INFRATECH
VALUE DRIVERS

WORLD BANK

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Contents

1. Context & Overview

1.1. Background

The 2020 G20 Presidency mandated the Infrastructure Working Group (IWG) to develop an agenda to accelerate the adoption and application of technology-enabled infrastructure (InfraTech). This agenda supports two existing IWG initiatives—the Roadmap to Infrastructure as an Asset Class, and the G20 Principles for Quality Infrastructure Investment (QII). Technology supports the roadmap by providing enhanced data, tools, and transparency for investors. In addition, it creates new investment opportunities by creating new markets, business models and potential for enhanced revenues. InfraTech also supports QII, as many technologies maximize the positive impact of infrastructure by enhancing sustainability, inclusivity, and resilience. The potential economic efficiencies that new technologies offer also help attain value for money across the project lifecycle and potentially reduce upfront or recurring public financial outlays. InfraTech also provides valuable tools for governments to respond to the COVID-19 health and economic crisis.

This is one of three Reference Notes supporting the agenda: Value Drivers of InfraTech; InfraTech Stock Take of Use Cases; and InfraTech Policy Toolkit.

1.2 Objective

This Reference Note supports the InfraTech Agenda endorsed by the G20 Infrastructure Working Group by outlining the potential economic, social, and environmental value to countries generated by adopting InfraTech solutions. It also provides a framework for evaluating the benefits of these solutions against their costs and risks. This paper focuses on the transport, energy, water, and digital infrastructure sectors.

1.3 Key Messages

1. InfraTech can help countries mount an effective public health and economic response to COVID-19.

The response to the COVID-19 pandemic highlights the important role InfraTech plays in helping countries improve resilience to natural disasters and pandemics.

InfraTech Approaches for an Effective COVID-19 Public Health and Economic Recovery Response

- **Broadening access to digital connectivity.** Digital connectivity is key to maintaining economic and social activities during social distancing. New connectivity solutions, such as Alphabet's Loon, launching in Kenya, can help connect rural areas. China is also focusing investment on a new generation of InfraTech elements, such as 5G, artificial intelligence (AI), and Internet of Things (IoT), to promote economic recovery.

- **Leveraging AI and big data.** Mobility data, gathered from technology or mobile phone companies, has become useful in helping to understand the impact of health and economic interventions. Korea leveraged public-private partnerships to leverage big data and AI to identify high-priority cases and track the routes of infected individuals.[i] Governments can also upgrade the data collected by infrastructure services through satellite imagery, smart shipping containers, and other methods used to monitor food and production supply chains and better target economic recovery interventions.

- **Promoting maintenance of critical infrastructure.** Remote and automated methods (e.g., drones, IoT, robots) can maintain or increase the frequency of physical inspections to ensure critical infrastructure services are not interrupted. Better use of big data and AI can also help reduce the costs of maintenance and extend the life of assets through predictive modeling. Enhanced use of automation and contactless solutions can also help ensure safety and continuity of logistics at border crossings, ports, and airports.

- **Enhancing safety of transport lines.** AI-powered solutions, such as temperature screenings to detect potentially sick passengers, can help reduce the spread of contagion in transit lines. Demand-responsive transport (DRT) models can also help to maintain public transport options, given potentially reduced ridership. Other technologies, such as contactless ticketing, can minimize ways for diseases to spread and provide useful data.

Data collected from contactless ticketing on public transit has also allowed agencies in Australia to create targeted transport responses for high-risk areas. Automation, using AI-based deep-cleaning robots, is also being employed to improve train hygiene standards in several public transit systems.

2. InfraTech offers the opportunity to realize significant economic, social, and environmental value across the asset lifecycle.

Improvements in the collection, collation, and curation of asset data is supporting a new level of data decision making. This ability offers an opportunity to deliver financial cost reductions and improve efficiency across the asset lifecycle. Increasingly advanced analytical systems are capable of processing large amounts of diverse data to support better infrastructure management. This will increase the safety, efficiency, and effectiveness of greenfield and brownfield assets and increase productivity. For example, utilities could achieve a 15-20 percent increase in efficiency with the use of augmented reality.[ii]

In addition, the positive externalities from broadening access to infrastructure services and economic opportunities, addressing environmental challenges, and progressing toward the Sustainable Development Goals (SDGs) will have a more significant impact than those realized from cost savings and efficiencies. For example, 5G could unlock $4.3 trillion in economic value across a range of industries.[iii]

3. Countries can prioritize adoption of InfraTech solutions depending on technology readiness, cost, existing applications, and country readiness.

While there are many potential InfraTech solutions, some require substantial capital investments and need a rigorous cost-benefit analysis to ensure a country is able to recoup the investment outlays. Countries will also differ in their adoption readiness to realize benefits from expensive or early-stage technologies. InfraTech solutions that rely on relatively mature technologies and well-tested use cases can generally be adopted by countries at even low levels of adoption readiness. On the other hand, countries will need to have relatively high levels of adoption readiness to implement use cases relying on early-stage technologies. However, this will give them a chance to establish industry leadership in those technologies.

4. Infratech also brings significant new implementation, economic, social, and environmental risks.

Given the complexity of many InfraTech projects, these projects often face heightened risks that the project will not be implemented correctly and will result in cost overruns or benefits that fail to materialize. Some technologies also pose broader economic or social risks as jobs or sectors are disrupted. Certain technologies may also have unintended environmental risks, due to a heavy reliance on energy or rare materials. Policymakers must put into place appropriate risk management frameworks to manage or mitigate these risks.

2. Understanding InfraTech and Types of Value

2.1 Key Technologies that Drive Value

According to its broadest definition, InfraTech includes any technology that significantly impacts the development, delivery, and ongoing operation of infrastructure. By this definition, we can include technologies that are used to meet the strategic requirements of infrastructure or that enable data-driven decision making; innovations in finance, funding, and fintech that support the commercial management of an asset; and technologies that are integral to managing the relationship a customer has with infrastructure and the consumption of its services. This definition focuses on technologies or technology applications that enhance the technical and economic performance of infrastructure services, and in some cases disrupts the status quo of an existing system or market. However, the challenge of using individual technologies to define InfraTech value is difficult for three major reasons:

- The inherent complexity of an increasing number and diversity of technologies;
- Major innovation impact being driven less by a single technology (i.e., drones) or capability (i.e., advanced analytics) but rather by the integration of multiple technologies designed to meet a specific need, such as mobility as a service, self-service operations, or contactless payment and remote management; and
- The increasing variation in how InfraTech value can be delivered, based on technologies of differing maturities, adoption levels, and global availability—all of which have potential and material use cases within alternative scenarios.

