infrastructure-build-a-strong-and-sustainable-sweden-for-the-future, accessed September 2017.
[73] "Dubai Plan 2021, Government of Dubai, www.dubaiplan2021.ae/dubai-plan-2021, accessed September 2017.
[74] "Dubai stimulating a new data economy," Vision, www.vision.ae/innovation-learning/dubai-stimulating-a-new-data-economy, accessed September 2017.
[75] "Dubai Has $300 Million To Entice The World's Best Start-ups To Its Accelerator," Forbes, www.forbes.com/sites/elizabethmacbride/2016/12/29/dubai-has-300-million-to-entice-the-best-startups-to-worlds-fastest-rising-city/#17a11ae758e4, accessed September 2017.

6.2 Appendix 2: Potential efficiency benefits range per service category

Category	Country	Project name	Sector	Saving description	Saving %
AI for asset management	France	Urban Environment Monitoring (UEM) Project	Energy, water and wastewater, transport	Improved efficiencies	10.0%
AI for asset management	Hong Kong	Distributed Ledger Technology (DLT) for Mortgage Loan Application — Proof-of-concept	Digital infrastructure	Improved efficiencies	50.0%
AI for asset management	Hong Kong	AI based Mass Transit Railway Corporation (MTRC) Project	Transport	Improved efficiencies	50.0%
AI for asset management	Indonesia	Early Flood warning system	Flood management	Increased flood forecasting accuracy	90.0%
AI for asset management	Japan	Distributed ledger technology (DLT) pilot	Digital infrastructure	Reduced fund transfer costs	90.0%
AI for asset management	Japan	i-Construction campaign	Construction	Increased productivity of trade workers	50.0%
AI for asset management	Singapore	PoPSeCo: Power Plant Security by Advanced Sensing and Computing	Energy	Reduced equipment cost	90.0%
AI for asset management	Singapore	Planning for Land Transport Network (PLANET) project	Transport	Improved efficiencies	67.0%
AI for asset management	UAE	Dubai 3D Printing Strategy	Infrastructure	Reduced labour	70.0%
AI for asset management	UAE	Dubai 3D Printing Strategy	Infrastructure	Reduced cost	90.0%
AI for asset management	UAE	Dubai 3D Printing Strategy	Infrastructure	Reduced time	80.0%
Public housing	France	Urban Environment Monitoring (UEM) Project	Energy, water and wastewater, transport	Net cost savings	10.0%–20.0%
Public housing	Singapore	Smart Nation program-Smart Yuhua Residential Estate project pilot	Energy, water and wastewater, solid waste	Cost savings	10.0%–15.0%
Public housing	Singapore	Intelligent Energy System (IES) program — Pilot	Energy	Reduced energy consumption	5.0%
Public housing	Singapore	Planning for Land Transport Network (PLANET) project	Transport	Cost savings	19.0%
Public housing	Sweden	GrowSmarter project — Smart energy-saving tenants	Energy	Increased energy savings	5.0%–15.0%
Public housing	Sweden	GrowSmarter project-Smart LED-street lights	Transport	Reduced energy consumption	50.0%
Smart City Complexes	Japan	Japan Smart City Pilot	Energy	Reduced electricity demand	4.2%–7.2%

Category	Country	Project name	Sector	Saving description	Saving %
Smart City Complexes	Japan	Japan Smart City Pilot	Energy	Energy savings	45.9%
Smart City Complexes	South Korea	Smart Garbage Cans and Swipe cards	Waste management	Reduced food waste	20.0%
Smart City Complexes	Sweden	GrowSmarter project- Smart waste handling	Solid waste	Reduced waste collection traffic	90.0%
Urban transport and traffic control	France	Connected Boulevard-Pilot	Energy, transport	Reduced traffic congestion	30.0%
Urban transport and traffic control	France	Connected Boulevard-Pilot	Energy, transport	Increased parking income	35.0%
Urban transport and traffic control	France	Connected Boulevard-Pilot	Energy, transport	Reduced air pollution and noise levels	25.0%
Urban transport and traffic control	France	Urban Environment Monitoring (UEM) Project	Energy, water and wastewater, transport	Reduced air pollution	15.0%
Urban transport and traffic control	France	Face-recognition software at Charles de Gaulle airport	Transport	Reduced waiting times	20.0%
Urban transport and traffic control	Netherlands	National Data Warehouse for Traffic Information	Transport	Reduced traffic congestion	10.0%–15.0%
Urban transport and traffic control	Singapore	Singapore Urban Transport Solution (STARS) initiative- Data Mall	Transport	Reduced overcrowding on buses	92.0%
Urban transport and traffic control	South Korea	Smart Expressways	Transport	Increased accessibility	8.2%
Urban transport and traffic control	Sweden	Congestion pricing trial	Transport	Reduced traffic congestion	20.0%–25.0%
Urban transport and traffic control	Sweden	Congestion pricing trial	Transport	Reduced air pollution	14.0%
Urban transport and traffic control	Sweden	Congestion pricing trial	Transport	Increased public transport travel	6.0%

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