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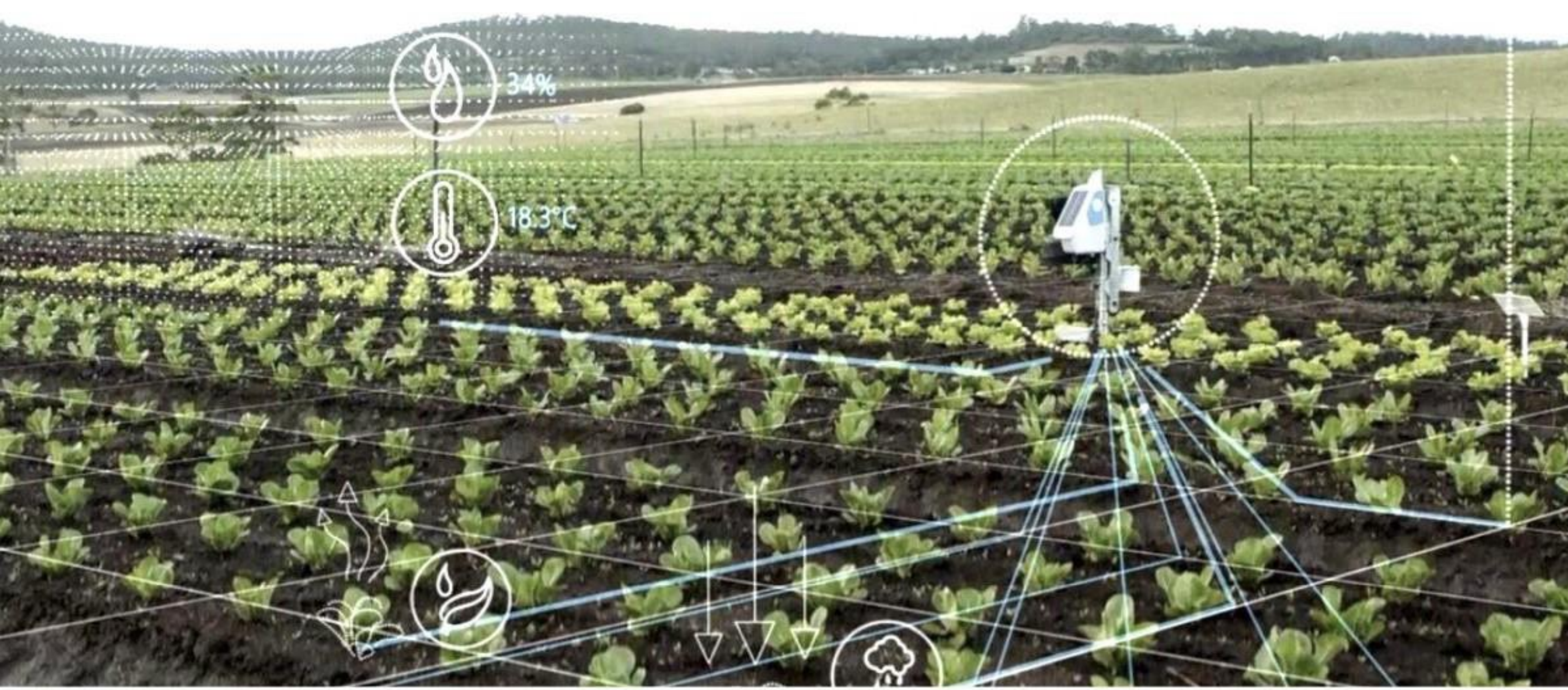
Leveraging Emerging Technologies to Improve Infrastructure Asset Management Practice

Columbia SIPA Capstone | Fall 2022



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List of Abbreviations

ANPR	automatic number plate reading cameras
AoT	Array of Things
APP	application (digital)
BMC	Bhubaneswar Municipal Corporation
BSCL	Bhubaneshwar Smart City Limited
CASTTC	China-Arab State Technology Transfer Center
CCTV	closed-circuit television
C-DAC	Centre for Development of Advanced Computing
CoSiCoSt	Composite Signal Control Strategy
BRI	Belt and Road Initiative
DFI	Development Finance Institution
IAM	Infrastructure Asset Management
IAMs	Infrastructure Asset Managers
ICOMC	Intelligent City Operations and Management Centre
IFC	International Finance Corporation
IO	International Organization
IoT	Internet of Things
IZSU	Izmir Water and Sewage Administration
MRF	Mechanical Recovery Facility
MOOC	Massive Open Online Course
NSF	National Science Foundation
PRASA	Puerto Rico Aqueduct and Sewer Authority
PRHTA	Puerto Rico Highway and Transportation Authority
PE	Private Equity
PRC	People's Republic of China
PPP	Public-Private Partnerships
SCADA	Supervisory Control and Data Acquisition
SDG	Sustainable Development Goals
SIPA	School of International and Public Affairs
SPV	Special Purpose Vehicle
UN DESA	United Nations Department of Economic and Social Affairs
VC	Venture Capital

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Executive Summary

Infrastructure development is a key bottleneck for unleashing sustainable growth in the developing world. Less understood, however, is how much infrastructure asset management (IAM), throughout assets' lifecycle, matters for achieving sustainable growth. Public officials in these roles face numerous challenges, such as budgetary constraints, organizational inefficiencies, political uncertainty, and geopolitical risk. In 2021, the United Nations Department of Economic and Social Affairs (UN DESA) published "Managing Infrastructure Assets for Sustainable Development: A Handbook for Local and National Governments" along with an associated Massive Open Online Course (MOOC) to develop a set of good practices for developing nations.

This report supports UN DESA's handbook by analyzing how smart-city technologies, such as connected sensors and open data interfaces, can improve IAM in the subnational context. We hypothesize that investments in more connected and open data systems can reduce information asymmetry, lower asset management costs, and empower subnational asset managers in executing their strategic management plans.

We look at the potential value of smart city technologies in four case studies: (1) Izmir, Türkiye's use of an open data portal to improve wastewater management; (2) Cairo, Egypt's application of data infrastructure to facilitate peer-to-peer knowledge sharing and help farmers increase yields and public water usage efficiency; (3) Bhubaneshwar, India's utilization of a unified data architecture to improve traffic and air quality management; and (4) San Juan, Puerto Rico's potential adoption of digital monitoring systems to increase climate resilience.

Each case study represents a unique example for how more connected information management systems can assist IAM for a variety of asset types and economic contexts. We find evidence that more connected data systems can lower costs by reducing data siloing and providing new revenue streams via responsible data monetization. We find that open information systems increase transparency and can provide asset managers with a more holistic view of the asset. Finally, we find that smart city technologies provide data to empower subnational asset managers when creating strategic life cycle management plans.

We recommend that subnational asset managers invest in smart data collection technologies that align best with their IAM needs as early as possible in the asset life cycle. This will improve the asset's strategic management plan and lower the cost of technology acquisition. Some of these case studies are in relatively advanced technological spaces, benefiting from unique investment opportunities. As such, these cases represent solutions that are less realistic for many developing contexts. However, these cases are not intended to be off the shelf solutions, but examples of how investments in smart city technologies pay dividends. Finding less comprehensive, or downsized solutions, that match each context and asset portfolio is the ultimate goal.