In this context, the most pragmatic approach to understanding InfraTech value is to first aggregate the technologies into a limited set of InfraTech categories, each of which meets a key value proposition for infrastructure. This approach allows us to articulate more effectively the multiple InfraTech value propositions across the asset lifecycle that impact infrastructure delivery.

Connectivity & Communications	Analytics & Computation	Cloud & Data Storage	Devices & Automation	Platforms, Interfaces & Systems	Materials, Energy & Construction
Wired or wireless technologies that connect people or devices and enable data transfer.	Advanced analysis that uses machine learning to process large amounts of unstructured data.	Tech solutions that enable efficient mass movement and storage of large data sources.	Physical interfaces and components that perform specific tasks or enhance automation. This includes robotics and drones.	Complex systems combining multiple technologies or that have whole of system design thinking.	Applied science and engineering directly related to efficiency or quality.
▪ 5G Mobile ▪ 6G Mobile ▪ LEO Satellite ▪ Wireless ▪ Industrial IoT ▪ Sensors / IoT	▪ Big Data ▪ Data & Analytics ▪ AI Augmentation ▪ Auto Cognitive ▪ Edge Computing	▪ Cloud ▪ HD Video ▪ BIM	▪ Robotics ▪ UAVs (e.g., drones) ▪ Wearables ▪ Biometrics	▪ Autonomous Cars ▪ Fintech and DLT (e.g. Blockchain) ▪ AR/VR ▪ Digital Twin ▪ GIS / GPS	▪ 3D Printing ▪ 4D Printing ▪ Nano-materials ▪ Modular Construction ▪ Advanced Energy Storage

While the categories above provide an overview of the diverse technologies on which infrastructure can draw, there are three foundational technologies that have to be in place to unlock the value from the others:

- **Connectivity**—Broadband, such as 4G and 5G wireless, are essential for gathering and transmitting data.
- **Cloud**—Distributed and virtual high-capacity data storage enable computing and analytical solutions.
- **Fintech**—Payments are an increasingly essential aspect of delivering infrastructure services.

2.2 Three Types of Value Created By InfraTech

Improving efficiency and reducing costs	Enhancing economic, social & environmental value	Reshaping infrastructure demand and creating new markets

2.2a Improving Efficiency and Reducing Costs

Using technology to better manage the construction and operations of infrastructure assets is not new. Infrastructure technology has historically been at the forefront of societal change. After a recent lull in productivity, the efficiencies promised by this next generation of InfraTech may provide a step forward in how infrastructure is designed and delivered. Improved analytical functions, data management, communications, and automation are already producing material cost savings in infrastructure. However, new data-driven decision making, with faster decision cycles, alternative service solutions, new asset-management offerings, or completely different approaches to inventory management will drive value in both greenfield project delivery and brownfield asset prolongation. Some examples include*:*

- **Advanced analytics for planning.** These include the use of complex city models with synthetic populations living in digital twins, which are estimated to result in a 10-percent improvement in construction business effectiveness and more than 20 percent gains in productivity.[iv] In transport, whole-of-system network models are used to rethink rail asset operations and renewals, allowing operators to manage operations risk and maintenance interdependencies more efficiently.
- **Enhanced service.** New technologically driven user interfaces and platforms, including payment mechanisms, are radically changing the customer experience. For example, large transit agencies are starting to reduce costs (operating and ticket prices) while increasing satisfaction and service levels, by focusing on self-service delivery and alternative business models.
- **Reducing construction costs.** 3D printing technologies are placing virtual warehouses in the backs of vans.
- **Reduced transport and monitoring costs.** Low-cost drones enable asset inspections to better target maintenance interventions. Smart shipping containers can regulate internal conditions, provide real-time GPS tracking, and enhance security; such containers enhance productivity and reduce lost or damaged cargo costs.
- **Real-time data and analytics**. Real-time reporting and visualization via smarthphones can turn large amounts of sensor data into usable intelligence to support complex asset decisions.
- **Flexible workforce.** Wearable technologies can allow smaller companies with limited resources to work remotely with staff on the ground, connected through 5G networks with fast processing speeds.
- **Back-office efficiencies.** Robotic process automation and AI are delivering new levels of processing speed and accuracy, and are improving supply-chain management, project controls, and claims.
- **Dynamic micro-grid integration.** Battery improvements enable energy storage at off-peak and cheap hours and allow on-peak support from a distributed grid.

2.2b Enhancing Economic, Social, and Environmental value

Gartner recently predicted that “by 2025, 60% of infrastructure and operations (I&O) leaders will drive business innovation using disruptive technologies, up from less than 5% who do so today.” While cost reduction and asset efficiency is starting to fuel an industry-wide transformation, InfraTech can also offer an opportunity to rethink how alternative infrastructure solutions can address larger global challenges. These will create not just economic value through market exchanges, but also improve social and environmental impact compared with traditional infrastructure services.

