A Consensus Framework for Smart City Architectures

IES-City Framework

(Internet-of-Things-Enabled Smart City Framework) Release v1.0 20180930

This IES-City Framework is the product of an open, international public working group seeking to reduce the high cost of application integration through technical analyses of existing smart city applications and architectures. This Framework documents the findings of the authors and provides valuable tools that are based on the findings and that can lower barriers to an expanded smart city marketplace.

Currently, three primary barriers exist that inhibit widespread deployment of effective, powerful smart city solutions:

1. Inadequate information and knowledge transfer: Most smart city deployments are based on custom systems that cannot exchange information with other cities, and therefore, are neither extensible nor cost-effective.

2. Diverse standards: Current architectural standardization efforts have not yet converged. This creates uncertainty among stakeholders [1]. There is a lack of consensus on both a common language/taxonomy and smart city architectural principles [2]. The result is that the many groups with smart city interests are likely to generate standards and practices that are divergent, perhaps even contradictory, which would not optimally serve the global smart city community.

3. Poor scalability: A third barrier is the insufficient interoperability and scalability of underlying Internet of Things (IoT), and Cyber-Physical Systems (CPS) technologies that provide the foundation for many smart cities applications [3].

Additional barriers include lack of resources, lack of clear principles for prioritization, and limited access to the necessary technical expertise and experience.

To lower these barriers, NIST and its partners, below, convened this international public working group to compare and distill a consensus language, taxonomy, and framework of common architectural features to enable smart city solutions that meet the needs of modern communities.

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Contents

1 Introduction and Overview

1.1 Summary

What

"The Smart City can be defined as the integration of data and digital technologies into a strategic approach to sustainability, citizen well-being and economic development."
– Scottish Government, 2014 [4]

The "smart city" concept inspires the vision of a space where key components of infrastructure and services—environmental, emergency response, traffic, and energy management to name a few—are integrated in such a way that features and applications can easily be combined with whatever capability already exists [5]. To achieve this vision, stakeholders must move beyond many of the current implementations. Current implementations within smart cities are limited in their integration of core subsystems, because legacy and fixed solutions are connected in patchwork fashion by custom integrations.

This IoT-Enabled Smart City Framework (IES-City Framework) represents the effort of this public working group to distill lessons learned by smart city pioneers [6][7][8] into a framework—a framework that will facilitate the emergence of smart city technologies that are Interoperable, Composable, and Harmonized.

"Interoperability" refers to the ability of diverse systems and components to work together, even as parts from diverse set of suppliers are substituted and integrated. As the reader will see in the descriptions of the CPS Framework (described in Section 4.2.2 of this document), there are many measures by which interoperability must be achieved. Stakeholders have various "concerns" that must be addressed by given technologies. Each of these concerns (e.g., cybersecurity, communications, or precision timing) represents another dimension of interoperability.

"Composability" refers to the ability to add various functions while maintaining continuous integration and improvement of the overall system. These functional additions should be achieved gracefully, as opposed to a wholesale replacement or substantial re-engineering of the system. Cities integrating each new capability should be able to simply acquire and add it to the existing infrastructure with a minimum of tailoring and reworking of existing component interfaces. The whole will be greater than the sum of its parts [9].

"Harmonization" refers to achieving compatibility between technologies and systems, even when they at first appear incompatible. For example, these technologies might come from different domains (e.g., transportation, public safety, or energy) or they might each be designed to conform to a standard from a different standards development organization. Through harmonization of the different specifications, it is possible to create interoperable and complementary solutions. Harmonization is essential to achieve the other two goals of the framework—interoperability and composability.

The principal goal of this framework is to provide useful tools that lower barriers to interoperability, thereby enabling stakeholders of smart city projects to perform more and faster implementations.

The framework offers a smart city application analysis tool that permits smart city stakeholders to do early research related to smart city applications—their breadth, the readiness of cities' infrastructures, and the benefits to citizens.

The framework also provides a comparative technical analysis of prominent smart frameworks that are now being developed and deployed, often with disparate architectures. The framework illustrates the potential for harmonization among these architectures. To lower barriers to interoperability between the various ecosystems currently being deployed, this framework introduces two concepts— "Pivotal Points of Interoperability (PPI)" and "Zones of Concern (ZofC)."

Why

Convening a public working group to achieve consensus on a smart city framework meets several needs. Cities and entrepreneurs worldwide seek to enable incrementally added "smarts" to various aspects of city life regardless of from which community of interest the components come. They do not want to wait to deploy these capabilities in anticipation of the arrival of some universally accepted grand scheme. A desirable framework draws on the existing work to minimize the barriers to integrating critical as well as new and novel applications to the benefit of citizens, city managers, and industry [10]. 80% of critical infrastructure in the US is owned by industry [11]. These have national security implications.

> Industry owns 80% of the critical infrastructures in the United States [11]. This significant industrial ownership has national security implications.

The recent progress of applications in smart cities has been explosive. NIST's Global City Teams Challenge (GCTC) [12] provides one example—over 150 cities and 400 companies and organizations from around the world are working in teams on over 160 specific smart city projects. Many consortia and standards organizations are developing frameworks of various scopes that can be used in various smart city integrations [13]. These stakeholders—from cities and industrial companies to standards group and consortia—would benefit from the ability to work together through a common language and shared architectural principles.

Governments—just like industry—have a keen desire to benefit from the efficient integration of "smart" into their cities. A recent report [14] predicted that as of 2018, 20 of the world's largest countries will have in place prioritized national smart city policies, and one third of medium and large cities worldwide will have developed a smart city roadmap. In the U.S., the Federal Government's Office of Science and

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Technology Policy recently announced a "Smart Cities Initiative to Tackle City Challenges with Innovative Approaches."[15] A shared smart cities framework can support informed policy and decision-making and promote the emergence of a vibrant global market for smart city technologies [16][17][18][19].

How

To meet the needs of all stakeholders, therefore, this public working group is a *technology and business-model neutral* forum for identifying a minimum set of commonalities that can be adopted to achieve the composable vision of a smart city. To achieve this goal, the working group:

- was free and open for participation by anyone, anywhere in the world, upon no-cost registration at the group web site;
- was composed of technical experts and stakeholders from industry, academia, and government worldwide;
- made its deliverables freely available on the web [20];
- held regular working meetings virtually (i.e., by phone or computer conference call) to eliminate barriers of geography; and
- developed this technical white paper on consensus principles for smart infrastructures derived from comparative analyses of existing concepts.

The working group built on the work of two related NIST efforts—GCTC [12], which encourages "action clusters" to form and collaborate to demonstrate technologies at city scale, and the NIST CPS Framework [21], which provides for a scientific underpinning of the description of the Internet of Things.

The working group produced a streamlined framework that emphasizes Pivotal Points of Interoperability (PPIs) (see inset to the right).

To determine these PPIs, the participants reviewed the following:

- Analyses of current architectures
- Success stories about how seamless integrations and portability of applications across and between cities were achieved
- Standards that support the modular integration of function at city scale
- Standards that support updates, publication, and access to information that describes what is going on in the city, even when that information comes from different sources
- Best practices on how to integrate PPIs into existing infrastructures

Pivotal Points of Interoperability

The principle of Pivotal Points of Interoperability (PPIs) is to find consensus standardized interfaces that deal with composition of CPS without constraining innovation. PPIs provide a middle ground between two unworkable scenarios. 1) If everything is standardized, innovation is stifled. 2) If nothing is standardized, the result is non-interoperable clusters that are not easily integrated.

- Educational materials and tools that facilitate consumer/commercial understanding and usage of smart city capabilities and technologies

A corollary concept to PPIs is that of Zones of Concern (ZofC) (see inset to the right). ZofC allow for the emergence of service providers that can offer a bundle of services that address the concerns represented by one or more PPIs. For example, a common authentication service, third-party authorization service, and privacy-enhanced data exchange could be bundled into a single ZofC service offering.

Zones of Concern

At certain interfaces within any smart city architecture, there exist unique sets of concerns that emphasize PPIs at the architectural interface. Zones of Concern (ZofCs) represent these sets of PPIs, and ZofCs allow for the aggregation and presentation of services that address these concerns.

Who

The smart city market is growing and expanding globally, creating significant competitiveness implications for both industry and municipalities. Several organizations have a strong interest in studying and addressing these implications. Several of these organizations are sponsors of this IES-City Framework. They are introduced below:

The National Institute of Standards and Technology (NIST) is the lead partner. NIST is an agency within the U.S. Department of Commerce, and it is coordinating this activity through its Cyber-Physical Systems Program, part of the NIST Engineering Laboratory. NIST's responsibilities include assisting industry in the development of measurements, measurement methods, and basic measurement technologies, as well as assuring the compatibility of United States measurement standards with those of other nations.

The American National Standards Institute (ANSI) serves a key role as coordinator of the U.S. standardization system and U.S. member to international standards bodies. For this IES-City Framework initiative, ANSI provides outreach and encourages technical experts to participate in this IES-City Framework initiative. ANSI will also use the working group's output in subsequent standards activities.

The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) is contributing to this technical white paper by analyzing and elaborating specific aspects related to standards and smart cities with a special focus on interoperability issues (especially but not exclusively based in Italy). For this purpose, ENEA is coordinating an Italian Convergence Table, which involves research and industrial communities and cities. The group is identifying common principles from a national perspective, as well as promoting and disseminating standards and interoperability approaches for smart cities.

The European Telecommunications Standards Institute (ETSI) and its technical groups are working on IoT service platform specifications that can be applied to smart city scenarios. Key examples include SmartM2M and oneM2M, a global standards initiative in which ETSI is a founding partner. In addition, ETSI is active in various European Union initiatives such as the Alliance for Internet of Things Innovation (AIOTI), which is examining the need for technical specifications and is making recommendations for additional standards to be developed that will support ICT technologies in Europe.

Through ETSI's collaboration in the IES-City framework, ETSI seeks to enable global cooperation and knowledge sharing, as well as development of global technical specifications and recommendations that will help accelerate the numerous smart city deployments around the globe.

The FIWARE Foundation is targeted to boost creation of an ecosystem around the FIWARE platform, which provides a simple yet powerful set of Application Programming Interfaces (APIs) that ease the development of smart applications in multiple vertical sectors. FIWARE API specifications are public and royalty-free. Supported by an open source implementation, this enable multiple FIWARE providers to emerge more quickly in the market with a low-cost proposition. The FIWARE context management API has been adopted by more than 75 cities to support real-time open data. The FIWARE Foundation aims at contributing to the definition of an open-source reference architectural framework for smart cities that it can then help implement and promote.

Korea's Ministry of Science and ICT (MSIT) is providing expertise that was gained from Korea's IoT Cluster Projects, such as Busan Global Smart City and Daegu Daily Healthcare Centre. These projects are facilitating convergence of various IoT services based on oneM2M, which is an International IoT/M2M Standard. (ICT refers to Information and Communications Technology, and M2M refers to Machine-to-Machine direct communication between devices using any communications channel.) In addition, as an agency of the South Korean government, MSIT plays a role in enabling numerous IoT businesses and start-up companies to build up profitable services. It also helps establish IoT ecosystems with the smart city frameworks derived from this activity.

The Telecommunications Industry Association (TIA) is the leading trade association representing the global information and communications technology (ICT) industry through standards development, policy initiatives, business opportunities, market intelligence, and networking events. TIA is a founding partner of oneM2M, and it believes that the communications industry can assist governments overcome the challenges of urbanization and address the current and future well-being of metropolitan populations.

The U.S. Green Building Council (USGBC), along with **Green Business Certification Inc. (GBCI)**, is committed to a prosperous and sustainable future through cost-efficient and sustainable buildings, infrastructure, communities, and cities. USGBC and GBCI are participating in this IES-City Framework project, because it aligns with their mission of market transformation through the Leadership in Energy and Environmental Design program (LEED) and other key programs. These programs offer a credible measure to evaluate, compare, manage, and improve the performance of urban systems through transformative actions that improve sustainability, quality of life, and wellness of citizens.