Introduction

Context & Background

Beset by budgetary and political constraints, officials in developing countries face numerous challenges in managing infrastructure investments. The UN Department of Economic and Social Affairs (UN DESA) has identified infrastructure asset management (IAM) as a key challenge for improving state capacity and achieving the Sustainable Development Goals (SDGs) by 2030. In February 2021, UN DESA and the UN Capital Development Fund published an IAM Handbook (Handbook) and online course to assist subnational asset managers and public officials in maximizing long-run social, financial, and economic welfare. This project centers specifically on IAM at the sub-national level in developing countries and regions.

Objectives

Our research focuses on how innovative smart city technologies can improve IAM processes outlined in the Handbook. We assess the utility of these technologies through the lens of four case studies: (1) Izmir, Türkiye's use of an open data portal to improve wastewater management; (2) Cairo, Egypt's application of data infrastructure to facilitate peer-to-peer knowledge sharing and help farmers increase yields and public water usage efficiency; (3) Bhubaneshwar, India's utilization of a unified data architecture to improve traffic and air quality management; and (4) San Juan, Puerto Rico's potential adoption of digital monitoring systems to increase climate resilience.

Though these four projects all utilize data infrastructure, they represent a diversity of funding sources, users, and levels of technological development. As such, assessing their relative success will enable us to test our central hypothesis—that a more connected and open data structure for subnational assets can reduce information asymmetry, relieve budgetary pressure, and empower subnational public officials.

Through this research, we aim to tell a story through our four case studies in which we learn from projects with more robust financial and technology resources, and use those lessons learned to provide an anchor by which to assess other more challenging scenarios.

Using the Handbook as a backdrop, we will compile learnings and also offer a series of recommendations, including ways in which emerging technologies may be applied.

Theoretical Approach

Infrastructure asset management recommendations for national and subnational actors emphasize a thorough strategic asset management plan for each asset.[1] The Infrastructure Asset Management Handbook provides local and national governments with good practices for balancing political constraints with financial sustainability and an asset life cycle mindset. Asset management information systems are a bridge between operations and the success of a strategy (See Figure 1).[2] Emerging smart city technologies can facilitate this bridge.

Our central hypothesis—that a more connected and open data structure for subnational assets can reduce information asymmetry, relieve budgetary pressure, and empower subnational public officials.

This research will focus on this bridge, asset management information systems, and how new innovations in smart city technologies could provide organizational and process advantages at a low cost for developing and managing subnational infrastructure.

Principal-agent models from the organizational and behavioral economics theoretical literature provide the foundation for the first element of our hypothesis. Whether it be potential moral hazard within an existing contract or adverse selection risk within the structure of new contracts and procedures, organizations face a number of information asymmetries that impede efficiency and coordination. These asymmetries appear everywhere. One can find them between national and subnational entities, between an asset manager and employees, between third party actors and government entities, even within an asset manager's staff.

We are agnostic on the structural orientation of these asymmetries. Every political system, in various stages of development, faces these problems. What a digital asset management information system provides is a way to increase transparency of information such that the efficiency of asset management goes up, and coordination improves.

The immediate benefit is lower costs. However, if better information management provides increased efficiency and better coordination, we also believe that budgetary planning will follow. Useful asset information is accurate and reliable. This makes long term strategic asset management planning more accurate. Most of the costs associated with IAM are life cycle costs, that is, they are spread over the course of the life span of the asset.[3] An asset management information system enables one to build a model of cost into the future.

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[1] United Nations Department of Economic and Social Affairs. "Managing Infrastructure Assets for Sustainable Development: A Handbook for Local and National Governments." *Https://Www.un.org/En/Desa*, UN DESA, 2021, www.un.org/development/desa/financing/sites/www.un.org.development.desa.financing/files/2021-07/IAMH_ENG_Jun2021.pdf#page=207.
[2] Ibid.
[3] Ibid.

Finally, we believe a better road map for life cycle management of an asset empowers subnational entities to make more informed strategic management decisions over the life of the asset(s). More reliable information and an accurate forecast for the life cycle of an asset, also makes one more reliable from a political and economic perspective.

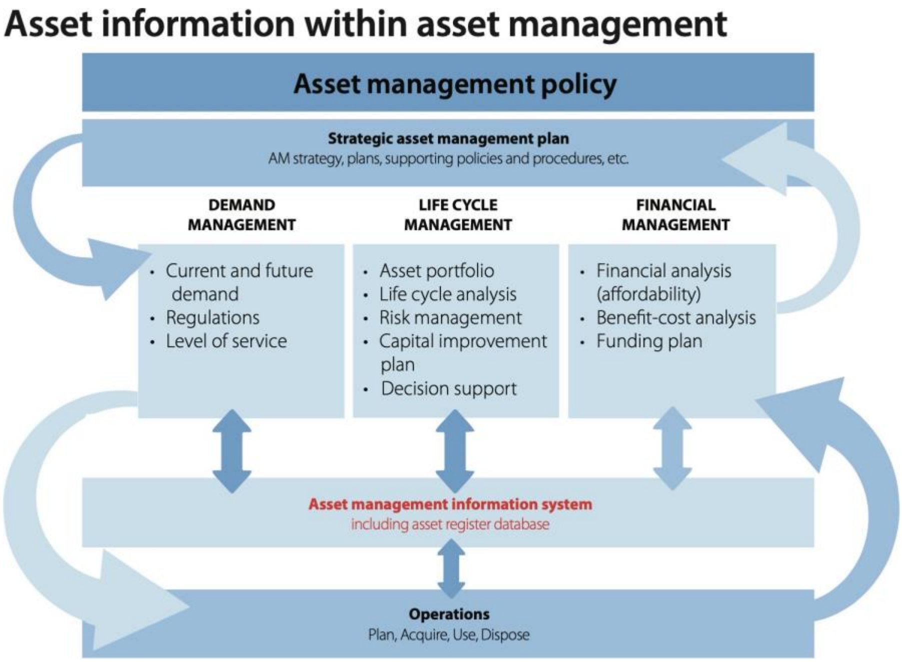

Figure 1 - *Infrastructure Asset Management Handbook*, Chapter 5, Figure 1 - Asset Information within asset management

Methodology

This research employs a qualitative case study approach, focusing on examples of smart city technology projects around the world. It involves a combination of desk research and consultations with representatives of the selected constituencies and various industry experts. For each case, we will utilize the parameters of our central hypothesis to assess the employed technology's ability or success in 1) reducing information asymmetry, 2) relieving budgetary pressure, and 3) empowering the subnational government via improvement in IAM practice.

By sequencing the case studies from the relatively more developed economic context to the less developed ones, we intend to juxtapose the insights and explore feasibility of adopting smart city technologies in the former to the latter. Key information for the four case studies is synthesized in Table 1 below.