- **Economic value—jobs, economic opportunities, and better services.** InfraTech can connect service offerings across sectors, unlock new pools of customer value, and generate alternative revenue streams.
  - **New economic growth areas.** InfraTech ecosystems also have the potential to create new areas of economic growth and activity. For example, future mobility, which will rely on 5G for connected and autonomous vehicles, is likely to more easily attract finance for network development. Once the network is in place, it will then be available for a vast array of alternative use cases. Off-grid energy solutions also enable new areas of economic activity in rural areas.
  - **Connecting people to jobs.** New mobility solutions are redefining transport ecosystems around customers, by giving them better access to multi-modal solutions. This has already proven to increase ridership and total market share across all modes.
- **Social value—broadening inclusion and saving lives, including through greater resilience and better responses to disasters and pandemics.** By making the communication of ideas, information, and data faster and easier, InfraTech is enabling greater and more seamless cross-sector integration, including along the following dimensions:
  - **Resilience.** InfraTech enables faster and more targeted responses to disasters and pandemics through improved use of data to track damage and the movement of affected people. The current COVID-19 response demonstrates the value of InfraTech in using data effectively to track the outbreak and intervene quickly.
  - **Accessibility.** Financial services, payments, open transport data, and utility companies can deliver connectivity to cities and rural areas and make services safer, cheaper, and more accessible. InfraTech can also help bridge gender gaps by helping make services safer and more accessible for women and girls.
  - **Reliability.** InfraTech can help ensure safer and more reliable services. For example, the emergence of mobility as a service (MaaS) is estimated to save more than 585,000 lives and reduce traffic-related public safety costs by more than $234 billion over a 10-year period.[v] However, MaaS will depend on the appropriate infrastructure being in place to achieve these benefits.
- **Environmental value—improving air quality, reducing emissions, and enhancing sustainability**. Tech-led industry entrants are developing innovative solutions in areas such as off-grid, smart cities and the future of mobility. These entrants are also exploring scale and trends in micro infrastructure solutions with the potential for macro adoption across sectors, which could have a significant bearing on major environmental and sustainability challenges. Some examples include:
  - **Electric vehicles (EVs)**. EVs are growing at a rate of approximately 40 percent annually. They have the potential to improve air quality and people's health through the reduction of exhaust air pollutants (nitrogen oxides) and particulate matter, as well as diminishing carbon emissions by replacing internal combustion engines.
  - **Wastewater technology**. New technologies are being developed that transform the standard emission-heavy wastewater treatment processes into more sustainable processes. Greenhouse gas (GHG) emissions of methane and nitrous oxide from wastewater treatment can be reduced through better monitoring technologies, optimized treatment processes, and the use of novel treatment processes.

2.2c Reshaping Infrastructure Demand and Creating New Markets

Finally, InfraTech has the potential to be not just highly disruptive to a delivery method, but also to change the underlying mechanics of an infrastructure demand model. This could happen through two means: i) creating demand for new infrastructure services that previously did not exist (e.g., mobility as a service, charging of electric vehicles), and ii) reducing demand for traditional infrastructure services that are superseded by another technology (e.g., 3D printing, 5G eliminating traditional forms of connectivity). The following are just a few technologies that have the potential to deliver this form of exponential innovation and disruption.

- **Mobility as a service**. Across a number of platforms, MaaS is critically changing how we view transit services, passenger expectations, and the customer experience—not just for taxis but across all modes of transport. Juniper Research estimates that the revenues generated by the use of MaaS platforms will exceed $52 billion by 2027, up from $405 million in 2020. The goal of MaaS is to leverage technology to provide users with the possibility to move easily and cost effectively without owning a car, attracting new users to public and shared transport and, by utilizing captured data, creating new mobility services to respond and adapt to the evolving demand for each user type. Increasing the availability and application of transit data has also shown that MaaS is not only increasing ride sharing, but has also been changing ridership behavior among modes and is increasing gross demand in cities for public transport generally.

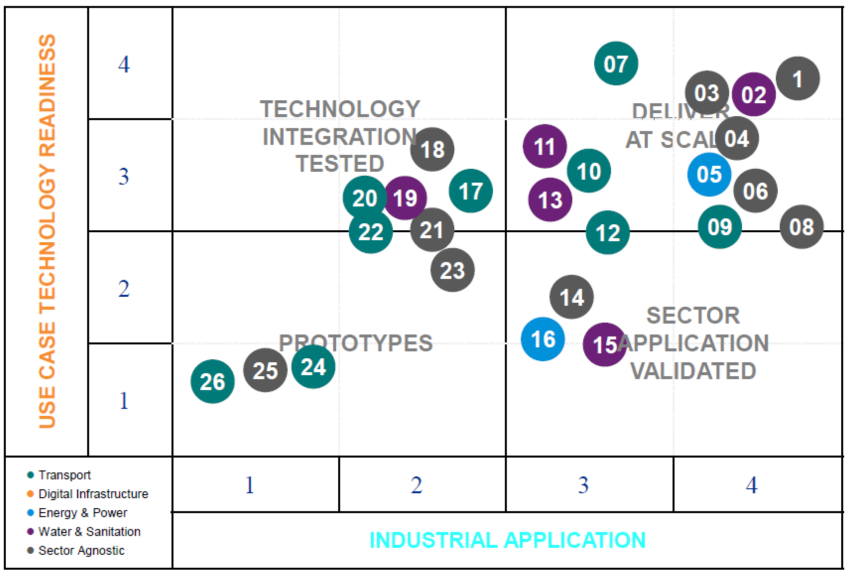
  MaaS is also having a broader social impact. The global movement toward MaaS is fueled by an overarching desire to make cities more livable and connected, which has been widely understood to mean less vehicle-centric. Greater flexibility and tailored offerings for users are contributing to lower travel times and an enhanced user experience. For example, Whim, an all-inclusive MaaS application developed by MaaS Global, initially for Helsinki in 2016, has begun expanding to Singapore, Birmingham, Tokyo, Vienna, Antwerp, and parts of the United States.

- **3D printing.** While 3D printing technology has seen widespread use by industrial manufacturers in developed markets, the number of applications in infrastructure is increasing at a rapid pace. For example, the recent construction of 3D-printed buildings in both China and the Netherlands has proven the maturity of this technology. The potential for fully printed apartment blocks, villages, or even cities is now increasingly viable. In the near term, the printing of replacement parts on site or on the move will disrupt current infrastructure processes. 3D printing will save significant construction costs, in terms of inventory, delivery times, and a reduction of wasted components. The downstream impact of 3D printing might have further implications for supply chains. For example, major market reductions in logistics and shipping may reduce the need for the supporting infrastructure (ports, etc.).

- **5G and hyper-converged connectivity**. 5G will increase connectivity from 100,000 to more than 1 million mobile connections per square kilometer. This environment will include connected phones, computers, wearables, traffic, roadways, hospitals, patients, warehouses, and parcels, enabling governments and businesses to optimize decisions and enhance outcomes in real time. 5G will be key to unlocking many early-stage technologies, including autonomous vehicles and other smart-city applications. Initial estimates of the potential economic value of 5G are in excess of $4.3 trillion.