1.2 Elaboration of the Challenge

This section discusses the complexity of the smart city challenge, the concept of the Internet of Things (IoT) and cyber-physical systems (CPS), and the current state of smart cities.

1.2.1 Complexity of Smart Cities

The nature and process of system development and deployment are in the early stages of a significant, fundamental evolution in scale, complexity, interconnectedness, and interactivity.

The Software Engineering Institute (SEI) drafted a technical report, titled *Ultra-Large-Scale Systems: The Software Challenge of the Future* [25], for the U.S. Army. The report assessed how to design, build, and operate interconnected systems of people, software, machines, and data so complex that they are, "…likely to have billions of lines of code…." It notes that: (1) current engineering methods, tools, and best practices are insufficient for designing and constructing ultra-large-scale systems; (2) new methods and tools of design, analysis, and operation are required; (3) it may not be possible to ever fully understand an ultra-large-scale system; and (4) it may not be possible to ever fully develop methods and tools to design and construct aspects of an ultra-large-scale system. Rather, the report suggests that ultra-large-scale systems must be *cultivated* into functional existence by continuous integration and optimization of their component systems of systems. This SEI report, although authored in 2005, is still very relevant today.

Systems of this level of complexity have been studied from various perspectives and are referred to by several different terms: cyber-physical systems [26][27]; socio-technical systems[28]; complex, large-scale, integrated, open systems [29]; and multi-scale systems [30].

These emerging complex, interactive systems bring new design, construction, and operational challenges. These challenges may be summarized by the following systems-of-systems characteristics:

- "A component(s) of a larger complex/interactive system of systems;
- Real-time hardware/software interactions that must bridge between internal and external systems to function successfully; and
- Real-time human-machine-software interactions essential to meeting user goals and expectations." [31]

For a more detailed list of characteristics, see the CPS Framework [21]. See especially Section 1.1.2, "What is different about CPS."

In response to these challenges, the literature about these types of emerging systems-of-systems projects also suggests that fundamentally new methods of design, analysis, and operation are required to successfully build and maintain these systems of systems. A significant challenge of these types of emerging projects is how to manage complexity (including interoperability) in a system of systems with many continuously changing components.

This IES-City Framework helps to manage this complexity by introducing two key concepts: Pivotal Points of Interoperability (PPIs) and Zones of Concern (ZofC). Figure 1: IES-City Framework Structure, illustrates how PPIs and ZofC facilitate the integration and realization of user requirements.

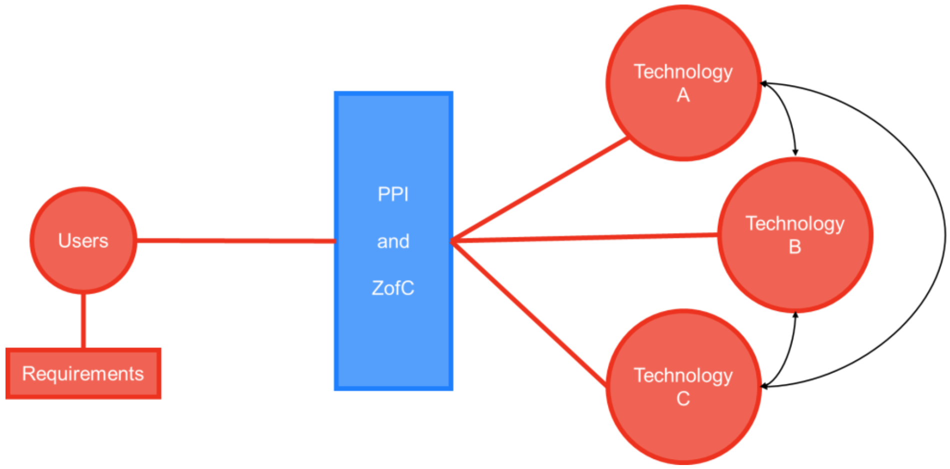

Figure 1: IES-City Framework Structure

These will be discussed in greater detail in Section 4.2, “Elements of the Technical Analysis.”

1.2.2 Internet of Things (IoT) and Cyber-Physical Systems (CPS)

In May 2015, NIST published the NIST CPS Framework Release 1.0 [21][22][23], which provides an analysis and technical framework for describing and analyzing CPS (IoT is closely related to CPS and may be considered a subset). This report represents the efforts over the course of two years of hundreds of participants from industry, academia, and government.

As described in the NIST CPS Framework, CPS are becoming increasingly common experiences in daily life. Examples include smart cars, intelligent buildings, robots, unmanned vehicles, and medical devices. The CPS Framework states, *“Realizing the future promise of CPS will require interoperability between elements and systems, supported by new reference architectures and common definitions and lexicons. Addressing the problems and opportunities of CPS requires broad collaboration to develop a consensus around these concepts, and a shared understanding of the essential roles of timing and cybersecurity*.”

CPS are complementary software/hardware systems of systems that are integral to ultra-large-scale systems and that manifest all the differentiating characteristics of these emerging project types presented above. As described in the CPS Framework, it makes sense to focus on developing standards to support interoperability in these complex applications. These standards will become the platform technologies upon which developing systems—whether described as socio-technical systems; ultra-large-scale systems; or complex, large-scale, integrated, open systems—will be based.

The CPS Framework introduces two powerful concepts—holistic, concern-driven analyses (referred to as *aspects* and *concerns*) and the grouping of system engineering activities (referred to as *facets*).

The holistic, concern-driven analyses show that all requirements are potentially cross-cutting. In other words, requirements reinforce or conflict with each other as design decisions are made to achieve stakeholder goals. By treating *aspects* (*functional, business, human, trustworthiness, timing, data, boundaries, composition, and lifecycle)* at every stage of the system engineering process all dimensions will be considered resulting in more complete systems.

The grouping of system engineering activities into three *facets—conceptualization, realization, and assurance*—can simplify the focus of the engineering activities and drive the creation of specific kinds of artifacts. These modes of thinking can be used in a variety of different processes—waterfall, spiral, V model, rapid development, or reverse engineering. The result will be comparable sets of artifacts from a completed process. The CPS Framework and its use in the IES-City Framework is elaborated further in Section 4.2.2.

Researchers find much overlap in the descriptions of IoT and CPS [32][33]. As used in this framework, "IoT" concerns itself primarily with the messaging interactions between nodes in a network. "CPS" considers, additionally, the important boundaries between logical and physical interactions across and within node boundaries. The more general case, "CPS," is the focus of the NIST CPS Framework[21].

As CPS become more ubiquitous over the next decade, they will alter the city infrastructure and its role in improving the well-being, health, and economic potential of its citizens.

Here are some examples of the changes expected soon:

- High-performance building standards [41]
- Requirements that building owners must monitor and publicly report energy and water usage periodically [42], and in real-time [43]
- Wellness standards [44]
- Ecodistrict/neighborhood-scale systems performance standards [45]
- Open telecommunications access protocols and infrastructure [46]
- Use of artificial intelligence to optimize systems efficiencies [47]
- Modeling of building information for facilities design and operations based upon semantic web architecture [48]
- Standards to support automated usage of drones for applications ranging from security and shipping/delivery to telecommunications access and disaster relief [49]
- Standards to support driverless vehicles [50]

- Systems to support mindfulness and cognitive performance [30].

Within smart cities, many ecosystems—buildings, transportation systems, infrastructure, and telecommunications—are emerging and evolving. As these ecosystems evolve, many metrics (e.g., energy expenditures, resource consumption, and impacts on human health, well-being, and productivity) will simultaneously be monitored, analyzed, optimized, and integrated into vast interconnected socio-technical ecosystems [55][52].

As just one example, consider the many standards for data monitoring, modeling, simulation, operationalization, and optimization that are related to the infrastructure of buildings. Then consider the many additional layers of industrial, commercial, and domestic networks of information and devices that service the economic, social, and physical needs of the populace. In a fully realized smart city, these networks and devices will all be interconnected and will be sharing information and access in near-real-time [57][58][59].

1.2.3 The Current State of Smart City Applications

Today's smart city deployments can be characterized best as constructed by ecosystems of collaborating entities—municipalities, engineers, contractors, developers. These teams can deploy one or more applications and gain economies of scale through repeat sales [24].

The challenge with this approach is that combining one smart city feature or application with another one, built according to a different ecosystem, confronts a large integration cost. This cost must then be born as a barrier to achieve the benefits. Alternatively, if a set of homogeneous technologies and applications—built by a single ecosystem—were deployed, the same benefits might be achieved without the large integration cost [5].

This argument makes no judgement about the excellence of the various competing ecosystem teams. It simply results from the fact that, because the teams and ecosystems are different, there is an integration cost. This integration cost can sometimes be prohibitive to deployment. In addition, the organizational dimensions of integration with differing ecosystem teams make integration even more challenging.

Below, Matt Turck [13] presents an illustration that dramatizes the diversity of technical components with which to construct Internet of Things (IoT) applications. Handling this diversity is a challenge to be addressed when defining the architecture of any smart city application. The prospect of convergence, especially within the IoT space, appears daunting.

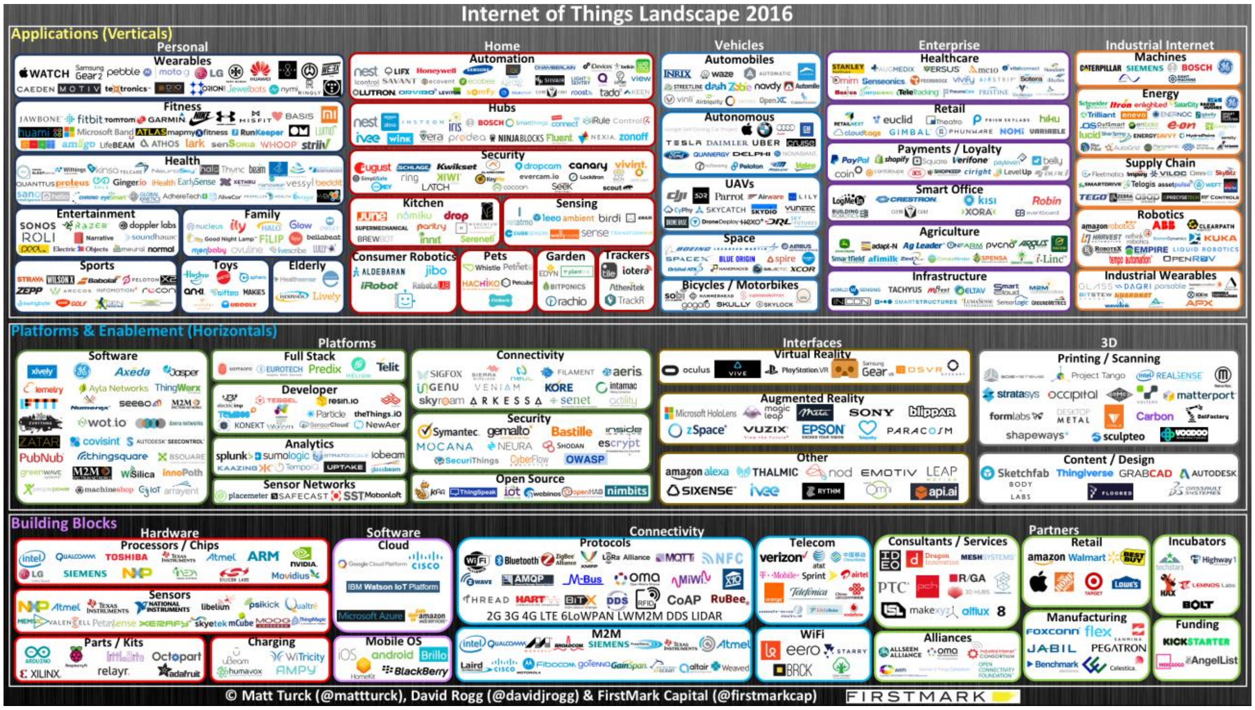

Figure 2: Internet of Things Landscape 2016

(Courtesy Matt Turk [13])

Today, nonetheless, there are a variety of initiatives under way that attempt to provide some convergence. These initiatives have been formed by various collections of enterprises, sometimes with government assistance. Efforts to converge their diverse approaches into a single architecture or design—a very desirable goal—have proven to be challenging [104].