	Izmir, Türkiye	**Cairo, Egypt**	**Bhubaneshwar, India**	**San Juan, Puerto Rico**
Physical Asset	Waste & water facilities; air quality monitors	Drip pipes, sensors, solar panels and wind turbines, smart water-extracting equipment	Interconnected system of smart traffic lights, cameras, and air quality sensors	Post-natural disaster infrastructure assets
Information System	Open data dashboard	Open data dashboard Internet of Things	Consolidated dashboard, remote system updating mechanisms	Internet of Things / Array of Things
Data Collection Mechanism	Centralized and published open-source data on physical assets across municipal departments	Distributed field sensors that provided open-source data about rainfall, humidity, light intensity, irrigation level, drip pip pressure, and water consumption.	Consolidated metrics from various data sources integrated into a centralized hub.	AoT monitoring nodes to provide real-time data on public assets
National Income level (2021) measured in GDP, GDP per capita, GDP growth[4]	$0.815 Trillion $9,586 per capita 11%	$0.404 Trillion $3,876 per capita 3.3%	$3.17 Trillion $2,277 per capita 8.9%	$0.1 Trillion[5] (USA: 23 Trillion) $31,429.90 (USA: $69,287 per capita) -6.5% (USA: 5.7%)
Data collection frequency and monitoring	Periodic monitoring	Continuous and just in time	Continuous and just in time	Continuous (could be contingent on climate event)
Funder	International Finance Corporation (IFC)	Belt and Road Initiative (BRI), People's Republic of China (PRC), and private contractors	Bhubaneswar Smart City Limited (Special Purpose Vehicle), IFC	Federal and State funding
Technology Procurement	Private companies	Private PRC companies	Private companies, government research organizations	City gov. & private companies
Asset Manager	City government (IZSU)	Academia - university labs	City government	City government

Table 1: Case Studies Key Information

[4] "GDP (Current US$) - Egypt, Arab Rep., Turkiye, India, Puerto Rico, United States." Data. Accessed December 6, 2022.
https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?end=2021&locations=EG-TR-IN-PR-US&start=2018.

[5] Puerto Rico's values are based on 2020; USA are based on 2021.

Case 1: Izmir, Türkiye

Case & Asset Overview

In this case, Izmir's municipal government partnered with the International Finance Corporation (IFC) in 2020 to raise capital to implement an open-data portal. This portal synthesized information collected on the city's various assets and published it as a resource for residents to keep them notified on the status of various services in the city. This open data framework has been applied to a suite of municipal assets across sectors, including water, waste, transportation, electricity, and internet. In the context of this report, we focus on three physical assets in particular whose management has been affected through this intervention: waste management facilities, the Supervisory Control and Data Acquisition (SCADA) water management system, and air quality monitoring stations.

Each of these three physical assets consists of different technologies and tools. The city's waste management system utilizes a Mechanical Recovery Facility (MRF) which uses anaerobic digestion and compost to separate out waste materials that can be recycled into biogas; in doing so, the facility relies upon an excavation software automation system. Izmir's air quality systems, on the other hand, consist of stations located across the municipality which collects data individually. Finally, Izmir's water management system, organized under a sub-municipal legal entity named the Izmir Water and Sewage Administration (IZSU), consists of the centralized water distribution and supply; this includes everything from pipes to water treatment plants to stormwater and sewage collection infrastructure.

Given the cross-cutting nature of this data collection effort, and the high volume of data centralized and published, this case is arguably an example of a robust and comprehensive implementation of open data solutions for infrastructure asset management.

SDGs Addressed

IAM Challenge Addressed

Data Siloing

As with any subnational entity tasked with serving a large population, especially one in an emerging market, Izmir faced several headwinds in upkeeping its many infrastructure assets, communicating the state of these assets to the populace, and doing so in a cost-effective way. By mobilizing IFC capital to comprehensively collect and verify data, Izmir has begun the process of making its IAM more efficient.

For one, this data portal has allowed for more accurate, easier, and up to date monitoring of the underlying assets as well as operational processes. Additionally, compiling all the data in one place mitigates the risk of information silos between different arms of the municipal government, an organizational challenge that continues to plague subnationals in both developed and developing countries. With this data in hand, citizens and businesses can potentially make more informed decisions on where to live and open up shops.

Utilization of Data Infrastructure and Emerging Technology

In compiling data from the city's 39 various departments and associated companies, Izmir and IFC utilized existing digital infrastructure programs including IzmirNet, WizmirNet, and BizIzmir and synthesized this data into the centralized portal. In implementation, the city created an Open Data Unit and worked to ensure that the underlying digital systems were in place to support the high amount of data needed for the portal. Given that the data came from various sources and agencies, verifying the quality of each data point is essential. To this end, Izmir implemented a set process in uploading any data to the portal, which consisted of a multi-step process of: assessing value and utility of data if there is even demand for the population for it; any legal hurdles or concerns in data publication; verification of data source and its validity; obtaining approval permits for the data publication; assessing the update schedule of the data and communicating that accordingly; identifying the data owner within Izmir and who is responsible for the dataset's maintenance and a contact point; application of an open data license; assessment of privacy risks to ensure that publication of data is appropriate; publication of the data; and finally, ensuring that the data's release is publicized and communicated to residents.

In addition to this process, Izmir also implemented a knowledge and training plan for its officials. This included training for select staff who would be tasked with collecting, implementing, and updating the data. Embedded in this training is a focus on the importance and benefits of open data, but also the importance of standards and making sure that privacy concerns are always accounted for. Additionally, standardized documentation and data upkeep procedures are also included in training to ensure that data quality does not degrade over time and that different portions of the data set do not once again become siloed.

Lessons Learned and Potential Applications

Importance of Cross-Sector Applications of Open Data

One notable element of Izmir's open data project has been its cross-sectoral nature, in which data has been collected from services as disparate as water, waste, wireless, roads, and air quality and centralized into one place. This makes accessing a wide range of data easier for residents, who can view relevant information in a one-stop shop.

From a cost perspective, this more holistic approach could be even more important in countries at a lower income than Türkiye, where the high upfront fixed cost of data infrastructure installation can be smoothed-out by ensuring that the system is applied across the management of municipal services. As this report will discuss in its analysis of San

Juan, Puerto Rico, this cross-agency interconnectivity through Area of Things (AoT) and Internet of Things (IoT) frameworks (through which real-world physical devices are interconnected through software to transfer data to each other over the internet) could provide IAMs with an expanded toolkit for managing their cities' assets at a relatively lower cost.

Process-Oriented Approach to Data Management

Although the data collection process and implementation of the data system was a tremendous undertaking requiring a significant DFI investment, the IFC has stressed that ongoing training of public officials and municipal staff is equally vital to ensuring that the data remains up to date, reliable, and usable by the population. Through its partnership with IFC, Izmir was able to utilize the DFI's capital and advisory services to help it establish an extensive set of best-practices and training for its officials. For other developing countries, this experience could be demonstrative for how to approach IO capital; namely, to pair financing with advisory services. In its section on Public Financing for Municipalities, this report will broach the subject of external funding for developing country subnationals in more depth.

Opportunity in Reduction of Information Asymmetry

This open data project is unique among the cases we analyze is its publicly disclosed nature, in which residents of Izmir can access this data live and contribute input themselves. On the governance front, the project has also added an element of transparency for Izmir's population, wherein citizens can raise problems and discrepancies between the data on the portal and what they experience in reality; in the long-run, this data transparency has the potential to reduce information asymmetries between Izmir's populace and asset managers.

Case 2: Cairo, Egypt

Case & Asset Overview

A smart and green irrigation project in Cairo, Egypt, bridged by China's Belt and Road Initiative (BRI), is another example of the application of open data infrastructure. The system is utilized by a mango farm, close to the desert highway linking Cairo and Alexandria. In this instance, the subnational governments, Cairo and Ningxia (China), aimed to improve agricultural productivity in a cost-effective and climate-resilient manner. Via a data sharing mechanism and a system of remote controlled smart devices and applications, the project increases transparency and allows subnational government counterparts to manage agricultural and water assets.