3. Framework for Technology Adoption

3.1 InfraTech Adoption Will Vary Depending on Technology and Country Readiness



#	Description
1	BIM Level 1
2	Water Height and Flood Management System
3	Virtual Reality (VR) or Augmented Reality (AR) for Training
4	Sensors and Robotics for Bridge Maintenance
5	Smart Street Lighting
6	Drones for Survey and Maintenance
7	Demand Responsive Transport
8	Predictive Maintenance of physical assets
9	Smart Parking Infrastructure
10	Drones for Deliveries
11	Smart Metering
12	Dynamic Road Pricing
13	Electric Fleet
14	Digital Twins
15	Last mile infrastructure for water provision in developing countries
16	Decentralized green micro-grids and peer-to-peer energy transactions
17	Mobility as a Service
18	Smart Containers
19	Intelligent process optimisation and real-time decision support for drinking water and wastewater treatment plants
20	Vehicle to Vehicle (V2V) Connectivity
21	AI for disease outbreak and pandemic
22	Real-time Traffic Management
23	3D Printing
24	Unmanned Aerial Vehicles for Passenger Travel
25	BIM Level 3
26	Hyperloop

3.1a Technology Readiness and Industrial Applications are Key Factors in Assessing the Risks of InfraTech Use Cases

The figure above describes a draft framework for countries to assess individual InfraTech use cases and prioritize InfraTech solutions for their own adoption. The use cases in the figure were taken from the case studies prepared by the Global Infrastructure Hub for the G20 IWG to support the InfraTech Agenda ("InfraTech Stock Take of Use Cases"). Each use case is assessed according to two factors:

- **Technology readiness.** This factor measures the readiness of the technology to be used based on the following:
  - Capital and whole-of-life costs for the solution;
  - Maturity of technologies underlying the use case; and
  - Implementation difficulty.
- **Industrial applications.** This factor examines how widespread the industrial applications are for the technology within the sector or industry. Industrial applications are generally divided into four main stages: i) prototype or industrial pilots; ii) usage in relatively controlled environments; iii) public and commercial usage; and iv) widespread usage including a relatively mature commercial market.

The use cases are grouped in four major categories:

- **Deliver at scale.** Examples in the top right quadrant are use cases that have both a high level of technological readiness and widespread applications. The cost-benefit analysis of these cases is relatively clear, and the risks are manageable, assuming the country has the appropriate capacity and complementary infrastructure in place.
- **Sector application validated.** Examples in the bottom right quadrant are use cases where there is widespread innovation and experimentation by the public and/or private sector to bring together relatively early-stage technologies and create new solutions. Adoption in this sector brings proven benefits, although

there are risks with implementation, because the underlying technologies are not yet mature and continue to evolve.

- **Technology readiness tested.** Examples in the top right quadrant are based on proven technologies, indicating fairly low technology or implementation risk. However, use cases demonstrating the cost-benefit analysis of adoption are still being developed, as the examples have not achieved widespread usage. As usage becomes more widespread, per-unit costs will likely decline.
- **Systems validation.** Examples in the bottom left quadrant carry a high degree of risk, given the low level of technological readiness and industrial applications. These technologies are often fairly expensive, because the technology is still nascent.

3.1b Adoption of Use Cases will Differ Among Countries, Depending on Their Readiness and National Goals

Some countries at high levels of readiness will adopt InfraTech solutions in the "systems validation" quadrant that are still technologically nascent and relatively expensive. If these are successfully implemented, these countries will not only enjoy the benefits of establishing industry leadership but will also benefit other countries by driving global per-unit cost curves down. Other countries will be more selective and focus on adopting relatively mature InfraTech solutions in the "deliver at scale" quadrant, to mitigate financial, technical, and implementation risks. Countries not encumbered with large investments in legacy systems or technologies can also "leapfrog" to new systems enabled by InfraTech. There is often also wide disparity within a country, as some cities have the appropriate capacity and conditions to more rapidly adopt InfraTech solutions and help lead the national agenda.

3.2 Technology and Country Readiness

3.2a Technology Readiness

As described above, technology readiness depends on three main factors:

- **Upfront and whole-of-life costs.** The implementation and deployment of InfraTech solutions can come with significant upfront or recurring costs. Many technologies will not be economically or financially viable at early stages of their maturity, although cost structures in many of these technologies have shown the ability to shift rapidly once the technology achieves a certain level of scale (e.g., renewable energies). Cost structures may also vary based on the country or local market context. It may be advantageous for some countries to wait for a cost structure to decline before implementing a certain technology. Even for technologies that have a favorable cost-benefit structure, poor implementation could result in significant cost overruns or underutilized capacity. The business models for technologies with large upfront capital costs, such as 5G, will need to be evaluated carefully from a cost-benefit perspective. Other technologies, such as sensors or drones, currently have fairly low upfront capital costs with significant near-term benefits.
- **Technology maturity.** Every InfraTech solution typically relies on several underlying technologies that may be at varying levels of technological maturity. The maturity of each underlying technology can be assessed based on how far it has moved on the scale from proof of concept to being proven in an operational environment at acceptable performance and operational standards. NASA's Technology Readiness Levels is one example of a technology maturity level rating system. Technologies at lower levels of maturity may carry greater operational and performance risks. In addition, technologies at lower levels of maturity typically have relatively high per-unit costs, which tend to fall as the technology achieves a high rate of industrial application. Some countries may choose to wait for the cost of technologies to fall before widespread adoption. For example, while developed countries were the primary early adopters of solar and wind technologies at relatively high cost structures, rapidly falling costs have now made these technologies affordable for all countries. The cost of cloud computing and sensors are now so low that most countries and sectors are also able to benefit from these technologies.
- **Ease of implementation.** The implementation risks associated with a specific technology's rollout will also vary based on the necessary scale and the accompanying local skills and capacity required to fully take advantage of the technology. Certain technologies, such as drones used for maintenance and upkeep, have relatively low-complexity rollout challenges. On the other hand, developing an integrated data platform that crosses industry sectors has various technical, organizational, and regulatory challenges. Implementation may also depend on a strong enabling environment. For example, the full value of implementing 5G will

not be realized until complementary infrastructure and technologies are developed (e.g., autonomous vehicles) and will vary depending on specific country and sector contexts.