However, because of the great potential value of convergence, the sponsoring partners of this IES-City Framework have each been making independent efforts at facilitating convergence. The following paragraphs describe some of those efforts. These brief descriptions are not intended to be an exhaustive list of efforts and standards. Rather, they provide an introduction to the scope of the challenge.

By presenting and analyzing what has been learned by studying these smart city applications and architectures, the authors of this IES-City Framework seek to reduce the high costs of application integration.

NIST: One approach that shows promise for facilitating convergence is the NIST-sponsored Global City Teams Challenge(GCTC) [12]. The GCTC is a multi-year activity bringing collaborators on smart city projects together to share requirements, and most recently "blueprints," for common categories of applications for reuse by other cities with lessons learned from earlier deployments. GCTC's long term goal is:

> "To establish and demonstrate replicable, scalable, and sustainable models for incubation and deployment of interoperable, secure, standard-based solutions using advanced technologies such as Internet of Things (IoT) and Cyber-Physical Systems (CPS) and demonstrate their measurable benefits in cities and communities."

ANSI: Following a flurry of national, regional, and international standardization activity, ANSI convened workshops in April and November 2013 exploring the need for coordination of smart city standardization activities. In May 2014, the ANSI Network on Smart and Sustainable Cities was established as a forum for information sharing and coordination. For the next two and a half years, the network featured monthly webinars with guest speakers on a range of topics. In its role as the U.S. member of the International Organization for Standardization (ISO) and, via the U.S. National Committee, the International Electrotechnical Commission (IEC), ANSI continues to monitor such activities and supports U.S. stakeholder engagement in this work.

ENEA: In the context of a research and development activity, supported by the Italian Ministry of Economic Development in order to improve national competitiveness, ENEA is designing and developing a set of specifications, Smart City Platform Specifications (SCPS). The goal of SCPS is to support the development of ICT platforms that cut across the sectors and services in a smart city (i.e., SCPS is "horizontal" with respect to the various "vertical" services). These ICT platforms will provide the services with the necessary data exchange interfaces for avoiding the creation of non-interoperable silos.

The Smart City Platform Specifications are adopting the Pivotal Point of Interoperability approach defined by IES-City. The specifications will be the base for defining technical attachments for calls for tenders (i.e., requests for proposals) made by smart cities for new public services, thereby mitigating the need for interoperability skills in public administration.

ETSI: In addition to contributing to the service-level platform specifications in oneM2M, ETSI has also created a dedicated group related to smart cities, the Industry Specification Group "City Digital Profile" (ISG CDP). This group helps cities come together and express their standardization priorities in a focused manner. It also helps cities dialogue directly with representatives of service providers, vendors, and researchers. ISG CDP was created in December 2017, and has already attracted several cities and places as contributing members.

Other ETSI groups actively working on city-related standards include the following:

- Industry Specification Group "Context Information Management" (ISG CIM) is tackling the complex issue of enabling multiple organizations to develop interoperable software implementations of a cross-cutting CIM layer. Several cities have identified data management between multiple sources as a Pivotal Point of Interoperability, and this issue is being examined in ISG CIM.
- Technical Committee "Access, Terminals, Transmission and Multiplexing" (TC ATTM) is working on Key Performance Indicators for Sustainable Digital Multiservice Cities.
- Technical Committee "smartM2M" is working on Smart Appliances REFerence ontology (SAREF), an interoperability language that is being adopted in oneM2M with their base ontology model.

FIWARE Foundation: the FIWARE Foundation has proposed the adoption of an open API for context information management, FIWARE Next Generation Services Interface (NGSI). NGSI is designed to cope with the diversity of technologies and products at IoT level, and also to solve the need to integrate information from other sources beyond the IoT. FIWARE can then define its reference architecture for smart cities, which incorporates a main context broker layer. This approach supports the NGSI API by providing a way to manage information coming from different IoT networks. NGSI API will also help with interoperability within a city and portability across cities for vertical IoT-enabled smart city solutions (e.g., for waste management, traffic management, etc.) and for smart city governance support solutions.

The proposed FIWARE NGSI API has experienced growing adoption in the last few years, as discussed in the following examples:

- The Groupe Speciale Mobile Association (GSMA) [60], which represents the interests of mobile operators worldwide, has identified the NGSI API as a cornerstone in the definition of a target reference architecture for IoT-enabled "big data" systems.
- TMForum [61], an industry association driving digital business transformation of the communications industry, has adopted FIWARE NGSI as the basis for a recommended reference architecture for smart cities. In collaboration with TMForum, the FIWARE Community is working towards bringing support to publication of right-time open data and data economy concepts, thus driving the transformation of cities into platforms.
- The Open and Agile Smart Cities (OASC) initiative [62], with a membership of more than 117 cities from 24 countries, has selected FIWARE NGSI has been selected as one of the mechanisms to support the interoperability of smart city solutions within a city and between cities, as well as to support the portability of solutions between cities.
- The Connecting Europe Facility (CEF) program of the European Commission has plans to adopt the FIWARE Context Broker technology as one of the CEF building blocks. It will be recommended to EU member states for building digital services infrastructures that support cross-border services.
- As mentioned above (see ETSI section), ETSI established ISG CIM, which uses FIWARE NGSI as the basis for the specifications of a CIM API [63]. Evolution of the FIWARE NGSI API specifications is planned to be driven through this ISG in the future.
- The FIWARE community—through its collaboration with ETSI, GSMA, OASC, TMForum—has launched an initiative that would create Common Context Information Models compatible with the FIWARE NGSI API.

MSIT: The Korean government has decided to promote smart city as one of the key agendas of the Fourth Industrial Revolution. The government is focusing on solving urban problems through the use of big data to increase smart city sustainability and increase citizen participation. Specific goals include creating a new world-class smart city, promoting the Smart City Renewal New Deal project, improving smart city performance, and to fostering economic growth within and outside the country.

As a first step to implement this agenda, Busan and Sejong were selected as the locations of Korea's first smart cities. The goal is to create the world's leading smart cities within the next five years, including adopting autonomous public transportation, managing traffic systems efficiently through big data and artificial intelligence data analysis, lowering energy consumption via smart grids and renewable energy, and increasing public safety through integrated systems that connect surveillance cameras and smart street lights that automatically turn on when a person is in need of help.

The residents will be moving to these trial cities starting in 2021. Because the cities are designed with fourth industrial revolution technology, the residents will experience the benefits of a future city in their daily lives. The smart city technologies will be applied to existing cities as well. The government plans to select four local governments every year until 2020 to run their own smart city projects.

The specifications defined by the IES-City Framework will serve as an important reference in implementing smart cities in Korea.

TIA: TIA represents manufacturers and suppliers of global communications networks through standards development, policy and advocacy, business opportunities, market intelligence, events, and networking. TIA is striving to influence the paradigm of global standardization by articulating American stakeholders' perspectives and concerns. The goal is to make global markets accessible to American industry and businesses.

Recently, TIA became the official Administrator of the U.S. Technical Advisory Group (TAG) Mirror Committee to the IEC Systems Committee on Smart Cities. The scope of the IEC Systems Committee on Smart Cities is to foster the development of standards in the field of electrotechnology to help with the integration, interoperability, and effectiveness of city systems. This will be done by:

- Promoting collaboration and systems thinking between IEC/Technical Committees, the Systems Committee, and other Standards Development Organizations (SDOs) in relation to city system standards.
- Undertaking systems analysis to understand the needs for standards and assess new work item proposals related to city systems.
- Developing systems standards where needed.
- Providing recommendations to existing Systems Committees, Technical Committees/Sub-Committees, and other regional and global SDOs.

Overall common smart city goals include sustainable development, efficiency, resilience, safety, and support for citizens' engagement and participation. An individual city, however, will follow its own approach to achieving these goals.

These objectives are carried out in the established IEC Systems Committee Working Groups. The IEC Systems Committee on Smart Cities is organized into three Working Groups (WGs): Terminology WG, Market Relationship WG, and Reference Architecture WG.

TIA's current efforts with the Systems Committee on Smart Cities and with IoT Convergence are not new. In the context of smart cities, IoT provides an overlay on top of the underlying ICT Infrastructure and acts as a catalyst to enable and enhance a city's smartness, thereby enriching the actionable insights for city operations, management, governance, and citizen engagement. A smart cities reference architecture will provide a common approach for architecting smart cities as systems to allow common solutions in similar contexts, aiming at improving efficiency and at increasing opportunities for business and innovation.

USGBC and GBCI: These organizations are committed to a prosperous and sustainable future through cost-efficient and sustainable buildings, infrastructure, communities, and cities. The LEED for Cities certification program was launched in December 2016, cultivating a new generation of high-performance cities. The program certifies cities and communities based on performance and provides common metrics for cities across the world to compare and compete. The program is offered on the Arc platform, where cities can interconnect all city departments, their visions, and goals. Using data-driven engagement, the platform can track performance on actionable plans and projects, including their climate action plan, sustainability plan, resilience plan, and other smart city activities.

1.2.4 Topics Beyond the Scope of the IES-City Framework

Technology exists within and as a tool of society. Society is governed by social, ethical, and legal norms and laws that make interactions between agents consistent, reliable, safe, trustworthy, and efficient (prerequisites for society to function at increasing orders of scale and complexity). The success of IoT/CPS-enabled smart technology deployment will depend on its usefulness in serving the advancement of society and this requires integration with the social, ethical, and legal norms and laws. Successfully integrating IoT/CPS-enabled smart technology with norms and laws promises new ways of enhancing equality, justice, wealth, security, risk management, personal achievement, and well-being. Conversely, failing to integrate IoT/CPS-enabled smart technology with norms and laws may exacerbate unintended consequences of IoT/CPS-enabled smart technology, including inequality, exploitation, injustice, terrorism, and risk. Given this, IoT/CPS-enabled smart technology cannot be considered to have reached maturity in its development until it is successfully integrated with social, ethical, and legal norms and laws. As importantly, technology's development must be entrained with the development of these laws and norms.

2018 has been a significant year for social awareness of the need to take a holistic view of new technology adoption and to address its integration with social, ethical, and legal norms and laws. There have been important public discussions about the ethics of new technology adoption, including: (1) manipulation of politics and elections using social media, (2) people's ownership of their data and rights to privacy and to be forgotten online, (3) companies selling people's data and targeting news and advertisements to them based on their data, (4) TVs, phones, cars, and personal home assistants listening to occupants without their knowledge/consent, (5) hacking of autonomous cars, drones, and homes, (6) and automation displacing workers. There is growing consensus that considering the social/ethical/legal implications of new technology adoption is needed, and this is also true for IoT/CPS-enabled smart technology.

For the purposes of initial development of smart cities, integration of social, ethical, and legal norms and laws is acknowledged as essential for the success of the technology but outside the scope of IES-City. The development of the IES-City Framework development has focused on laying technological foundations.

1.2.5 A IES-City Framework Smart City Use Case

Technologies, use cases, infrastructures, and communication needs all coalesce in a smart city. How can one optimize the efficiency, effectiveness, and equality of access to such a smart city?