SDGs Addressed

Stakeholder Relations

This project showcases how cross-national cooperation can be additive to subnational IAM. The facility that carries out the partnership is a technology transfer facility between China and Arab States that primarily focuses on smart irrigation in arid ecosystems through the project named "Ningxia (China-Arab) Key Laboratory of Resource Assessment and Environment Regulation in Arid Region." This project (the Lab) was founded in 2016 by Ningxia University in Yinchuan, and approved by the national Ministry of Science and Technology in response to a BRI program called the China-Arab State Technology Transfer Center (CASTTC). The CASTTC, established in 2015, aimed to actively engage irrigation solutions between Chinese and various Arab States countries.

For the development of this project, Ningxia University contributed $200,000. Together with Egypt Agriculture Research Center's desert farm, they built two 50-acre experimental irrigation farms. Ain Shams University received the technology and is responsible for technology localization, which transfers knowledge to local farmers on how to use the system in their own farms.

Another key stakeholder in the project is West China Electronic Business Co. Ltd, a private company that builds platforms to accelerate academic research. After the proven success in mango farms in Egypt, the company has played a key role in scaling up the technology in other countries. The company sells a packaged service that includes both physical assets like dripping pipes, sensors and operating software and earns revenue. After a sale, it manages maintenance and upgrades of the physical equipment and the software to monitor the agricultural assets. West China Electronic Business Co. created an application (APP) that enables farmers and researchers to remotely monitor the corps via smartphones. The APP displays real-time conditions of the crops, signals updates, and alerts actions in-need.

The physical irrigation devices source their energy from newly constructed solar and wind farms. The irrigation pipes are also installed underground to shield the system from ultraviolet radiation. The project placed sensors near the crops to track humidity, soil quality, and other environmental data. In addition to using open data, it also manages irrigation with the Internet of Things (IoT) and precision irrigation to conserve resources. As a result, the project reduced the labor to land ratio and reduced water use for agricultural irrigation by 50%. Additionally, it improves asset monitoring and extends the service life of physical assets. According to Zhaojun Sun, Dean of the School of Resources and Environment of Ningxia University and the Director of the Lab, the project saw significant improvement in yield and savings in cost credited to the irrigation system.[6]

IAM Challenge Addressed

High human capital cost

Before the project is implemented, farmers need to stay on their farms and personally check the conditions for plant growth, which is time-consuming and requires massive investments in human capital. The system now enables remote monitoring and maintenance thanks to IoT, in which farmers can now use their mobile phones to check the data. The system will make recommendations on irrigation based on the data that has been processed, examined, and studied at Ningxia University. As a result, the ratio of labor to land was reduced from 18:1 to 1:1 from the mango field pilot project.[7] For the municipality, it is easier for the government to monitor the yields, agricultural meteorology and farm irrigation, as well as promote stronger development in the agricultural sector in the future.

Limited natural resources

Egypt's lack of water resources is a problem due to the country's ongoing drought, changing climate and ineffective use of water. The system is located close to the desert highway linking Cairo and Alexandria. In this environment, water resources are limited. The system addresses this problem utilizing precise irrigation and delivers water to plant roots directly, which has reduced water usage by 50%.[8] Egypt can still develop agriculture in the future if the system is dispersed around the country despite its limited water supply. In addition, the system uses solar and wind energy to power the infrastructure that limits greenhouse gas emission and poses low pressure to the local grid.

Utilization of Data Infrastructure and Emerging Technology

In Egypt's application of IoT technology, farmers can monitor the environment where their plants grow and adjust irrigation operations via mobile phone software. This is made possible by a system of underground pipelines equipped with sensors for measuring soil temperature and humidity. Underground drip pipes enable precisely managed water delivery,

[6] "中埃农业合作亮点纷呈"Highlights of China-Egypt Agricultural Cooperation, accessed December 10, 2022, http://www.chinaarabcf.org/zagx/gjydyl/202202/t20220224_10645092.htm.
[7] Ibid.
[8] "China-Arab Technology Transfer Deepens BRI Cooperation,", April 28, 2019, https://www.sohu.com/a/310808573_267106.

which is an improvement from traditional irrigation practices. The decision maker, the mango farmers, only press the button when they have a clear picture of all of the data collected from the sensors and off the ground—processed by the IoT system to display the effective rate of rain and evaporation rate. The decision making process is facilitated with recommended actions given by subject-matter experts who monitor the field separately.

The system, including the hardware and software, gathers information from daily activities including rainfall, irrigation level, plant yield and productivity, drip pipe pressure, carbon dioxide concentration, and light intensity, etc. After collection, data is sent to the university to be evaluated and processed. By building a forecast model with accumulated data collected in a long term horizon, these data enable Lab researchers to generate strategies on whether and when to execute the irrigation using the university's expertise in agriculture. These datasets and strategies generated from backstage analysis are shared with the farmers. Open data architecture enables peer-to-peer information transfer from the lab to the farm.

These technologies are all transferred from Ningxia University to Ain Shams University under the Lab. Technology localization, incorporating local resources, labor, and services, fostering local businesses, and supporting implementation are localized and implemented by Egyptian stakeholders. More than 150 people, including agriculture efficient water technology personnel and farmers, have received training to safeguard long-term asset management.

Lessons Learned and Potential Applications

Physical devices bundled through IoT can be applied in general farming industry

Smart and green irrigation systems effectively improves water-usage efficiency and saves production costs for managing agricultural assets. Bundling with the physical sensors, the software designed for auto irrigation adjusted to real-time absorption conditions can be applied to improve the efficiency of other production activities beyond the agriculture sector. For fishing, seafood farming, and livestock farming sectors, the open data dashboard and IoT system are also applicable by capturing and processing natural conditions and auto-reacting correspondingly. Depending on the natural endowment, for local governments that must help its local first industry businesses adapt to rising environmental challenges, using IoT to capture production efficiency and identify points for improvement is a critical first step.

In Cairo's case, water-saving is not possible without a sound understanding of precisely how much to irrigate and at which part of the mango trees to irrigate. The sensors and the dripping mouths placed in the soil will be useless without being triggered remotely. Quantifying natural conditions and driving analytical output enables informed decision-making; massively deployed output signal devices like temperature, moisture sensors and labor and delivery equipment like irrigation drip lines enables remote controls.

Open data, or data that is free for everyone to use and enhance, is the core to the success of this project. Should this same data framework be applied to agriculture in other developing countries, there could be further potential gains for water infrastructure and data tracking for those subnational governments as well.

Actively engage academia know-how in life cycle asset management

Collaboration scheme between Ningxia University and Ain Shams University in this case demonstrates the possibility to move innovation from lab to field and achieve commercialization. Notably, these two universities are located in arid or semi-arid geographical regions where agricultural sustainability is at the heart of local development. The partnership is based on sound subject-matter motivation. It manifests the core of the 17^{th} Sustainable Development Goal (SDG) iterating on the idea of partnership in achieving sustainable development.

With the involvement of research institutions like academia, the project secures itself with a third-party stakeholder whose engagement mitigates political risks from the public sector, such as change of local administrations, funding and political agenda, and eases financing stress from the private sector, such as securing funding or demonstrates cost efficiency at very early stage. Such a structure is more stable for long-term maintenance and operation in infrastructure asset management life-cycle. The know-how capacity from universities also enhances the results-driven motivation for all stakeholders.