3.2b Country Adoption Readiness

A country's readiness to adopt and benefit from different technologies will depend on the following criteria:[vi]

- **Foundational technologies.** The level of connectivity, data infrastructure, and fintech systems within the country will have a large bearing on the country's ability to adopt many InfraTech solutions.
- **Legislation and regulation.** Countries can improve this aspect—which includes the enabling environment around the adoption of InfraTech—by adopting national or sub-national InfraTech approaches, fostering a data ecosystem, and encouraging a local entrepreneurial ecosystem.
- **Procurement and contract management.** The ability of a country to procure innovation solutions is often limited by inflexible procurement approaches. Countries can better procure InfraTech solutions by using collaborative procurement and contracting approaches, focusing on value-for-money and life-cycle costs, and better using data to improve governance and monitoring of projects.
- **Funding and financing.** Sector or project-level subsidies are often needed to accelerate adoption of InfraTech with strong positive economic, social, or environmental externalities.
- **Institutional capacity.** The capacity of government institutions to provide effective support to, and oversight of, InfraTech issues is critical to implementing InfraTech approaches and managing risks.
- **Future enabled workforce.** Digital skills are increasingly critical to addressing the current and emerging needs of technology-enabled infrastructure.

4. Key Risks and Challenges of InfraTech

4.1 Implementation Risks

4.1a Managing the Uncertainty of InfraTech Rollout

Rolling out InfraTech solutions requires managing the complex interplay between different sectors' requirements, specific locations' adoption readiness, technology maturity, and market dynamics. The cost of mismanaged deployments of technology may be larger than the potential benefits. A country's readiness to adopt a particular InfraTech solution will be key to ensuring successful implementation. In addition, any rollout of new InfraTech solutions must ensure high standards of affordability, safety, reliability, and dependability are maintained.

4.1b Delivery Differences between Infrastructure and Technology

The cycle times for both innovation and adoption of disruptive infrastructure technology are materially different to the cycle times for infrastructure development itself. Governments need regulatory and legislative frameworks that protect citizens while helping to provide appropriate incentives for private sector investment and engagement.

4.1c Technological Obsolescence

Given the long lead time in project preparation and the rapid pace of technological change, an InfraTech investment may become stranded or obsolete within the asset's intended lifetime. Policy makers will need to ensure forward technological compatibility of infrastructure assets, and use innovative design and procurement models, to mitigate this risk.

4.1d InfraTech Procurement Capabilities

Current infrastructure procurement and contracting mechanisms are not set up to deliver InfraTech enabled projects. They do not support the agile and flexible management approach required to continually develop technology from one viable solution to the next, which is standard within technology innovation.

4.1e Public-Sector Skills Gap

Any InfraTech solution must recognize and plan for the fact that the role of government in infrastructure is materially changing. Simple asset ownership through civic planning and contract management compliance will not deliver the collaborative and customer-centric projects that will be needed in the future. Governments may not have the necessary capacity to put in place the right enabling environment or implement large-scale technology-driven projects. Governments also need capabilities to manage new, more agile and collaborative procurement and contracting approaches.

4.1f **Market structure:** The adoption of InfraTech solutions may be hampered by the structure or incentives of stakeholders within the relevant infrastructure market. For example, existing contracts or concessions may hinder the introduction of new technologies within the transport sector. A lack of interoperability can also hinder the adoption of new solutions by locking governments or companies into one technology or a single vendor.

4.2 Economic Risks

4.2a Understanding the Impact on the Job Market and Human Capital

Process automation, sensors, and AI are just a few of the technologies that will have human capital and job impacts associated with their implementation. These technologies could make some jobs redundant, creating temporary unemployment and social issues. While new jobs will be created, public support will likely be needed to help with the transition to develop the new skills required.

4.2b Impact of New InfraTech Ecosystems

Some traditional infrastructure sectors will be disrupted by the emergence of new business models. Owners and investors are challenging traditional asset classes in favor of integrated ecosystems, and new delivery models are being applied to increasingly diverse supply chains. Infratech may shift levels of demand, as seen in the various new kinds of ride-sharing services that emerge under mobility as a service, or demand for charging of electric vehicles. There may also be a reduced demand for traditional infrastructure services because they are superseded by another technology. For example, 3D printing may reduce the demand for freight transportation.

4.2c Loss of Global Competitiveness

Countries that underinvest in Infra-Tech may risk falling behind in both adoption of InfraTech solutions and domestic economic growth opportunities. For example, countries that enabled rapid mobile penetration rates are also benefiting from the development of a local entrepreneurship ecosystem enabled by the mobile industry. Countries that are currently slower to promote electric vehicle policies and supporting infrastructure are also seeing less development of local market and industry development. This will hamper their ability to participate in the development of this rapidly growing global market.

4.3 Social Risks

4.3a Widening Digital Divide

A greater adoption rate of InfraTech in urban environments (e.g., 5G) may amplify the digital divide in the short term. The national and local support to connectivity is foundational to realizing the potential value of data for all parts of society. Governments will need to be actively engaged to manage digital divides along spatial, gender, or economic lines. In addition, there may be a tendency for existing or large operators to achieve high levels of market concentration, hampering innovation and growth by smaller and/or local players.

4.3b Data and Social Contract

InfraTech will collect increasingly large amounts of data on people. For example, as mobile devices become increasingly connected, data holders are acquiring unprecedented knowledge about the movement and activity of people. Governments have a critical role to play in the development of the policies, governance, and plans to both safeguard rights and incentivize innovation. Specifically, recognizing data as a public good is critical to driving an appropriate level of public-private sharing of data, while recognizing privacy and security concerns.

4.4 Environmental Risks

4.4a Increased Energy Costs

As the quantity of data collected and stored continues to increase at exponential rates, the need to use more power to cool data centers may have a material impact on a country's energy consumption.

4.4b Mining Scarce Resources

Some InfraTech solutions (i.e., batteries) draw upon scarce natural resources (e.g., lithium) where environmental and social standards along the supply chain may be lacking. Policymakers should focus on improved standards, monitoring, and evaluation along the entire supply chain for new technologies, and prioritize the development of technologies that do not rely on scarce resources.

4.4c Pollution

While many InfraTech solutions are cleaner and leave a smaller environmental footprint than existing technologies, some technology-led solutions could cause higher rates of pollution or worsening air quality. For example, ride sharing services have in some cities led to an increase in cars on the road. The increase in electronic production has also seen an exponential growth in e-waste.