In this section, a use case is elaborated to show how the tools produced by the IES-City Framework can be used in practice. It is written as an aspirational narrative of how a city administrator recognizes a coming (in 72 hours) emergency and determines to put in place plans within the year so that next season, the city infrastructure is less vulnerable to such a short notice event. Illustrated is how the IES-City Framework artifacts might be deployed to facilitate such a plan.

Here is the premise of the use case:

> A city administrator is considering an infrastructure enhancement to benefit the citizens.
>
> During the previous year, a new traffic management system was deployed enabling central control of traffic light sequences and scheduling.
>
> This city administrator is familiar with the IES-City Framework and seeks to exploit its concepts and tools to enhance the capabilities of this traffic management system in dealing with a flood emergency.
>
> **Use Case: City Administrator in a Citizen-Oriented Smart City Deployment: Dealing with an anticipated flood**

This section tells a story about a smart city application development and deployment and discusses how this IES-City Framework and its deliverables will impact that process. The following figure illustrates the process flow of the use case. Of course, any actual process flow would reflect the needs of the stakeholders, and this one is for illustration purpose only.

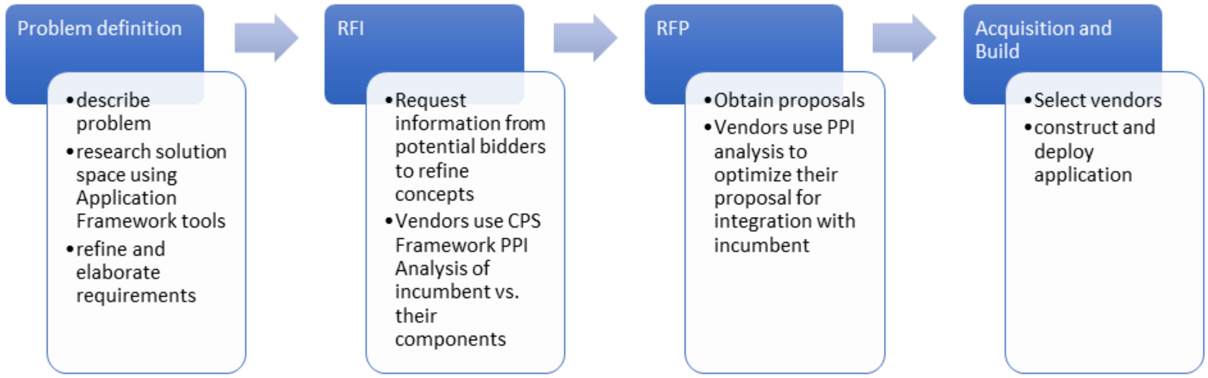

Figure 3: Smart City Application with Incumbent

1.2.5.1 Statement of the problem

You are a city administrator responsible for the integrated city infrastructure. As you are riding the bus from your apartment in downtown to your department's office in mid-town, your smart phone populates a list of upcoming appointments and tasks for the day. It also identifies relevant news articles related to your primary concerns.

There have been torrential rains this past week because of an approaching, slow-moving hurricane. The predictive models of the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) suggest that there is a 67% chance that your city will be flooded with a foot of water within 72 hours. The urban infrastructure that manages the city will be challenged during an atypical event like this hurricane. When you arrive at the office, you are consumed with preparation. You acknowledge the limitations of the tools at your disposal for this event and endeavor to remedy this with an extension to your city infrastructure for next year.

Your city has previously deployed a smart transportation application, and you are familiar with the IES-City Framework tools. You have previously used the concept of *concern-driven requirements analysis* from the NIST CPS Framework. Your urban infrastructure team had developed an identified set of interconnected *aspects* that cut across the domains of manufacturing, energy, healthcare, transportation, education, commerce, etc. The team had identified *pivotal points of inter-operability (PPI)* between the embedded systems, mechatronics, robotics, cyber-physical systems, and the complex, large, integrated open systems that serve functional, business, human, social, and policy *concerns*.

The *aspects, categories* of concerns, considered included: *functional, business, human, trustworthiness, timing, data, boundaries, composition, and lifecycle*. These *aspects* will provide guidance for how to compose and combine new functions into the existing infrastructure.

During an event such as an anticipated flood, the weighting of concerns of the systems of systems that run the city will briefly, but profoundly, shift. The key to successfully surviving the flood and minimizing damage and loss of life and property is to extend the infrastructure. It should support the change from the existing, optimized-for-normal-conditions state of the system of systems to the anticipated target flood-emergency state of the system of systems. This shift in mission preparedness must be achieved to survive the disaster with minimum negative impact on life, property, infrastructure, and business.

The difficulty of managing such a scenario without automation would be overwhelming without smart infrastructure and an appropriate architecture framework with which to operationalize it. You will use the IES-City Framework tools to prepare and sustain transportation services through the coming flood event. Instead of viewing this flood scenario as a disaster, you view it as an opportunity for your smart transportation system to evolve the emergency preparedness of your municipality–in other words, to further smarten the city!

1.2.5.2 Using the application framework tools to determine feasibility and define requirements

You (the administrator) begin by reviewing the case studies in Section B.1, "Smart City Case Studies," to see if other municipalities have encountered similar flood emergency use cases and learn how they addressed them.

You provide your team with a brief review of flood impact mitigation strategies using the Smart City Application Framework tool—an easy-to-use spreadsheet that contains a feature-rich data set of requirements and benefits based on previous smart city deployments. You first use the tool to navigate to the "Public safety, policy and emergency response" category. You choose "flood monitoring and forecasting" in the subcategory field of the main dialog. From these choices, you can review the high-level functional requirements identified for the CPS *concerns*.

Additionally, the tool presents a summary of significant infrastructure technologies and the respective *readiness* attributes that are typically required to support flood emergency applications. You find that your infrastructure is, indeed, sufficient as a starting point. This task is feasible!

You carefully review the associated benefits to determine that you believe the results are both desirable and presentable to your management. You are then encouraged to go ahead and submit a Request for Information (RFI) to vendors to see if they are interested in participating in the system acquisition. Later, you will use the information received to generate a Request for Proposal (RFP) to obtain actionable quotes for the service.

Your team's task is to develop the requirements for the needed alternate state of the smart city transportation CPS with respect to storm water inundation and its impacts on mass transit assets. In addition, the CPS will track and compare incoming real-time data about conditions within the city versus the conditions as represented in the steady-state systems model. This comparison will be used to validate the model's integrity and to identify the needed transformations in the CPS' functioning that must occur over the 72 hours warning period to minimize damage and disruption caused by the flooding.

You know that parts of the city infrastructure are monitoring incoming data from smartphones, wearables, vehicles, drones, buildings, storm water inlets and outlets, hospitals and clinics, and the local energy and telecommunications utilities from all over the region. This access to data is facilitated by many government and private policies, legislative, and contractual requirements that have allowed an open exchange of data that directly and materially impacts the health, wellness, safety, and prosperity of human agents, software agents, infrastructure, and organizations.

Your team monitors real-world conditions. Cell phone data indicate that citizens are stocking up on food, water, and batteries in anticipation of the flood. You seek to be able to increase bus and train service to areas with food stores, pharmacies, general merchandise stores, and hardware stores, including subtle shifts in the timing of street lights. You also want to have suggested route guidance transmitted directly to driverless vehicles and drones. Your model plans a gradual transition from favoring transportation to and from these stores (for 72 to 24 hours before flooding begins) to transportation to and from the city's three major hospitals (starting 12 hours before the flood begins).

In this instance, your team has contacted the automated traffic system operator and the police and fire departments, because you've realized a valuable opportunity afforded by their respective smart city CPS. Because the automated traffic system operator and the police and fire departments all utilized the IES-City Framework process in defining their PPI, it is practical to integrate their CPS and to use the automated traffic system to facilitate orchestration of police and fire services prior to and during the flood.

In the 60 hours before the flood hits, law enforcement and the fire department will go door-to-door requesting that residents evacuate. The timing of the traffic lights will be orchestrated to support the flooding scenario by maximizing the flow of traffic along evacuation routes, as well as the flow of traffic to priority locations (e.g., hospitals and shelters) during the flood event.

In the RFI, you present the fact that the new storm management features must integrate with the existing smart traffic feature that was acquired from vendor team "A" the previous year. The PPI identified by that team is summarized in their analysis using the data sets provided by the IES-City Framework PPI analyses.

Vendor teams "A" and "B" respond to the RFI, saying that they can do it. (Note: a third team "C" will later respond to the RFP.)

Of course, a design, modeling, and operations challenge such as this can only be successfully addressed because of methods developed to decompose the problem into addressable parts. In this case, this system-of-systems challenge is tractable, because systems developers and operators have agreed on a shared framework and protocols for CPS information exchange that allows information to be malleable and adapted to emerging use cases.

Teams "A" and "B" have previously adopted the PPI Zones of Concern (ZofC) and identified two such ZofC: "Northbound interfaces" (where applications connect) and "Southbound interfaces" (where IoT devices connect). Several infrastructure vendors have supported these ZofC to provide a trustworthy infrastructure that allows applications of the system of systems to be easily composed without adding additional infrastructure. These PPI allow the vendors to mix and match application components (at the Northbound ZofC) and sensor components (at the Southbound ZofC). This, in turn, minimizes their anticipated integration costs.

As a side note, it is this same smart city framework malleability that allows the smart city CPS to adapt to emerging natural crises, based upon a shared, open framework of data exchange. This malleability also makes the smart city's CPS resilient with respect to disruptive technologies, thereby safeguarding the city against economic competitiveness crises.

1.2.5.3 How the technology providers will be able to respond using PPI and ZofC

Based on the successful RFI and the feedback received, an RFP is developed and transmitted. The three vendors that respond— "A", "B" and "C"—cross-reference the PPI with their corresponding support for the concerns in their product offerings.

Additional questions must also be considered, including the following:

- How many other PPIs are dependent upon any one PPI? (an indication of how essential the PPI is to the functioning of the CPS)
- How many concerns are dependent upon any one PPI? (an indication of how essential the PPI is to the functioning of the CPS)
- How many alternative paths of data flow exist for each specific data type? (an indication of the resiliency of the system)
- Which PPIs relate to the most essential concerns during the crisis? (e.g., schools will be closed, so PPI related to education concerns are less critical during the flood than PPI related to emergency medical response capability)
- What PPI infrastructure is most critical to monitor and maintain during the crisis event? (e.g., medical facilities and transportation)
- How well does the resulting CPS predictive analytics model track with incoming data about actual events? (an indication of the predictive model's external validity that can instill confidence that the CPS's functionality has been sufficiently adapted to address the crisis)

For example, smart transportation is essential for safety, security, and search-and- rescue services. The city's automated traffic management system is part of the smart city CPS infrastructure. Though the complexity of the automated traffic management is great, its interfaces with other city services occur through a relatively small set of PPI. Therefore, the challenge of preparing the automated traffic system for this flood is more tractable because the operator of this existing system:

- Has a shared vocabulary to use when communicating with the city and related systems operators about how to operate it.

- Has a limited set of PPIs to consider to maintain system functionality—and this simplicity during a crisis is valuable.
- Can trust the robustness of the PPI infrastructure. (Because a shared set of PPIs and a shared PPI infrastructure is of critical importance for many city services and infrastructure, the stakeholders have invested to ensure that the PPI infrastructure is robust and resilient.)

Thus, the vendors can submit their proposals to the city with confidence in their estimates. Importantly, they can allocate a minimum of cost to the integration with the incumbent vendor team "A" based on their expectations from common PPI.

You, the city administrator, are encouraged that the initial choice of vendor was sound because three competitive bids were received and vendor lock-in did not occur.