In an interview with Mohamed Wahba, the Vice President Honoraria of the International Commission on Irrigation and Drainage (ICID), chairman of the African Regional Working Group, and the ex-chairman of the Egyptian National Committee on Irrigation and Drainage (ENCID), capacity building was identified to be at the center for any city to manage irrigation system assets after a pilot program has proven the upleveled efficiency for small irrigation farmers and a larger scale application is ready to be put in place. Wahba stressed the need for “an integrated approach that could be implemented . . . through research centers and training centers” which focuses on “increasing the capacity of staff, starting from technicians, engineers, decision makers, [and] stakeholders.”

Zooming out from the technical support facilitated by the academic counterparts hosted under the Lab, ICID functions in a similar way as it provides technical knowledge to young professionals, small farmers, women and children in the local community.

Rising interest seen in private investment pinning on the proven technology and locked-in revenue through pilots

VC does not normally take infrastructure related risks, but flexible ways to tie VC if the underlying scalable model is possible, investing in companies developing innovation improving the efficiency or reducing cost of asset management. Diversifying the portfolio, and large public funding through policy initiatives like the BRI or Inflation Reduction Act (IRA) are intended to lower financial risks associated with long-term research and development (R&D) and deployment. Early derisking used to support subcontractors facilitating infrastructure asset management is likely to attract investors focused impact (e.g. family office, and impact investment and venture capital funds). “I anticipate funding for innovation to continue to accelerate in the venture capital space, supplemented by ‘non dilutive’ capital, such as increasing government assistance. Return-driven, actively-managed private equity will be primarily placed post technology being successfully demonstrated in real world applications and after indications of profit market fit have been established. Concrete metrics for measuring impact will be of increasing importance and will need to fit into rubrics and auditing processes that are still being created," said Kim Kolt, co-founder & general partner of Bay Bridge Ventures. Kolt also explained that separating a physical development project into specific modules or phases, each with different risk and return profiles, will be more attractive to private equity investors and other forms of financial products catering to different risk appetites and investment horizons. "Look at commercial real estate finance as an example of how segmentation and specialization in new physical assets addressing climate change may unfold." Similar cases like Cairo would be attractive for impact vehicles because impact is proven through pilot projects in Arab States including Egypt under the Lab, government funding, and new forms of equity financing de-risking financial risks for venture capitals.

Wahba pinpointed that quality pilot programs for smart irrigation systems are frequently used for scaling up solutions on local levels, because they are the most efficient way to demonstrate the benefits of the system to farmers. "It was clear for all the farmers about the benefit, which is the gains from improved soil, controlled salinity, and the increased final yield." Wahba commented, "If we don't have this kind of pilot project, it is difficult for farmers to know." As such, pilot programs should be operated in accordance with open-data principles, for which all of the information collected is shared, "so farmers come and see, discuss in between themselves if they see a neighbor, and then be convinced to take a next step."

Applying the pilot model from this project as a starting point could act as an impetus for developing country subnationals to test the viability of these IoT solutions for improving management of agriculture and irrigation to build climate resilience and more efficiently use resources.

Case 3: Bhubaneswar, India

Case & Asset Overview

Bhubaneswar, one of India's premier smart cities, provides an example of an integrated system of physical assets and data architecture that synthesizes data collection management across city departments and services to assist in the management of the municipality's underlying assets. In this case, Bhubaneshwar Smart City Limited (BSCL) partnered with various technical and implementation partners (i.e. Honeywell Automation Limited) to design a framework for a centralized hub, the Intelligent City Operations and Management Centre (ICOMC), that integrates existing and future data and technologies. In parallel, various technologies have been implemented across development sectors such as traffic, safety, and environmental improvement. These technologies allow for integration of data collected from their respective physical assets, and over time their data will flow into ICOMC operations and management.

Various assets are being developed for projects across the city. This case highlights three in particular. First, the city is implementing an array of pedestrian light controlled (pelican) signals for traffic control. An adaptive traffic signal control system is being developed to integrate traffic data and operations. The traffic control system utilizes a technology called the Composite Signal Control Strategy (CoSiCoSt), an application developed by Centre for Development of Advanced Computing (C-DAC). Through CoSiCoSt, traffic intersections may be better controlled, as the system responds to changes in traffic patterns in real-time and calculates optimal signal timings based on the detected volume of traffic. As a result, drivers can benefit from reduced delays, shorter queues, and increased safety due to the decrease in road congestion. Bhubaneshwar has also installed hundreds of closed-circuit television cameras (CCTVs) and automatic number plate reading cameras (ANPRs). A command and control center will manage and operate a target 350 CCTV cameras installed at 90 locations. Lastly, the city has also installed environmental sensors for air quality monitoring. Aurassure, an environmental technology company, has developed an IoT-enabled intelligent system to address environmental concerns effectively. Their air monitoring devices are being installed in various locations across the city to monitor various environment gasses, dust and weather parameters. Key metrics are collected and reported via a real-time dashboard, and devices can be maintained and updated remotely.

In addition to the logistical framework, the financial implementation for this project offers a blueprint for other cities. Specifically, this strategy will be implemented through a Special Purpose Vehicle (SPV), which includes the Bhubaneswar Municipal Corporation (BMC) as well as the IFC. headed by a CEO. Support is provided by a Smart City Advisory Forum, an inter-departmental task-force, and a range of partnerships.

SDGs Addressed

IAM Challenge Addressed

Streamlining of various development efforts

As discussed in the analysis of the Izmir case and of IAM more broadly, one persistent need in cities around the world is the lack of cross-cutting, centralized data solutions. This is particularly applicable in a city like Bhubaneswar, which has become a focus of global development financing. Ensuring that data collection and tracking is integrated and centralized is crucial to helping Bhubaneswar's public officials more effectively manage their traffic and air quality. By implementing solutions that not only utilize physical assets but also provide improved data system applications, Bhubaneswar has an opportunity to streamline efforts to monitor and evaluate performance of these infrastructure investments.

In terms of the specific infrastructure assets in question, data quality is highly relevant. Air quality issues are endemic for many cities like Bhubaneshwar, and a system that allows for a more streamlined and efficient data collection will help public officials address these issues; the inclusion of IoT technology to this end is expected to bring further benefits. Traffic issues are also a persistent issue in the city (as with many developing country cities), and the monitoring systems which are interconnected through this data infrastructure are vital in helping public officials monitor the state of traffic density and manage road infrastructure accordingly.

Through this data program, Bhubaneswar has invested in a variety of development projects to improve city infrastructure. The resulting increase in efficiency is large in part due to the ICOMC, which will provide an architecture to link complementary efforts as well as track various metrics that are unique to and shared by various projects across sectors.

Utilization of Data Infrastructure and Emerging Technology

In Bhubaneshwar's application of data integration, the ICOMC, the municipality can not only monitor asset performance from a centralized hub, but also monitor and evaluate data in real time. Various smart city development projects across the city have been implemented, most of which utilize a system of data collection from a sensor or device. The promise of the ICOMC is that it can intake data from various sources and safely store them in one place. In this case, data is collected from the pelican signals, CCTV and ANPR cameras, and environmental sensors. Data are collected from these sources routinely, and asset managers sitting in the ICOMC may analyze these data to make just-in-time decisions. Over time, information technologies including IOT and neural network algorithms may be integrated to enhance the system's ability to predict warning signs.

Over time, the ICOMC will be able to integrate not only traffic, safety, and environmental sensors, but other technologies as well. The architecture designed will allow for integration of new services including a common payment card, transit operations, and emergency response services. Furthermore, city services such as water, waste, and energy may be linked in via fiber optic cables and wi-fi access points. The data collected by the ICOMC may be utilized by various departments including education, health, and social welfare.