5. Capturing Value across the Asset Lifecycle

Effectively capturing value from InfraTech requires a disciplined, ongoing, and managed process that starts in the early project-development stage and continues through operational delivery. The leakage of value often goes unnoticed and unmanaged, seeping away during an asset's lifecycle. The following section looks at the potential drivers of value for InfraTech across the five major asset lifecycle stages and some examples of how this might be translated into practical activity.

5.1 Strategy and Planning

The long-term success of major assets has always been predicated on getting the upfront strategy and objectives of the project right.

5.1a Gathering the Right Data

There has been an exponential increase in data sources helpful to the design process, including from satellite imagery, mobility records, social media, logistics, and transaction records. The cost of gathering data is also decreasing exponentially, with drones or crowd-sourcing techniques, proving highly cost effective. Using and collecting data effectively can produce very high returns. For example, creating high-resolution digital elevation models and hazard maps for all cities in low- and middle-income countries would cost a few hundred million dollars (as drone and LIDAR-based technologies are becoming increasingly affordable) but save billions of dollars by making urban infrastructure more resilient.[vii]

5.1b Advanced Analytical Modeling Techniques

New analytical capabilities in capital strategy and portfolio planning are using more detailed and diverse data sets to feed complex infrastructure, land use, and city planning models (including design) that more accurately project benefit outcomes to enable better, data-driven decisions that are expected to deliver capital expenditure savings on the order of 10 percent and 20 percent. However, it is the growing ability to bring together complex and diverse big data sets that is needed to support the next generation of city planning. InfraTech allows improved use of disaggregated data that could fed into better models and predict the impact of interventions. Such advanced prediction models could provide governments with tools to isolate impacts of infrastructure investments as well as land value uplifts. Digital twins, activity-based models, or whole system network models for assets can reshape the decision management landscape. Augmented reality and virtual reality help to create immersive experiences that provide engineers, builders, managers, and stakeholders insight into potential design flaws, risks, and issues before and during construction.

Melbourne Agent and Activity Based Transport Model (MABM). To analyze travel patterns for Melbourne and identify the potential impacts of various transport network demand-management policy options, an activity-based model that inputs individuals' behavior patterns was developed. This model utilized a fully synthetic customer data set (which anonymizes actual data) where real data was lacking in the initial infrastructure development and planning stage. This model helped in understanding the impacts of introducing new transport solutions.

National Digital Twin Program (United Kingdom). A digital twin provides a platform to analyze and simulate complex interdependencies within the national infrastructure system, allowing data-driven decision making for planning and organizational productivity, and optimize service delivery. It may also provide real-time participation opportunities for stakeholders rather than waiting for public hearings. The National Infrastructure Commission estimates that data may contribute around £50 billion a year to the U.K. economy and AI could add up to an additional 10 percent. Concerns that must be fully addressed before implementation include data security and a lack of common technical communication standards between data twins. The heavy computational demands of digital twin systems may also be a stumbling block even as computational infrastructure develops further.

5.2 Finance and Funding

5.2a Providing Data to Investors

The ability of InfraTech solutions to provide and analyze large pools of real-time data can help investors better structure projects and ensure appropriate risk allocation. Combining data from different projects in one sector can be particularly helpful in giving investors more insight into the market. Using InfraTech solutions to better gather and analyze data will help to mobilize private sector investment and potentially lower financing costs.

5.2b Using Real-Time Data

Dynamic pricing is the practice of varying the price of an infrastructure service to reflect changing market conditions. By employing sensors and other IoT devices, applications can be used to bring in more revenue, as well as achieve other goals, such as minimizing congestion on transport networks, improving utilization of parking infrastructure, and improving quality of life. Real-time data also allows for pricing and pay-as-you-go models that supports new capital expenditure (CAPEX) financing models.

Stockholm congestion pricing. Stockholm has implemented a congestion pricing zone, which aimed to reduce traffic entering the central city. The tax varies depending on the time of day and is collected automatically using license plate scanning technology. The scheme has proved a dependable source of revenue for Stockholm, and similar schemes are being employed in London and Singapore. It has also shown to decrease pollution in Stockholm by 5 percent to 15 percent.

Untapped smart water solutions. Untapped enables water operators to adopt smart water systems to provide safe water up to the "last mile." Untapped and Mathira Water and Sanitation Company (MAWASCO) ran a proof-of-concept project in Malindi, a coastal town in Kenya with a population of more than 300,000, installing 6,500 pay-as-you-go smart meters on an 18-month capital lease. Over three years, MAWASCO recovered arrears and saved operating costs amounting to 111 percent of lease payments. Moreover, the cash flow going through the Untapped digital payments platform was 5.4 times lease payments.

5.3. Project Delivery

As the construction industry has had relatively low adoption of digital technologies, InfraTech has the potential to increase efficiencies and reduce costs through the following areas.

5.3a Procurement and Contracting

The use of new technology is expected to deliver from 5 to 10 percent in cost savings on project delivery and materials costs. Changing material specifications, improved inventory and supply chain management, enhanced project controls and real-time contract performance management capabilities can all potentially unlock value for the constructor community. Furthermore, data-driven decision making, digital twins, building information modeling (BIM), construction ecosystem and digitally connected supply chains, distributed ledger technology (DLT), combined with open data, increased intra and inter industry data sharing and reference class modelling data will help build buyers' knowledge and capability. Approaches to improving procurement are detailed further in the accompanying reference note "InfraTech Policy Toolkit".

5.3b Construction Execution

Often characterized as the management of time, quality, and cost, project execution is a highly complex system that is already benefitting from the application of technology to manage delivery, scheduling, communications, and governance. The use of AI and robotic process automation in project management back offices is expected to generate savings of up to 20 percent in contractor costs and claims. However, it is the increased level of data availability, real time reporting and on-site performance transparency available to asset and contract owners as a standard in the next generation of infrastructure procurements and construction contracts that will be the real driver of value. One example is a reshaping of the claims process, a key profit driver for the construction industry/asset operators, that will be the primary motivator for the contractor and sub-contractor community to employ InfraTech enabled efficiency gains.

5.3c New Manufacturing Processes and Materials

New manufacturing processes, such as 3D printing, have the potential to dramatically reduce costs as well as reshape supply and logistics chains. Houses, bridges, and even entire communities are being 3D printed faster, with less waste and lower costs than traditional methods. In the water sector, automated welding technologies can significantly reduce infrastructure costs through pre-fabrication.