1.2.5.4 Acquire, Build and Deploy

Three bidders make an offering, and this allows your procurement management process to make an award. Because the proposals have specifically addressed the concerns allocations from the RFP, tracking the progress of the implementation is straightforward. The winning proposal included an acceptance test process that was specifically aligned to the requirements and concerns and this makes tracking straightforward and less prone to error or misunderstanding.

The deployment occurs in record time and has been demonstrated and commissioned in time for the next storm season. The city administrator goes on to win higher office and the contractor team teams up with the original vendor to market the joint solution to other municipalities.

1.3 What the IES-City Framework Provides

A key component of the IES-City Framework is a simple-to-use analytical tool that enables early investigations of potential smart city applications. Stakeholders can make these analyses before they commit substantial time and funds pursuing an actual deployment. This tool enables review of various smart city application categories and subcategories and their representative applications about three criteria:

- The breadth of functional requirements for these applications.
- The readiness of the municipality infrastructure to mount these applications.
- The benefits to their citizenry from acquiring them.

This tool is further described in Section 3, "Smart City Application Framework."

As the reader observed from the "City Administrator" use case, above, the IES-City Framework addresses a key barrier to marketability of smart city technologies—the integration of a smart city feature when there is an incumbent technology.

The authors of this report suggest that, although there are many differing ecosystems providing solutions to smart cities, there are probably similarities that can be discovered and documented. These similarities are termed Pivotal Points of Interoperability (PPIs) and an approach is developed to reveal them. PPIs promise a simplification of integration due to the discovery of common choices made by independent ecosystem teams to address common concerns for design and deployment of smart city applications.

Further described is the concept of Zones of Concern (ZofC), which recognizes that there are distinct interfaces in any architecture where common requirements addressing common concerns can direct these PPIs toward a readily integrable design. Another key idea is that there are three principally unique roles played by the supporting vendors who help deploy a smart city ecosystem — (1) the applications developers, (2) the end-device vendors, and (3) the infrastructure providers. These concepts are elaborated in Section 4, "Discovering Pivotal Points of Interoperability (PPI)."

Finally, a subset of timely smart city applications is discussed and highlighted as micro-case studies to assist those interested to see what has been done already. These applications are described in Appendix B, "Use Cases and Analyses for Select Smart Cities."

1.4 Organization of this Document

The sections of this document are organized to facilitate their use by varied smart city stakeholders—both technical and non-technical.

Section 1	introduces the IES-City Framework and the smart city scope it seeks to address.
Section 2	is a guide to how to use the framework document.
Section 3	describes the Application Framework—including the creation of a readily useable tool that allows the stakeholder to review a wide array of smart city application categories and understand the high-level functional requirements, the needs for existing civic infrastructure, and the benefits these enhancements to city life can afford.
Section 4	provides a technical analytical methodology for comparing overall interoperability requirements for suites of technologies currently being deployed in smart city applications.
Section 5	summarizes the results presented in this framework and offers conclusions and recommendations for future work.
Section 6	contains references for this work.
Appendix A	provides details on the Application Framework spreadsheet tool.
Appendix B	presents some representative smart city use cases and business cases.
Appendix C	summarizes some of the prominent technology suites in use in smart cities around the world.

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2 Use of this Document

The IES-City Framework is designed to support the needs of key stakeholders of smart cities—the city leadership, policymakers, vendors and integrators, standards development organizations (SDOs), and academic researchers. This section briefly describes what is in this framework to support each stakeholder grouping's interests.

It is important to recognize that the citizen is the primary beneficiary of technologies, frameworks and architectures for smart cities. Governmental institutions make decisions based on how such decisions benefit the taxpayer. This document is aimed at providing frameworks, tools and information to assist stakeholders in making optimal decisions in such a context.

Cross-cutting issues such as privacy and infrastructure resiliency are important and are but a few of the operational requirements of smart city applications. While not elaborating the full dimensions of the issue of privacy, which is at the center of current debates by diverse stakeholders, it is assumed that policymakers take responsibility in developing such requirements to appropriate stakeholders. Thereby, the document provides the guidance of the full set of concerns that should be considered during a smart city deployment.

With this recognition that the citizen is the primary beneficiary of smart cities and communities, the role of multiple stakeholders is recognized in making decisions. Therefore, this document is targeted at cities, policymakers and regulators, vendors/integrators, standards development organizations, academic researchers, civil society, and the concerned citizen.

2.1 Cities

Administrators and participants in the management and evolution of smart cities benefit from this framework through the availability of the framework tools initiated by this project. These tools will facilitate early evaluation of smart city applications and their applicability within any smart city endeavor. Those responsible for specifying and evaluating tenders will benefit from the common language and requirements categorizations provided by the concerns-based methodology revealing Pivotal Points of Interoperability (PPI) and Zones of Concern (ZofC).

2.2 Policymakers and Regulators

Policymakers and regulators can likewise benefit from the application framework tools in considering the needs for smart city applications. These analyses can form the starting point for specifications and approvals of roadmaps using a consistent terminology.

2.3 Vendors/Integrators

Vendors and integrators can benefit from the technical analysis of Pivotal Points of Interoperability, which will reveal key technical markers in technologies with which they may have to integrate. Knowledge of these points reduces the distance to interoperability and allows proposals and development efforts to focus on benefits added, as opposed to, integration complexities.

2.4 Standards Development Organizations

Standards development organizations (SDOs) can benefit from the requirements analysis terminology provided by the NIST CPS Framework and can use the methods of Section 4 to recognize similarities and differences between their smart city and IoT efforts and those of other SDOs. This facilitates potential harmonization as common alternatives are reviewed and selected.

Because every SDO has its own constituency and history, the IES-City Framework can provide some unifying and open principles around which to organize. If SDOs utilize and present their efforts with respect to PPIs and ZofC, there will be common ground for discussing similarities and differences. Additionally, by reviewing these commonalities, SDOs can launch initiatives that will result in convergence across the standards domains.

2.5 Academic Researchers

Academic researchers can utilize the tools of the IES-City Framework to extend their smart city projects by incorporating consistent terminology and concepts from the framework. Elaborations of the tools can further enrich the ecosystem of smart cities and IoT by adding dimensions through additional analyses. Researchers can additionally study impacts and outcomes, assess betterment of living, develop research frameworks, and provide feedback to policymakers based on the concepts of the framework.

3 Smart City Application Framework

This application framework component of the IES-City Framework provides the stakeholder a simplified view of the wide range of smart city possibilities.

It addresses the challenges facing municipal technical offices. The objective is to provide the capacity for:

- Evaluating a list of cases that are being implemented (or being considered for implementation), thereby improving the management of municipal resources and delivery of services to citizens.
- Identifying the needs and priorities of a city and assessing whether the city is ready, from a technical point of view, for absorbing "smarts."
- Measuring the benefits that can be expected from the solutions evaluated and/or determining whether the goals (benefits) have been accomplished.

Here are definitions for two key words used in this section.

Solution: A solution is defined as the ensemble of administrative, policy, and technological actions that solves a socially related challenge. Solutions can seek to better the environment, save money for the taxpayer, infuse innovation, or any combination of the above (note that some goals might be mutually exclusive). Two examples of solutions are:

- Automating wastewater routing systems to benefit the environment.
- Providing eGovernment services to save money, increase efficiency, and provide services for rural citizens.

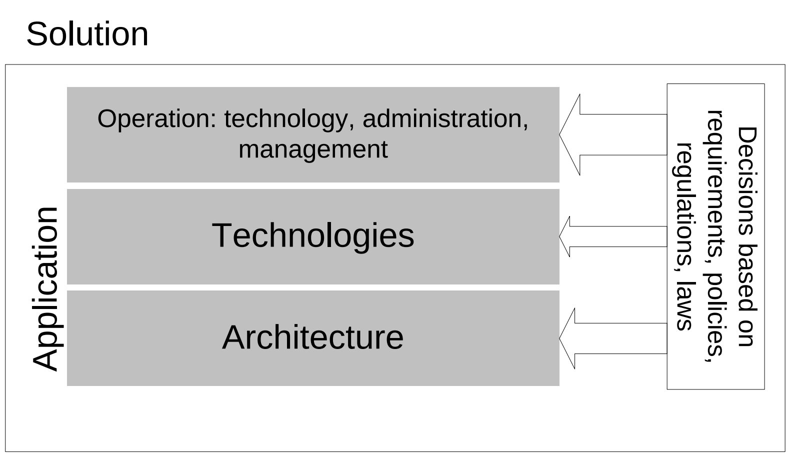

Figure 4: Solutions and Applications for Smart Cities

Application: An application is defined as the use of technology for the management and operation of a physical, public service, or social asset. Examples of applications are traffic management, energy provision, eGovernment services, etc.

Civic leaders and service administrators are challenged with technical, architectural, management, and administrative decisions upon which smart city services will operate. Furthermore, at an operational level, they are challenged with the daily operational decisions of how best to optimize different resources and provide adequate services to citizens.

The promise of smart city technologies is to make quicker and better decisions—particularly at the operational level—through ready access to data and information that are dramatically more current and comprehensive. For example, real-time traffic, energy, and resource data enable administrators to intervene and manage city services and resources in direct response to normal operation, under system stressors (e.g., accidents, weather, over-utilization), and under constantly changing citizen demands due to urbanization (e.g., health, safety, water, and energy).

Determining which smart city applications provide cost-effective and proven benefits is a challenge. In the technical realm, the flood of internet-enabled sensors and applications for managing and monitoring civic systems, resources, and services can overwhelm users—users who may be technical experts, non-technical public officials, or operational managers. Therefore, a matrix of available smart city technologies would provide a guide by which civic leaders and their technical teams can develop their unique vision. It would also be helpful for stakeholders to share a common understanding of core issues when they make or implement joint decisions.

Likewise, civic leaders—who must assign scarce financial and human resources to their smart city initiatives—can gain meaningful guidance from objective descriptions of the benefits each technology can realistically be expected to provide.

Finally, while the promise of smart cities affords an exciting set of new civic capabilities, the deployment implications—political, legal, financial, and technical—are unique, and the city needs to be ready to face them. These technical and social solutions are cross-functional, challenge existing policies and processes, lack legal precedence, and demand complex technologies and technical skills. Therefore, it is not enough for stakeholders to simply define, design, and implement smart city solutions. Civic leaders, administrators, and their technical teams need a means of assessing their own readiness to integrate these new tools into their existing city management policies and services.

Note that comprehensive analyses and determinations are costly and detailed endeavors. The analyses in this framework are designed to facilitate initial research into these dimensions, thereby enabling less-costly feasibility analyses on which to base decisions regarding the need for deeper investigations.

Table 1: Dimensions of the Application Framework, which follows, summarizes the dimensions by which solutions and applications for smart cities are analyzed in a readily usable tool, the “Application Framework Tool”, which is the principle product of this part of the IES-City Framework.

Table 1: Dimensions of the Application Framework

Dimension	Description
Breadth: List of applications and related metrics	It consists of both a framework (metrics) for evaluating the breadth (elaborated based on existing models) and a list of evaluated applications
Readiness: A framework for assessing a city's Readiness	A list of metrics to assess the readiness of cities to absorb smart city applications (elaborated based on a subset of existing maturity models)
Benefits: A framework to measure benefits	Metrics for measuring benefits that can be derived from assimilated applications

The sub-sections that follow describe the individual analyses for each dimension. Each section details the scope of the metrics realized in the Application Framework Tool and the method by which it was derived.

Additionally, Appendix B (Use Cases and Analyses for Select Smart Cities) provides:

B.1 Smart City Case Studies: case study summaries of selected smart city deployments

B.2 Business Cases for Implementing IoT-enabling Technologies: business case briefs

B.3 Summary Analyses of Selected Smart City Deployments: key questions and answers about selected deployments

These appendices are not intended to be thorough. Rather, they capture a useful sampling of information about smart city deployments from several different perspectives.