On top of the data infrastructure optimized for municipal administrators, a citizen interface is being developed as well. Through this, data may be accessed through web portals, mobile apps, and variable message sign (VMS) boards. Currently, discussions are underway regarding the ownership of all this centralized data. Some argue that big data should be publicly owned to enhance accountability and the rights of the users of the public goods produced by infrastructure assets. Monetization of data can not only be a cost saving opportunity and minimize risks, it can also generate revenue. Arguably, these high value datasets are valuable to businesses, developers and non-profit entities in order to foster a data-driven ecosystem of innovation. A deliberate vision and strategy to ethically monetize big data related to IAM over the assets' life cycle can be a material source of revenue to local governments, particularly to finance their maintenance costs.

Lessons Learned and Potential Applications

Importance of Early Investment in Data Collection Capacity

The example of Bhubaneswar has shown that a centralized, integrated, and cross-cutting data infrastructure can be implemented in cities at various points of the development spectrum. While Izmir's open data portal offers an expansive data system implemented through a DFI capital infusion, Bhubaneswar's system is funded by the local government without DFI support, but rather through partnership with various private sector partners.

Additionally, India's status as a lower-middle income country, as opposed to the higher income level of Turkey, shows that this model, if adjusted in implementation, has the potential to be viable for less developed countries as well. In fact, investing in this infrastructure early could lay the foundation for further building out of the data infrastructure as the municipality's capacity increases over time.

Benefit of Integrated Data Systems for Physical Assets

As with Izmir, the benefits of integrated data systems in Bhubaneswar consist of more reliable and easily accessed data, in this case for public officials specifically. When it comes to traffic systems and air quality sensors, the importance of data quality and access is even more important. The data architecture installed through this project is necessary in ensuring that these data is centralized and therefore easily accessible and usable for IAMs.

Facilitation of data-driven decision making and governance

In addition to the challenge of decentralized data networks, the availability of data itself is a persistent challenge for Bhubaneswar and comparable cities. Bhubaneswar's smart city investments have addressed this issue by increasing the availability of data, which can be leveraged to inform decisions in urban planning, infrastructure investment, service delivery, and asset management. Additionally, these data can reduce levels of information asymmetry between governing bodies and asset managers, which in other instances have led to the misuse of resources or lags in development project timelines.

Case 4: San Juan, Puerto Rico

Case & Asset Overview

San Juan, Puerto Rico represents a challenging case study for applications of smart city technologies to facilitate information systems for IAM. Puerto Rico's tenuous political status; a US territory, but not a state, complicates the island's access to federal funding and economic opportunities. In theory, the island is directly connected to the largest economy in the world and should have access to the most advanced technology on the market. In practice, the effects of deindustrialization, uneven political leadership, and underutilized tax incentives, have saddled Puerto Rico with increasing budget deficits and a dearth of economic investment opportunities.[9]

In this case, the public services in question are the city's public road network and its water supply and wastewater. The former is managed by the Puerto Rico Highway and Transportation Authority (PRHTA) and the latter is managed by the Puerto Rico Aqueduct and Sewer Authority (PRASA). Both asset managers have faced immense challenges in the wake of hurricane events. Residual flooding along transportation networks, failure to deliver clean water, and the frequent wastewater overspill. Each of these problems has hampered post-storm recovery and places immense strains on maintenance and organizational capacity.[10, 11]

Our hypothetical solution is to take advantage of the access to advanced technologies found in the mainland US and install an Array of Things (AoT) system to assist with data collection and management for these assets. Flowing from our hypothesis, a smart data system that can collect data on the status of road and water supply systems has the potential to assist with post-storm maintenance by improving accountability and organizational capacity. The system can also reduce human capital costs and improve safety in storm and post-storm situations by remotely assisting with data collection and analysis.

One example is the "The Array of Things" project, a partnership between Argonne technology, the University of Chicago, and the National Science Foundation (NSF), for usage in urban areas and cities. This AoT project aspires to foment an urban-scale instrument for research and development to be applied to a myriad of disciplinary fields. The successful realization of this aim will necessitate data collection, such as the instrumentalization of cities with new types of sensors and measurement strategies.[12]

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[9] Stojanovic, Lorae Stojanovic, and David Wessel. "Puerto Rico's Bankruptcy: Where Do Things Stand Today?" *Brookings*, 17 Aug. 2022, www.brookings.edu/blog/up-front/2022/08/17/puerto-ricos-bankruptcy-where-do-things-stand-today/.

[10] Fine, Camille. "Hurricane Fiona Floods Homes, Streets in Puerto Rico: See the People and Places Impacted." *USA TODAY*, 19 Sept. 2022, www.usatoday.com/story/news/world/2022/09/19/hurricane-fiona-puerto-rico-damage-photos/10430023002/.

[11] Romo, Vanessa. "Puerto Rico Has Lost More than Power. The Vast Majority of People Have No Clean Water." *NPR*, 20 Sept. 2022, www.npr.org/2022/09/20/1123984002/hurricane-fiona-puerto-rico-lost-more-than-power-vast-majority-no-clean-water#:~:text=Vast%20majority%20has%20no%20clean%20water%20%3A%20NPR&text=Press-.

[12] Catlett, Charles E, Rajesh Sankaran, Peter H Beckman, and Kate Kusiak Galvin. "Array of Things: A Scientific Research Instrument in the Public Way." *SCOPE*, April 21, 2017, 1–9.

This AoT technology could be beneficial to San Juan, Puerto Rico. The integrated CCTV and atmospheric monitoring capabilities could help with prioritizing maintenance, observing safety conditions and testing toxic wastewater. Moreover, Puerto Rico is planning an infrastructure rebuild with smart city technology, with an emphasis on risk management. Puerto Rico is one of the leading Hispanic-Caribbean countries on IoT and smart city technology. We propose that San Juan adopt AoT technology to enhance data collection to improve IAM and climate resilience.

SDGs Addressed

IAM Challenge Addressed

Budget constraints

In implementing AoT, Puerto Rico faces a budget constraint, due to its challenging political economy. Puerto Rico is part of the world's wealthiest country; yet, at the same time, it is hamstrung by economic and political headwinds. Puerto Rico's low fiscal base and limited economic leverage deepens the constraints to expenditure on infrastructure management. The per capita income on the island is less than half of that on the US mainland as a whole. Although this is nominally the richest subnational case in this research, at mainland prices for goods and services, the income differential represents a particularly hard economic case to present a possible technological solution for improving IAM. We are proposing that affordable, high-tech investments, such as AoT, can change this dynamic.

Climate resilience

Puerto Rico's location makes it particularly vulnerable to climate change. The island territory is located at the eastern end of the Caribbean island chain, placing it in the center of "hurricane alley," the route that warm moisture and high pressure storm systems take into Central America. With rising sea levels resulting from a warming climate, Puerto Rico has already seen the effects of climate change on the intensity of storm systems in this region. Most climate scientists expect this trend to continue to get worse throughout this century.[13] The implication for IAM in Puerto Rico is that climate resilience is increasingly a primary concern for the long-term sustainability of basic public services. For this case, recovery after hurricane events is a yearly concern for road utilities, maintaining safe drinking water delivery and removal of waste water.