Acueducto Gran San Juan project.[viii] The Acueducto Gran San Juan project in Argentina (jointly funded by the Kuwait Fund for Arabic Economic Development and the Argentinean government) consists of the installation of a new drinking water system to transport water from wells located approximately 25 kilometers west of the city of San Juan to complement the existing water system. The use of new welding technologies transformed the economics of the project, allowing fabrication to be completed in 162 days instead of the original timeline of 720 days with traditional welding methods.

5.3d Operations Readiness and Handover

InfraTech is beginning to significantly change the way that infrastructure looks at operations readiness and testing (ORAT). Operational technology readiness, BIM, and complex knowledge transfer requirements mean that project execution teams need to work far more closely with the end-stage operators. Front-end loading of projects to manage earlier engagement with operators, which focuses on outcomes, business readiness, and data requirements, is key to realizing the expected benefits from InfraTech.

RedEyeDMS knowledge access platform for construction and maintenance. RedEyeDMS is currently being used by a range of clients in Australia, the United States, and Europe in the infrastructure, mining, and utility sectors to provide a single source of engineering drawings so all personnel have the right drawing at the right time. For example, the Southern Nevada Water Authority saw an increase in productivity and accessibility from using RedEyeDMS, with the time to find drawings reduced from 10 minutes to 2 minutes. Similarly, the Las Vegas Valley Water District was able to find and remove more than 300,000 obsolete drawings with a return on investment realized in the form of labor cost savings, increased workflow efficiencies, risk mitigation, and data security.

Job Site Insights (PCL Construction). PCL developed a cloud-based analytics solution called Job Site Insights using IoT technologies to improve site performance. IoT sensors provided a real-time flow of information for analysis resulting in improved productivity, shorter time to market, decreased risk, and material cost savings. In order to fully take advantage of Job Site Insights and similar tools, companies must overcome resistance to change. These can include shifting from paper-based to electronic reporting and using wearable technologies to generate insights.

5.4 Operations and Maintenance

5.4a Enhanced Safety, Quality, and Customer Service

Technology is enabling new and more efficient ways of meeting customer needs with greater levels of safety, quality, and service. The introduction of "as a service" business models for mobility or other sectors, the rapid adoption of self-service, micro infrastructure solutions, fintech, and integrated infrastructure options are creating new business models that use platforms to optimize use of private or public infrastructure assets. Furthermore, the provision of increased data is enabling customers to make different choices about how they consume and even contribute to infrastructure outcomes. Increasingly connected vehicles and motorways are helping improve safety for pedestrians and reduce transit times for drivers.

Real-time traffic management in Barcelona. Using real-time traffic management systems, traffic data can be combined across a network to provide a holistic picture of the current traffic in an area. With the right tool, future traffic can also be predicted, therefore allowing agencies to develop strategies that simultaneously predict the scenarios with the best outcomes and prevent congestion from getting worse. Barcelona's Urban Lab dynamic traffic forecasting allows for increases and decreases in the number of green lights and available parking spaces, according to the level of traffic/demand.

Pedestrian-recognition IoT in Finland. Finland piloted an IoT and AI-based solution that detects when a pedestrian is planning to cross the street at an intersection. The system was able to achieve up to 99-percent accuracy during the day and 75 percent at night. This type of technology can help to keep pedestrians safer and also optimize traffic-light management.

Singapore water authority. Singapore piloted a smart meter and app solution that rewarded users for certain results and led to a 5 percent reduction in water consumption. This case study demonstrates how technology can help change customer behavior by giving them real-time data.[ix]

London street-light Radio Frequency (RF) mesh network. Given narrow streets and tall buildings, connectivity is a problem in the City of London. The city created a low-spectrum RF mesh network, where each lamp post is connected to the internet and acts as a node. Furthermore, conversion of streetlights to light-emitting diode (LED) is expected to result in energy savings of 70 percent in addition to reduced CO2 emissions and maintenance costs.

5.4b Asset Utilization Optimization

InfraTech solutions can have a major financial impact on operations through improved data-driven decision support that optimizes the use of assets. Connectivity, IoT, and advanced analytics are enabling precise adjustments in water, transport, and energy services to more precisely match demand. E-logistics platforms also help optimize use of private logistics assets. Long-haul e-logistics business models, such as China's Full Truck Alliance and Nigeria's Kobo360, continue to spread globally and across sectors. Last-mile e-logistics platforms and companies using technologies to facilitate delivery of goods in urban areas are also seeing rapid growth.

Calgary AI intelligent process optimization for water treatment. AI provides an opportunity to optimize drinking water and wastewater treatment plant processes to reduce costs and improve the reliability of water quality. In Canada, the City of Calgary serves over 1.2 million residents and over 20,000 industrial, commercial, and institutional customers. Calgary used AI to generate real-time pump schedules to minimize the cost of operations and save 21 percent compared to baseline operations.[x]

Network Rail's ORBIS and digital rail. Passenger demand for rail is expected to more than double over the next couple of decades, and freight demand is also rising quickly. U.K. operator Network Rail established a five-year project (Offering Rail Better Information Services, or ORBIS) to apply enhanced data collection and analytics to improve performance on the system's 12,000-plus connected assets.

Smart containers. Smart containers are shipping containers used in freight and logistics that are integrated with IoT, sensors, GPS tracking, and solar panels. These containers can regulate internal conditions (e.g., temperature) to reduce cargo loss and provide real-time GPS tracking to optimize supply chain logistics. Major shipping companies are investing in this technology, and an estimated 10 percent of the global container fleet is predicted to be outfitted as smart containers by 2023.[xi]

San Francisco smart parking. SFpark combines real-time data on parking availability and dynamic pricing to make parking easier for drivers in San Francisco and improve utilization of infrastructure. While overall parking demand grew, parking availability improved dramatically in SFpark pilot areas. It also resulted in less circling and double parking, leading to cleaner air and safer streets.[xii]

5.4c Predictive and Targeted Maintenance

Traditional asset maintenance is often ineffective due to infrequent monitoring, costly maintenance, and manual data analysis. Using IoT to perform real-time monitoring and advanced machine learning methods to develop predictive models about failure could help to dramatically lower the costs of maintenance and reduce the risks of service disruption.