3.1 Evaluate Breadth

3.1.1 Goals

This section has two main objectives:

- Definition of an approach for evaluating the breadth of applications: this approach was developed starting from some existing models.
- Definition of a framework for evaluating the breadth of applications: practically, this framework is a software tool, based on the defined evaluation approach.

3.1.1.1 What Was the Goal?

As in any engineering solution, smart city needs can be translated into requirements. These requirements can be situated into a set of coordinates that will also represent the breadth of an application. This framework and approach are relevant, because there is no one-fits-all solution, as the requirements arising from city needs will differ in the various dimensions.

So, to evaluate the breadth, it is necessary to:

- Classify the applications' kind or type.
- Define sets of requirements for each application's category and subcategory.

Through this approach, the requirements for an existing or to-be-designed application can be deduced starting from the subcategory it belongs to (Figure 1).

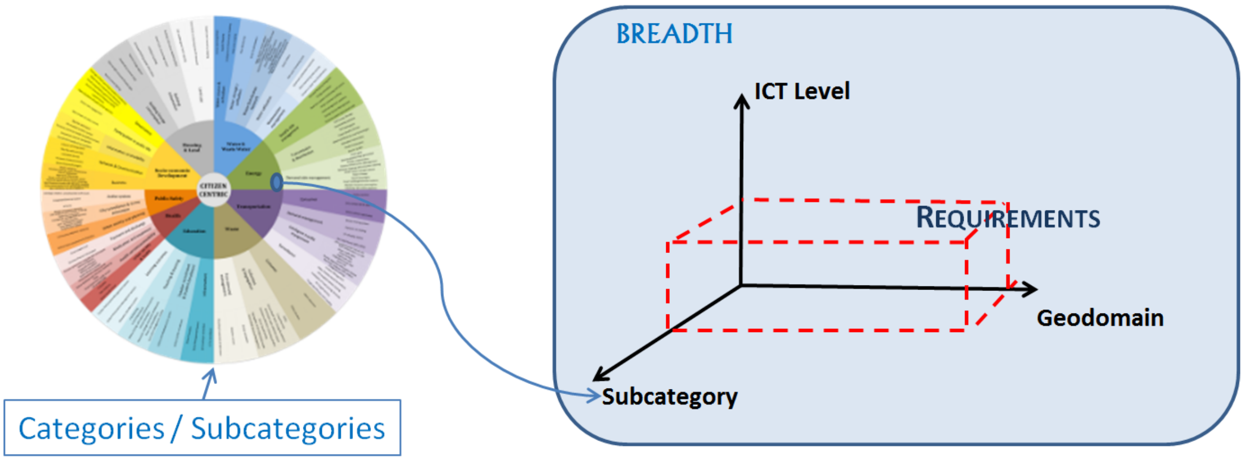

Figure 5: The Meaning of Breadth of Smart City Applications

3.1.1.2 Why Does This Matter?

The establishment of a shared list of requirements could be a common basis for the development of a smart city application. These requirements will further pave the way to the identification and implementation of the Pivotal Points of Interoperability.

Moreover, the tool has different potential users with different needs. For example, potential users include:

- Technical and other stakeholders who, prior to developing an application, need to know the requirements that such an application must satisfy.
- City managers who need to be assured that the technical requirements to be satisfied match the city reality, in terms of existing infrastructure and plan for deploying new ones.
- Application vendors who desire to evaluate the breadth of an application that they have developed.

3.1.1.3 How Was It Developed?

The steps that achieve the desired results include the situating of the application within a general multi-dimensional context and the further specification in such a context, including:

1. Identification of:
   - Sets of **categories** (e.g., health, transportation, …) and **subcategories** (e.g., governance, participation in public life, ….)
   - A set of “contexts” to fix the features, such as:
     - Geo-domains (home, building, campus/aggregation, district, city, land, country, mainland)
     - ICT Architecture level (user interface, application, data, sensor/actuator), where:
       - Sensor/actuator refers to the physical devices that provide sensing, actuation, control and monitoring activities.
       - Data refers to the level in which data are aggregated, stored, and analyzed.
       - Application refers to the level that provides the needed “intelligence to the system,” providing controlling, monitoring, decision, and prediction capabilities.
       - User interface refers to the user interfaces and GUI enabling an easier use of the system.
2. Utilization of literature and case studies to identify the requirements of each context and its link with each category and subcategory. For example, the subcategory “Traffic Management” (included in the “Transportation” category) will yield a set of requirements such as large communication network, scalability, capability of managing heterogeneous data from different sources, etc.

Other requirements will be inherited from the context of use of the application. Figure 6: The Final List of Requirements from the Coordinates shows how the universe of potential smart city applications was constrained in the present analyses and how requirements in the contexts were derived to provide a description of the breadth of requirements for these categories.

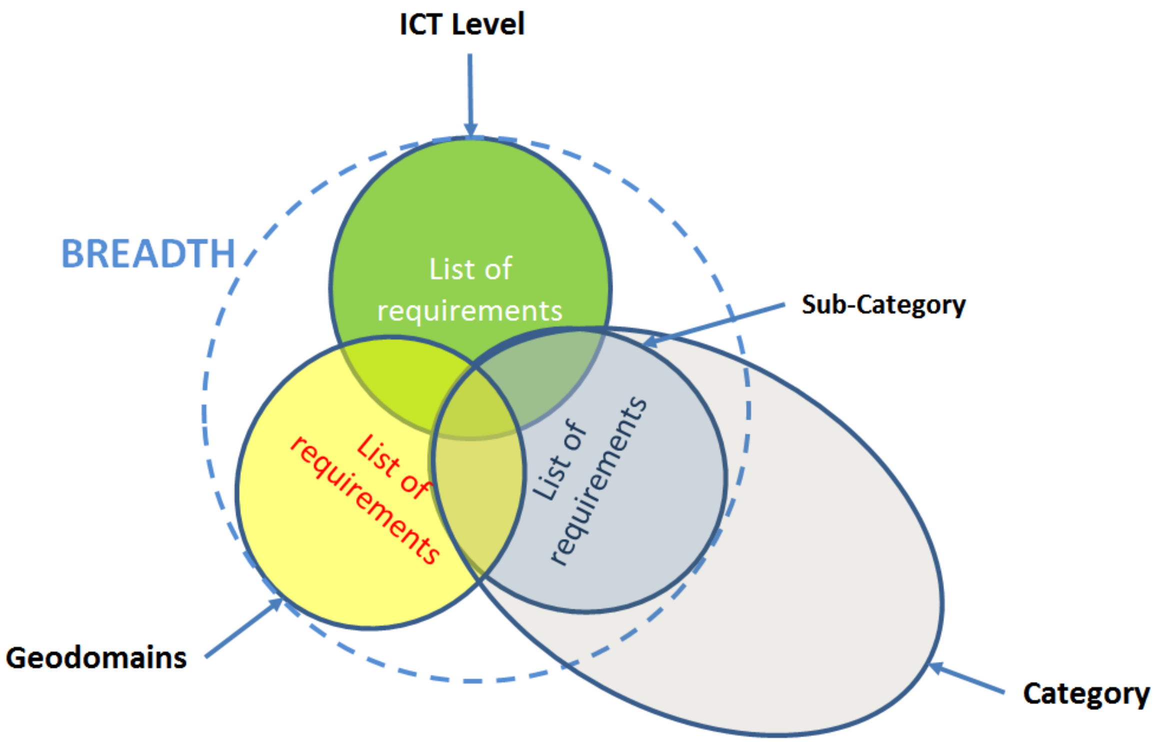

Figure 6: The Final List of Requirements from the Coordinates

This analysis, in turn, was used in the design and development of Application Framework Tool implementing the previously defined evaluation approach. The following sections describes the previous work reviewed for the analysis.

3.1.2 Descriptions of Previous Work

In this section, a more detailed description of previous work is presented. In the first paragraph, the definition of categories and requirements is explained. In the second one the design of the tool is shown.

3.1.2.1 Identification of Categories and Requirements

The application categorization into categories and sub-categories (classifying the world of the applications for smart cities) plays a key role in the assessment of the breadth of such an application.

The **sets of requirements** have been identified from "Aspects" and "Concerns," as defined in the *Framework for Cyber-Physical Systems* [21].

The adopted process is as follows: an aspect identifies a wide perspective of analysis by which an application can be evaluated; this perspective is further specified by concerns. A concern produces a set of "abstract requirements" that become "implementation requirements" for applications.

There are two kinds of implementation requirements:

- *Geo-domain*: Specifies the geographical domain on which the applications of each subcategory can act.
- *Architectural*: Specifies the application's ICT architecture level on which the abstract requirements impact.

> Terms and definitions
>
> ***Category***: Wider area where an application is to be applied to improve everyday urban life. It is characterized by specific issues/priorities.
>
> ***Sub-category***: A specific part of a category.
>
> ***Concern***: Perspective of analysis by which an application can be evaluated.
>
> ***Aspect***: A major category of concerns.
>
> ***ICT architecture level***: A level of an ICT architecture; in the scope of this work, four levels have been identified as relevant: "Sensor", "Data", "Application", and "User Interface".
>
> ***Geo-domain***: A geographical area that is considerable from a smart city perspective.

The list of categories and subcategories identified using the bibliography is shown in Table 9: List of Smart City Applications Category/Subcategories. Moreover, to facilitate the identification of the sub-category to which an application belongs, the table also provides a list of issues characterizing each one and some examples of kind applications. Another important source for this analysis was the recommendations from “Common Requirements of the Internet of Things,” within the ITU-IT set of recommendations about “Global Information Infrastructure, Internet Protocol Aspects, Next-generation Networks, Internet of Things and Smart Cities” (Study Group 20 of ITU-T – Y.2066) [69]. This analysis is summarized in Appendix Section A.4.

Starting from this categorization of applications, the requirements have been identified for each of them. An example of the requirements for a specific subcategory is shown in Table 10, to make clear the approach (the complete list is provided in another document).

3.1.2.2 The Tool

Based on the previous categorization, a tool has been designed and implemented that enables the stakeholders to understand and have a common understanding of the main requirements associated with the breadth of the applications. These stakeholders could be application designers/developers, city managers, or application vendors. The tool further points to potential technological requirements of which the administrator of policymaker will need to be aware to allocate financial and human resources.

These stakeholders can get benefits from having a simple tool providing them a list of requirements on the base of the breadth coordinates of the application.