[13] Colbert, Angela. "A Force of Nature: Hurricanes in a Changing Climate." *Climate Change: Vital Signs of the Planet*, 1 June 2022, climate.nasa.gov/news/3184/a-force-of-nature-hurricanes-in-a-changing-climate/.

Utilization of Data Infrastructure and Emerging Technology

The Existing AoT Project in Chicago, Illinois

One of the main cities in which AoT has been installed and seen as an example for San Juan to follow has been in Chicago, Illinois, United States. AoT currently serves as a "fitness tracker" for the city of Chicago, Illinois. It does so by measuring factors that affect the livability in Chicago; such as: climate, air quality and noise.[14] In collaboration with the Chicago Department of Transportation (CDOT) Division of Electrical Operations (DEO), approximately 130 AoT nodes were installed between 2018-2020. A fully-equipped node costs roughly $2,500, for parts and assembly.

Chicago has received diverse funding for AoT research. Preliminary research was conducted at the University of Chicago on a $3.1 million grant from the NSF. The AoT project also received smaller investments from the Chicago Innovation Exchange and from the Argonne National Laboratory. Additionally, the City of Chicago has provided in-kind support via the installation and power for the nodes.[15] The full implementation of the AoT would necessitate partnership with the city government; particularly, with units that install and manage public infrastructure. This divide would also need to deliver value over an extended period of time.

The AoT project was designed to be implemented in other cities as a turnkey data collection system. The potential vision for San Juan would be to install a similar network AoT geared towards climate response as an extreme variation of livability monitoring purposes seen in Chicago. Placing nodes in key road arteries to track flooding and assist with recovery logistics. Placing unique sensors on major piping systems and sewage lines to track water quality. Even after pumping stations and water treatment facilities are brought back online, contamination and spillover issues plague the recovery effort to deliver clean water and remove waste water safely. Such a network could provide an improved map of where contaminated water might be, which pipes or pump systems might be inoperable or in need of repair, and help the direction of aid to areas without clean water.

Lessons Learned and Potential Applications

Take advantage of technology access

San Juan's major advantage compared to other developing countries and territories is its easy access to the US technology marketplace. The US has other cities near the gulf that have suffered persistent flooding and hurricane related damage. This presents an opportunity for sharing lessons learned, technologies used and organizational strategies. The availability of accurate data can aid in this shared effort to respond to climate events.

Privacy and Data management considerations

Most of the proposed data accumulation is environmental and not private or sensitive. However, some CCTV footage may potentially capture citizens on video without their consent.

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[14] Catlett, Charles E, Rajesh Sankaran, Peter H Beckman, and Kate Kusiak Galvin. "Array of Things: A Scientific Research Instrument in the Public Way." *SCOPE*, April 21, 2017, 1–9.
[15] Ibid.

The selection of sites for AoT nodes in Chicago is determined by a rubric that prioritizes: interest, or concern, from the residents; an engaged science team and a relevant city official interested in analyzing the data.[16] A similar approach should be taken in San Juan to observe privacy standards. Similar to the Bhubaneswar case study, asset managers should be cognizant of the risks when designing technology contracts with third party actors so as to protect private citizens data.

Limitations of the current AoT Technology

Chicago's AoT nodes measure temperature, barometric pressure, light, vibration, carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, ambient sound pressure, and pedestrian and vehicle traffic. The research to include new sensors on these nodes is in progress, including to observe flooding and standing water.[17] This is to say, tracking clean and waste water would still require an engineering solution to assist PRASA in a post-storm event.

Another limitation is the post-storm environment. One of the main considerations after a hurricane in Puerto Rico is maintaining power to the island. This can take days to restore. In that interim, when the power grid is partially off, areas with these nodes installed would be inoperable. The potential for a solar powered variant of these nodes could circumvent this node provided that satellite internet connection continues to service the island. However, this does not help with the infrastructure assets that require power, such as the pumping stations and water treatment facilities.

AoT Funding

Like many of the smart city technologies discussed in this report, this will add higher costs that IAMs will need to account for in the short-term. Following the Chicago model and seeking funding from US federal entities, such as the National Science Foundation could help. San Juan can also work with Puerto Rico's Department of Economic Development and Commerce as well as Puerto Rico's Science, Technology and Research Trust for financial and ideological support in the AoT project. Private funding sources from US companies operating on the island can also aid in investing in climate resilience initiatives, including: Intel Corp., AT&T Inc., IBM, Microsoft Corp. and Hewlett-Packard Co. Finally, Puerto Rico's low tax climate creates footholds for large firms that would mutually benefit from improved IAM in San Juan.

[16] Ibid.
[17] Ibid.

Financing and Funding for Emerging Technologies

Financing for Municipalities

Given the fiscal challenges that subnationals in developing countries face, identifying the most efficient and effective channels for financing infrastructure projects is vital. When it comes to providing funding for municipalities and local governments, funding from national governments can often be the first and most obvious source of funds. As discussed, however, this funding in developing countries is often subject to fiscal constraints that those national governments themselves face; additionally, strengthening subnationals' ability to be resilient and self-sufficient in their own right will help improve IAM in the long-run.

As such, focusing on non-central government sources of funds could be useful for municipalities to consider. For one, financing from IOs such as the World Bank, BRI, and IFC (as we have seen with Izmir, Cairo, and Bhubaneshwar). Though this funding can be useful in providing the initial investment for the implementation of comprehensive data infrastructure projects as discussed in this report, the long-term maintenance and operations cost of these efforts require a sustainable source of income. In this context, blended finance - in which one lender, often a DFI, takes on a riskier tranche of debt so that other lenders can join the credit facility with more favorable terms - has emerged as a useful tool in incentivizing investors to provide more debt financing to developing country subnationals.

Through all these potential sources of funding, an important consideration is the financial viability of the project on an ongoing basis through either revenue collection or (more applicably in our cases), the cost savings for the municipality as a whole that comes from the efficiency gains of these data and technology interventions. On the revenue front, data mismanagement concerns can be addressed through funding incentives of maintaining control of IAM data by the managers and not outsourcing data management to third party actors. In the case of Bhubaneshwar, for example, installing data monitoring systems will collect vast amounts of data that could be monetized without divulging personal information. If the municipality can actualize this revenue, this will reduce lifetime costs of managing both the assets and the data management system in question. This has the added benefit of maintaining public data outside of firms that are less accountable to the public.

On the cost front, our cases can also be demonstrative. To the extent that a cross-cutting open data portal in Izmir and Bhubaneshwar can save asset managers' time by having all the data in one place, for example, this can streamline IAM in general. In Cairo, meanwhile, increased efficiency of water use has the potential to help reduce the cost of water system management in the municipality. These examples demonstrate that open data solutions for subnationals in developing countries are most effective when implemented through a long-term cost or revenue lens.

Emerging Technology Funding

In the development finance space, focus is often placed on public financing and the ways in which governments - national and subnational - can secure funds for projects and initiatives. In the context of using open data infrastructure for IAM, however, funding for the firms that supply the technology and software is also vital. Given the emerging nature of some of these technologies, these firms often face hurdles to securing funding from venture capital (VC) and private equity (PE) investors. This section will provide an overview of these challenges and explore what types of companies and technologies developing country subnationals should partner with in that context.