Netherlands AI water management. Amsterdam employed an adaptive self-learning algorithm, Aquasuite, to make accurate predictions of water demand using machine learning. It manages over 50 percent of all water systems in the Netherlands, including the Amsterdam supply network. Aquasuite provides supply, distribution networks (leak detection), sewage networks (flow control), water, wastewater and sludge treatment. Royal HaskoningDHV's Aquasuite OPIR makes better predictions of water demand for the next 72 hours using machine learning. It automatically analyzes and identifies an area's daily drinking water consumption patterns. Therefore, it can recognize deviating behavior to anticipate and respond to sudden changes by optimizing pump scheduling and operations. Aquasuite OPIR has been shown to improve water quality and reduce energy usage by up to 20 percent. Aquasuite OPIR has also been applied in Canada, Portugal, Poland, and Germany.

Sydney Water advanced analytics. Sydney Water worked with technology companies to research advanced analytics approaches to solving water industry challenges, including prediction of water pipe failure and sewer chokes, and prioritizing active leakage detection areas. Sydney Water found the potential to reduce maintenance and renewal costs by several million dollars over a four-year period and minimize inconvenience to customers from pipe breaks.[xiii]

5.4d Remote Supervision

Data from a variety of new sources, including satellite imagery, unmanned aerial vehicles (UAVs, or drones), and social media are enabling remote supervision of infrastructure assets. This not only reduces the cost of supervision but also enables supervision that might otherwise be impossible due to safety concerns or travel restrictions.

Geo-Enabling Initiative for Monitoring and Supervision (GEMS). The World Bank's GEMS initiatives combine remote sensing through satellite imagery, spatial data from various sources, and systematic real-time field data collection through smartphones to more efficiently supervise infrastructure projects. The GEMS method uses simple and free technology, so it is affordable, easy to implement, scalable, and sustainable. This method is particularly important in fragile and conflict-affected areas, which are difficult to reach, and has been used by the World Bank in countries such as the Central African Republic, the Democratic Republic of Congo, and Mali. Given disruptions in travel due to COVID-19, the GEMS methodology may be a useful tool to replace traditional supervision techniques. The World Bank is currently employing GEMS in over 450 infrastructure projects in Africa.

WaterNSW water monitoring network. In New South Wales, more than 5,000 monitoring stations measure the quality and quantity of rivers, streams, groundwater bores, and dams. More than 1,200 of these stations deliver real-time data through telemetry and remote data capture networks. This assists in efficient management of the state's surface and groundwater resources[xiv].

Zanzibar mapping initiative. The World Bank financed a project in Tanzania whereby local university students were trained to capture UAV images and managed to cover 2,300 square kilometers of Zanzibar for the first time with high resolution images that became the baseline for further information extraction. The World Bank is also increasing use of UAVs for supervision, given COVID-19 restrictions on movement. For example, UAVs were used to capture the progress made for the Ubungo Interchange construction using in-country specialists.

5.4e Automation

In the logistics industry, increasingly sophisticated automation technologies, driven by advances in AI, sensors, and robotics, is optimizing the performance of repetitive and routine tasks while reducing the risk of mistakes, accidents, injury, and delay. For example, the use of automated robot cranes and vehicles at automated container terminal

Yangshan Deep Water Port in Shanghai is expected to result in a 70-percent reduction in labor costs, a 50-percent increase in handling efficiency, and a 10-percent decrease in carbon emissions.

5.5 Renewal and Disposal

5.5a Decreasing Costs for Renewal Budgets

The renewal and disposal stage can benefit from the use of advanced analytics and whole-of-system network models to determine how to optimize renewal capital and/or the state of good repair budget. This new data-driven decision making and analysis is having a highly positive impact on the renewal budgets and complex asset management regimes for long, linear assets—decreasing costs while increasing asset uptime.

5.5b Increasing Life of Assets

Use of new materials, processes, and analytics supports an increase in the life of assets. InfraTech thus both increases the total value extracted by an asset and defers latent demand, potentially bridging gaps in technology update cycles.

Kansas City Smart Sewer program. The Kansas City (KC) sewer system is reaching the end of its serviceable lifespan, with some sections approaching 150 years of age. KC has embarked on an ambitious journey to revitalize the city's failing sewer infrastructure using technology to mitigate the impacts of aging and nature. KC Water's Smart Sewer program aims to optimize the aging system and return it to like-new condition by applying new technologies for monitoring conditions and detecting faults, among others. KC has deployed focused electrode leak location (FELL) technology to quickly and effectively detect leaks and a network of sensors to track conditions in real time. The Smart Sewer program saves KC money and keeps the cost for ratepayers down.

UK's Network Rail Linear Asset Decision Support (LADS). Project ORBIS, the United Kingdom's digital railway project, sponsored LADS focused on track replacement, a significant budget item. Through the development of improved decision support using a whole-of-system network model, it applied risk and utilization data to save up to 12 percent on steel.

[i] https://blogs.worldbank.org/eastasiapacific/koreas-response-covid-19-early-lessons-tackling-pandemic.
[ii] https://www.power-technology.com/comment/why-augmented-reality-will-increase-safety-and-efficiency-in-utility-sector/.
[iii] Forthcoming KPMG study.
[iv] "Prepare for the Impact of Digital Twins," Gartner, (accessed May 20, 2020).
[v] Intel Strategy Analytics (June 2017). "Accelerating the Future: The Economic Impact of Emerging Passenger Economy," retrieved from: https://newsroom.intel.com/newsroom/wp-content/uploads/sites/11/2017/05/passenger-economy.pdf?cid=em-elq-26916&utm_source=elq&utm_medium=email&utm_campaign=26916&elq_cid=1494219.
[vi] Based on IMD Digital Competitiveness Index
[vii] *Lifelines. The Resilient Infrastructure Opportunity* (World Bank Group publication, 2019).
[viii] *Automated Pre-fabrication* (Global Infrastructure Hub Reference Note),.
[ix] *Smart Metering* (Global Infrastructure Hub Reference Note).
[x] *Intelligent Process Optimization for Water Treatment.* (Global Infrastructure Hub Reference Note)
[xi] *Smart Containers* (Global Infrastructure Hub Reference Note).
[xii] *Smart Parking Infrastructure* (Global Infrastructure Hub Reference Note).
[xiii] *Predictive Maintenance of Physical Assets* (Global Infrastructure Hub Reference Note).
[xiv] *Water Height and Flood Management System* (Global Infrastructure Hub Reference Note).