The interface of the tool has been implemented as follows:

- The input form allows a user to choose, first, the category and subcategory among the available ones:

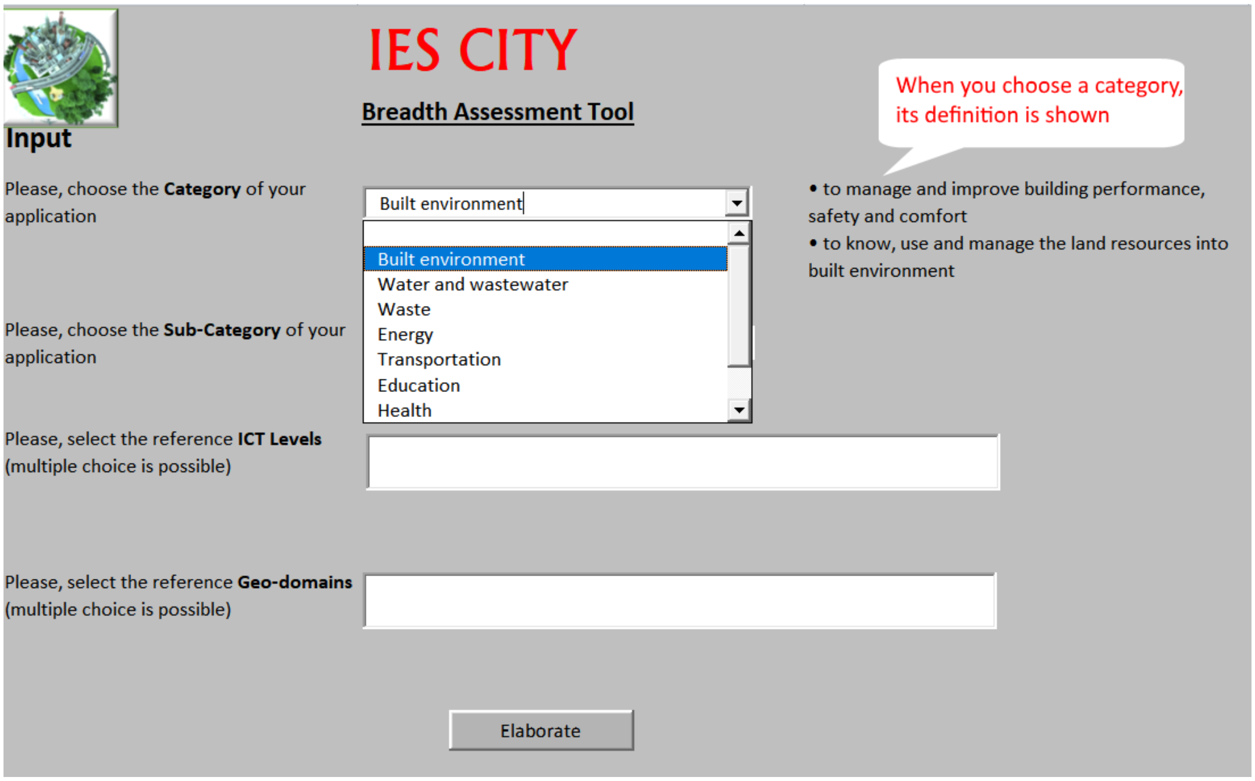

Figure 7: Category Choice

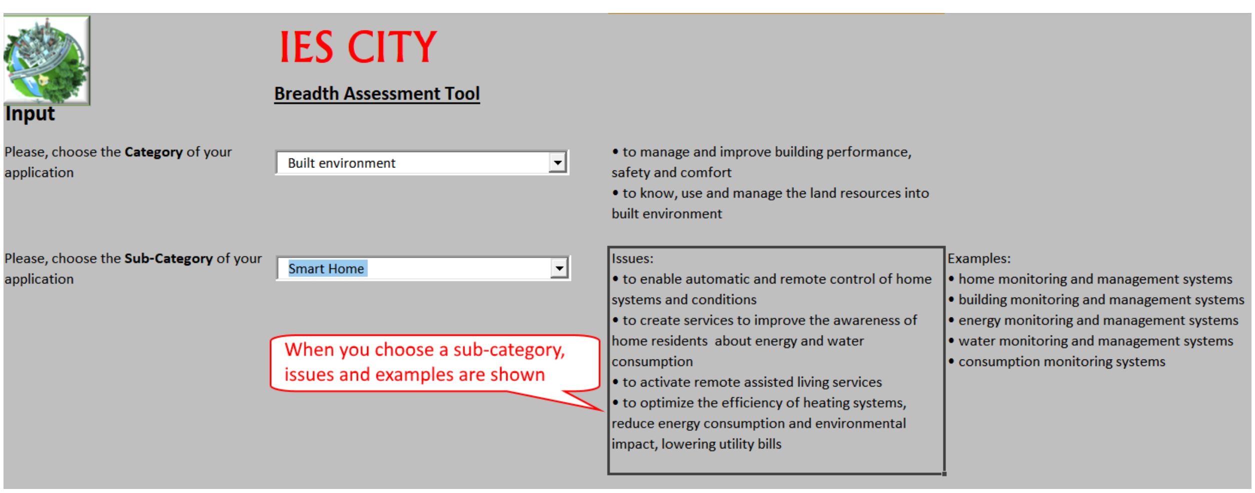

Figure 8: Subcategory Choice

- Then the ICT levels and the geo-domain are chosen:

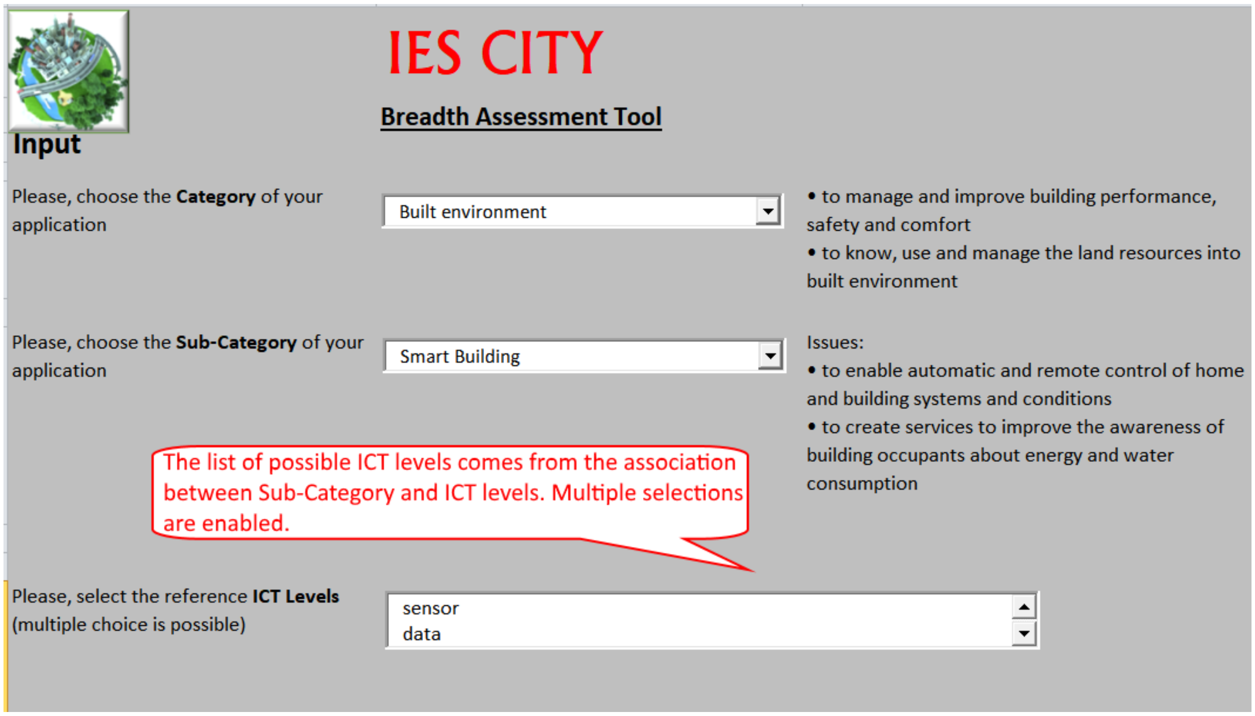

Figure 9: ICT Levels choice

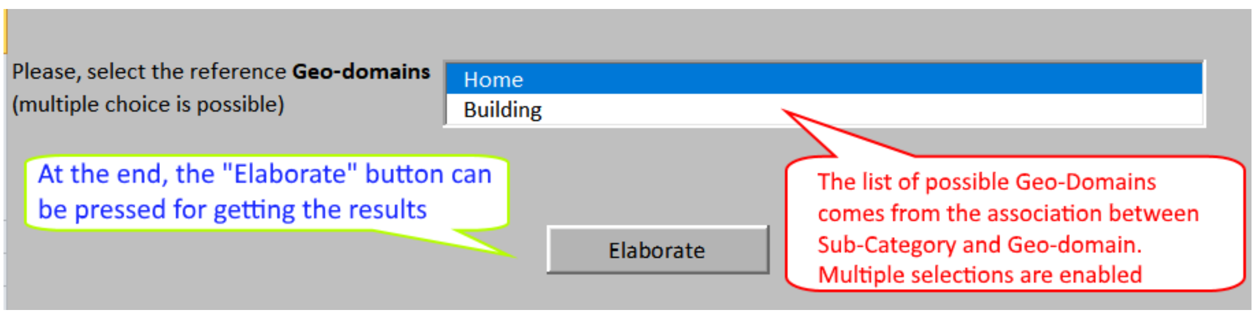

Figure 10: Geo-domains Choice

By choosing the features of the application and then clicking on the "Elaborate" button, the list of requirements, split into CPS Aspects and Concerns is shown (Figure 11).

List of *Requirements* *for the following kind of Smart City applications*

Category: Built environment
Sub-Category Smart Building
ICT Levels:
Geo-Domanis Home

Aspect	Concern	Abstract requirements	Specific implementation requirements
Functional	**Actuation**	- to control building energy systems	- actuation capabilities - smart devices
	Communication	- capacity to exchange information internal to the system	- Home management systems - Sensor network
	Functionality	- energy management - alarm management - fault detection and diagnosis	- Automation and real-time analytics - integration with utilities and city infrastructure
	Controllability	- to remotely control/access to the systems	- Internet connection - remote control software
	Performance	- to provide feedback in time to act	- fast and reliable network - real-time systems
	Physical context	- to detect presence of people	- sensors (motion, presence, ...)
	Sensing	- to detect presence of people - persistent communications - to elaborate data received from home energy systems - capacity to analyze and elaborate received data and make decisions	- sensors - persistent communications technologies - decision support systems
	Monitorability		
Human	**Usability**	- to provide human readable, unambiguous and aggregated data	

Figure 11: Output Sheet Showing the List of Requirements

The tool has been developed in Microsoft Excel™ using Visual Basic for Applications (VBA) macros within the sheets.

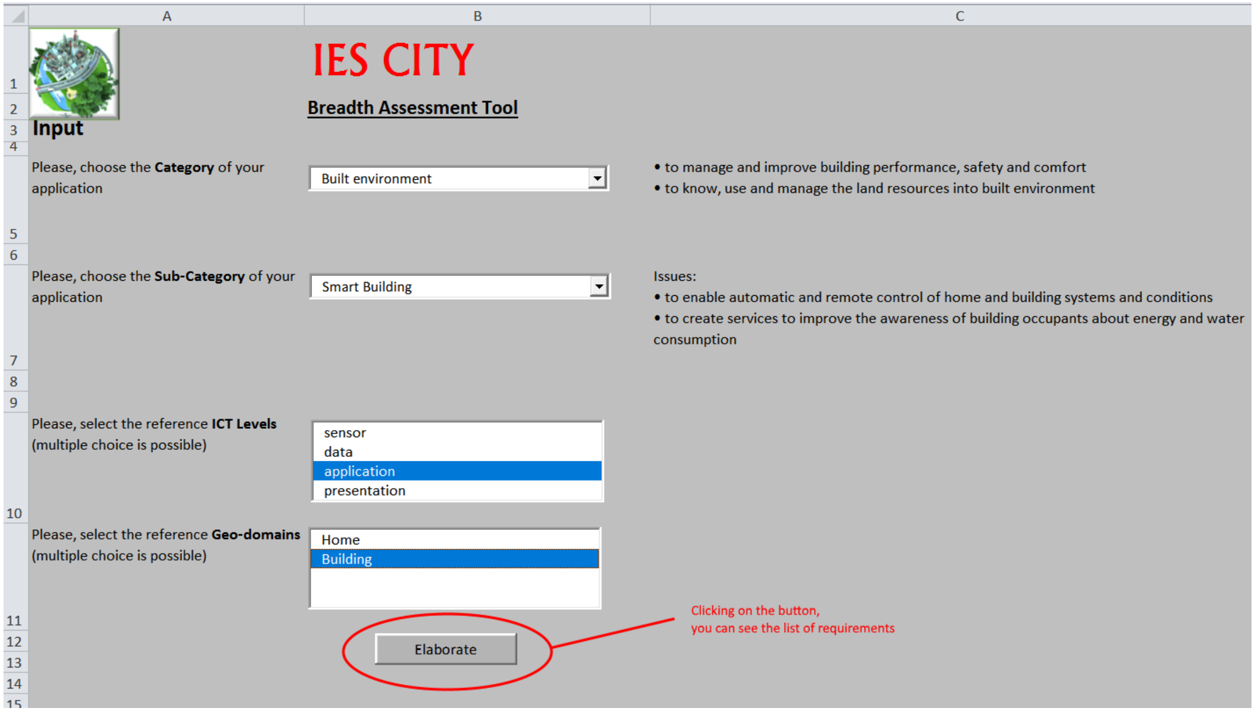

Figure 12: Input Sheet of the Developed Tool

Here is a complete example of the resulting list of requirements (see Table 2):