The challenges that technology ventures face in this space are heightened by the fact that the customers in question are developing countries that do not have the same access to capital and scale in purchasing as governments in developed countries. The aforementioned purchasing of AoT nodes and the technology's implementation in Chicago, for example, would be more difficult for a similar subnational in a developing country. As such, these developing country subnations would be best-served by partnering with and purchasing from companies that are already established in a developed country and looking to scale their operations elsewhere. In doing so, developing country subnationals can work with partners whose products are already field-tested and whose upfront R&D and capital costs have already been covered.

Kim Kolt of Bay Bridge Ventures discussed this potential for emerging market scalability for these technology ventures; in a research interview, she explained that a customized pilot project in a developing country would not generally be the best application of a prototype technology, particularly one that seeks VC funding, to get financing. Rather, VCs are more likely to invest in companies that have demonstrated projects which are replicable with a couple successful pilots underway. Likely, later-stage (Series B and beyond) with more "contracted revenues with a reliable purchaser/down-stream client already in place." "You have to demonstrate the technology in a real world application, and if a unique opportunity in an emerging market is the only way to prove out your technology as a physical development project, then at least know that the challenges, costs, and timelines of building in emerging markets are often significantly underestimated. The types of hurdles that emerge in a physical development, particularly those with large real estate footprints, are often unpredictable even in the developed world, and these factors are multiplicative in emerging markets. Investors do not like high idiosyncratic risk." Kolt believes it will be harder for young companies to finance future projects if their first project is in an emerging economy and future projects are meant to be in a different geography because emerging market projects will be too nuanced to underwrite confidently. The VC funding, therefore, would be geared not toward initiating the project but rather at increasing scale and number of units, and expanding sales to other markets - such as developing country subnationals.

Given the global push toward climate funding, governments across the world have increased incentives for improving infrastructure sustainably. Perhaps the most notable example is the U.S. Inflation Reduction Act, through which hundreds of billions of dollars have been set aside for climate investment. As Ms. Kolt explained in the research interview, there is particular demand from both VCs and governments for water infrastructure-related investments. Given the centrality of water and wastewater management for IAM in subnationals (as is seen in the cases of Izmir, Cairo, and San Juan), this increased focus creates an opportunity for companies that produce software and hardware that assists public officials in subnationals in managing water pipes and facilities.

Roadblocks to Implementation

In the case of Izmir, there is a trade-off with open data investment. One does not want to gather every possible piece of information, creating reports and roles that are not providing information that is useful for IAMs. The handbook is explicit about the difference between systems that gather data and systems that gather information. An ambitious but conservative approach is key. Investments that collect superfluous data that asset managers do not know what to do with, or do not have the time to deal with, are not useful.

The initial investment in smart city technologies could be challenging from a cost perspective, but can be mitigated if IAMs target low hanging fruit and less comprehensive solutions for one's assets. The costs of open data management systems will be amortized over life cycle management. The more successful IAMs are with strategic management plans, the longer the asset will function which lowers costs. If smart city technologies enable longer asset life spans, this increases the costs savings over the long-term.

As always, in many developing countries the human capital requirements for digitizing information management systems for IAM is challenging. This report has striven to demonstrate the adoption of these smart city technologies from more developed to less developed contexts. The long term aims should be where we started. Fully digitizing an open data system in a medium sized city is the goal. The sooner IAM has transparent and sustainable smart technologies, the more likely they can grow and nest with other infrastructure assets to provide clearer long term views of the full asset portfolio. The same goes with the human capital requirements. Large investments that require a large human capital investment is difficult. However, starting with one system or asset and building expertise while a subnational government grows can create a virtuous development cycle.

In Bhubaneswar and Izmir, there are ethical considerations when monetizing public data and this is not always the best choice for every political environment. Transparent contracts with third party actors should be part and parcel with these monetization efforts. However, because this data is the property of the citizens and should be protected by the state, in most cases, this data should remain in the hands of the national or subnational authorities.

Finally, the benefits of smart city investments are not silver bullets. In the case of the proposed AoT solution for climate resilience in San Juan, a sensor array network cannot prevent the hurricane in the first place. Technologies like these accent the recovery phase. In Puerto Rico's case, the central government and/or US federal agencies will have to be involved in every instance to restore power and provide aid in post-storm environments. Other nations looking for similar climate resilience solutions should factor in the political constraints of past recovery experiences to calibrate expectations and investments.

Conclusions

Our findings from these four case studies group into three categories: (1) the opportunity to lower costs or increase revenues, (2) the reduction of information asymmetries, and (3) empowerment of subnational IAMs.

Smart city technologies have the potential to lower costs over the life cycle of the asset first by reducing data siloing. We saw in Izmir and Bhubaneswar that cross-sectional integration of data collection can not only give IAMs better data for making repairs but can assist in building a life cycle maintenance plan. In the case of Izmir, this also allows new kinds of information to factor into IAMs decision-making. Izmir's open portal has multiple mechanisms for public feedback, which can assist in the delivery of public goods. A potential benefit in Izmir and Bhubaneswar is the option to ethically monetize the data that these integrated systems gather. If done responsibly this can increase the revenue, or create entirely new revenue streams associated with an asset. In the case of Cairo, we find evidence that efficient irrigation monitoring systems can lower the water provision burden and lower labor costs for municipalities. And though hypothetical, the potential for an Aot system in San Juan could also create revenue through data monetization. As with the other cases, remote networked monitoring can lower costs by making post-storm recovery inspection and repairs more efficient.

The reduction in information asymmetries tracks closely with many of the potential cost savings. In Izmir, making the entire public infrastructure network viewable in a single portable ensures transparency between all actors, be they subnational officials, national officials, international organizations, third party firms and the public. We believe this leads to better public services delivery over time. Specifically for IAMs, this provides a comprehensive overview of the entire asset portfolio which can inform the strategic management plan. Bhubaneswar is at an earlier stage of smart city technological development, but is moving towards Izmir's openness model. In both cases as well as in San Juan, a transparent data collection system would support an ethical data monetization model. And in Cairo, the downstream sensor system provides both the farmers and the municipality with accurate information about how much water is actually needed for efficient irrigation.

Finally, we find that smart city technologies can provide data to empower subnational asset managers when creating strategic life cycle management plans. Subnational officials are typically operating with less resources than national officials. Providing reliable and high value information can help subnational actors circumvent these constraints. In all four cases, the implementation of a smart information management system resulted in providing IAMs with the ability to own, collect and take responsibility for asset data.

Recommendations

Our recommendations based on this research are divided by stakeholder. For UN DESA, we recommend further exploring data ownership as a potential revenue source with regard to public facing assets. If implemented with considerations for privacy concerns, this can become a new revenue stream for IAM.

We also recommend that UN DESA emphasize implementing smart information management systems as early as possible with new or existing assets. The goal should be to match the smart-city technology with the data IAMs require to best manage the asset over its life cycle. For environments with few assets, or few existing smart city technologies, implementing these systems sooner can increase the lifespan and returns of an asset.

For participating country delegates and public officials, we recommend exploring how to implement, or augment smart-city technologies for IAM. Certain locales may already collect some data but it is not interacting or feeding up to the IAMs—the silo effect. Looking for simple and transparent solutions to acquiring accurate data on assets will make one's asset investments more profitable.

For infrastructure asset managers, we recommend identifying the key information one would need to better manage each asset within an asset portfolio. Then, identify smart-city technologies that could address that problem. A city or town-wide portal with all asset information is not the solution for many environments. Simply creating a method for gathering the needed information using off the shelf technology can be connected with smarter networks over time. In all cases, better data improves IAM.