Table 2: List of Requirements for an E-Governance Application, Involving the Data Level for the Country Geo-domain

List of Requirements for the Following Kind of Smart City Applications	
Category:	Built Environment
Subcategory:	Smart Building
ICT Levels:	Data
Geo-Domains:	Home

Aspect	Concern	Abstract requirements	Specific implementation requirements
Functional	**Actuation**	- to control building energy systems	- actuation capabilities - smart devices
	Communication	- capacity to exchange information internal to the system	- home management systems - sensor network
	Functionality	- energy management - alarm management - fault detection and diagnosis	- automation and real-time analytics - integration with utilities and city infrastructure
	Controllability	- to remotely control/access the systems	- internet connection - remote control software
	Performance	- to provide feedback in time to act	- fast and reliable network - real-time systems
	Physical context	- to detect presence of people	- sensors (motion, presence, ...)
	Sensing	- to detect presence of people - persistent communications - to elaborate data received from home energy systems - capacity to analyze and elaborate received data and make decisions	- sensors - persistent communications technologies - decision support systems
	Monitorability		
Human	**Usability**	- to provide human-readable, unambiguous, and aggregated data	
Business	**Utility**	- to provide effective information to reduce costs - to improve quality of life of residents	- fast and reliable network - real-time systems
Trustworthiness	**Safety**	- persistent monitoring - to provide data in time to act	- fast and reliable network - real-time systems

	Privacy	- to define privacy policy	- privacy protection mechanisms
	Security	- to preserve authorized restrictions on access and disclosure - to prevent modification or destruction of system - to ensure non-repudiation and authenticity - to ensure timely and reliable access to and use of a system - digital signature - cryptography	- firewall - antispyware - antivirus
Timing	**Logical time**	- to take into account the sequence of the events	
	Time awareness		
	Managing timing and latency	- to send data in a timely manner	
	Synchronization	- to send data with a common time scale	
Data	**Data semantics**	- to correctly understand the meaning of the data - standard data models	
	Operations on data	- to harmonize data from different sources - electronic data format (based on standard)	
	Relationship between data	- to connect data from different sources - public, shared, and standard data models	
Boundaries	**Behavioral**	- capacity to interact with system from other domains	- software interfaces

3.1.3 Conclusions

The lack of information and a lack of common understanding of different issues can be a huge impediment in the conception of smart city solutions. The wealth of information on cases of smart city solutions and applications can create information saturation for different stakeholders. The IES-City Framework has processed a substantial quantity of such information and categorizing it to facilitate the conception of smart city solutions, thus providing a valuable starting point for city administrators and other stakeholders. The tool provides further capacity to the different stakeholders who will need to determine application requirements, to assess different application requirements to explore benefits comparatively, and to explore the application where their current infrastructure and capabilities could be of immediate use.

Thus, the concept of this section was to classify the kind of applications and define the sets of requirements at category/subcategory level, so that the requirements for an application could be deduced from the subcategory to which it belongs, as well as two features of the "application space": the ICT levels on which the application works and its reference geo-domains.

The aim is to provide different kinds of stakeholders (e.g., application designers/developers, city managers, and application vendors) with a simple tool able to produce a list of requirements on the base of the category. This list of requirements is organized in terms of Aspects and Concerns of the CPS framework, making it compatible with other analyses made by other groups of the IES-City initiative.

3.1.3.1 Key Messages

Within this section the concept of breadth of smart city applications has been developed. The breadth of a smart city application provides a set of coordinates and features to identify the list of requirements for an application category, to satisfy smart city needs. It is not a simple concept, and the ability to define and measure it is an important prerequisite for being able to implement Pivotal Points of Interoperability. The resulting list of requirements can fix a base for a shared understanding of smart city applications in terms of their categorization, domain, issues, and requirements.

The recommended next step is to validate the list of requirements with domain experts.

3.2 Evaluate Readiness

3.2.1 Goals

The goal of this dimension of the application framework is to provide an easy-to-use tool to evaluate potential applications for smart cities by posing simple questions to administrators and planners.

3.2.1.1 What Was the Goal?

Evaluation of readiness can be an enormous task. There have been substantial references and standards efforts [97][98] to define the various requirements and metrics for applications. However, there is a much smaller set of key characteristics that a smart city requires to practically deploy a given application.

This readiness dimension of the framework is a comprehensive and easy-to-use tool for cities to make a quick and prudent decision to identify and deploy smart city applications. It is also expected to be a concise set of metrics and indicators to measure progress. A methodology was designed that will allow a quick, high-level readiness assessment to be done. This quick assessment can then be followed up with a much more robust and long-term assessment process that is consistent with the initial activity.

It can assist policymakers in prioritizing actions (i.e. e-procurement, indirectly highlighting most pressing needs, etc.).

3.2.1.2 Why Was It Done?

As an example, assume there exists a wonderful centrally distributed citizen-alerting application that relies on a cell phone's application for alert distribution. Yet, assume also that a municipality considering the merits of adding this service has spotty cell phone service and that most residents don't have smart phones. Such a locality would not be *ready* for this application.

Such broad but simple metrics can help both filter out smart city features that could be prohibitive to deploy because of the corresponding infrastructure that must be built, or, provide guidance to stakeholders on the need for roadmaps that acquire the desired infrastructure over time and to achieve readiness.

Thus, readiness here is scoped in a very narrow sense to enable the kind of analysis envisioned by this framework. Naturally, the more detailed metrics and maturity models specified by other projects and organizations will be appropriate for next-level detailed studies, designs, and planning. This tool is not intended to substitute for them.

3.2.1.3 How Was It Developed?

In 2014, the organization from the Scottish Smart City Readiness and Maturity Self-Assessment Model [1] summarized a set of organizing categories for readiness metrics:

- Strategic intent
- Data
- Technology
- Governance and service delivery models
- Stakeholder engagement

This categorization was adopted as the overall organization for the readiness indicators for the framework.

A digest of indicators was then constructed from the readiness and maturity models already produced by various smart city standards and efforts [97][98][99]. A reduced set of 54 key characteristics was derived from that work, and these characteristics are organized under the categories above.

This resulted in a matrix that allows for each category and subcategory of the application framework to identify by a checkmark as to whether that characteristic was necessary or desirable to support it.

3.2.2 Descriptions of Readiness Addition to Application Framework Tool

3.2.2.1 Readiness Metrics

Using the references in [97][98], a set of metrics were derived and organized according to the categories of the Scottish model.

Table 3: Summary Readiness Metrics

Category	Metric	Notes
Strategic Intent	<no metrics identified>	
Data	Current sources of open data from government services	If there are existing sources, the addition of new sources is less costly.
	Availability of online city information	Again, this indicates an existing infrastructure for this kind of availability.
ICT Infrastructure/Technologies	Substantial percentage of households with internet access	If the application involves dissemination of information via the internet, this would be a necessary characteristic of the community.
	Availability of wireless broadband subscriptions	This is required if the application offers data streams or audio/video over wireless networks.
	Availability of fixed broadband subscriptions	This is required if broadband connections within premises is relied upon (e.g., building premises monitoring).
	Availability of Wi-Fi in public areas	This is relied upon in many wayfinding applications.
	Availability of public internet access centers	Ensures that all citizens have access to the application features.
	Extremely high reliable broadband	Needed if delivery to almost every subscriber is essential to the application.
	Availability of ultra-high-speed wireline connection	For data-intensive applications, this may be required.
	Substantial percentage of digital broadcasting network	A substantial degree of coverage of the citizenry with digital broadcasting as

Category	Metric	Notes
		an information distribution means.
	Availability of sensors network infrastructure	The ability to add sensors to an existing sensor network infrastructure is needed.
	Substantial percentage of mobile-cellular telephones	Most citizens have mobile phones.
	Extremely high reliable mobile broadband	Mobile broadband can be relied upon for continuous and relatively error-free service.
	High city coverage with 3G-enabled mobile network	Most locations have at least 3G mobile service.
	High city coverage with 4G- and higher technologies-enabled mobile network	Most locations have at least 4G mobile service.
	Substantial percentage of smart phones and tablets	Most citizens have smart phones and/or tablets.
	Substantial percentage of households with computer/laptop	Most households have computers and/or laptops.
Governance and Service Delivery Models	Use of integrated management and command center	An existing integrated management and command center is established.
	Centralized collaboration between emergency response, police, fire, water, and power	There is coordination between police, fire, water, and power administrations.
	Availability of online city feedback mechanisms	There is a digital means of providing online feedback for municipal services.
	Government access to cloud services	The government has access to cloud services.
	Emergency phones (DSPT-Digital Satellite Phone Terminal-etc.) at selected locations-disaster situations	There are public-access reliable phones at strategic locations.
	24/7 ICT Services	There are reliable computer ICT systems and services.
	Information security of public services and systems	Information security is established for public services.
	Provision of online systems for administering most public services and facilities	Public services are administered electronically

Category	Metric	Notes
		and through managed networks.
	Availability of services to support persons with specific needs, regardless of ability and affordability	Support for citizens with specific needs and financial abilities.
	Availability of needed citizen-centric services over mobile applications/website portal - require support to continuously provide value to users	Website and application access portal(s) are established for at least some services.
Stakeholder Engagement	Adult digital literacy rate - high percentage of households with at least one family member who is digitally literate	
	Existence of strategies, rules, and regulations to enable ICT literacy among inhabitants	
	Availability of education program for citizens on smart city applications	
	Most citizen-centric web portals are mobile capable	
	Most web portals/apps are universally accessible (also compliant to disabled persons)	
	Government connection/policies for substantial use of social media	
	Substantial use of social media by the people	Many or most citizens use social media.
	Availability of programs for online citizen engagement	Existing programs for online engagement with citizens exist.
	Existence of systems, rules, and regulations to ensure privacy protection in public service	Privacy protection mechanisms and regulations are in place.
	Substantial use of internet by city inhabitants	Most citizens use and are familiar with internet and applications that use the internet.

3.2.2.2 Integration into the Application Framework Tool

To integrate this dimension into the tool, a second output consisting of a list of readiness parameters for the selected input category and subcategory will be needed. (Figure 13 shows a screenshot from this output, and Table 4: Example of Set of a Complete Readiness Table for a Sub-category.)

List of Readiness Parameters for the following kind of Smart City applications		
Category:	Built environment	
Sub-Category:	Smart Home	
Strategic Intent	**Techonology**	**Readiness parameters**
Data	Open data/information platform	- Current sources of open data from government services
ICT Infrastructure/Technologies	Internet network	- Substantial percentage of households with internet access - Availability of fixed broadband subscriptions
	Broadcasting	
	Sensors networks	- Availability of sensors network infrastructure - Substantial percentage of smart phones and tablets

Figure 13: Example of Readiness Output from the Tool

Table 4: Example of Set of a Complete Readiness Table for a Sub-category

List of Readiness Parameters for the following kind of Smart City applications		
Category:	Built environment	
Subcategory:	Smart Home	
Strategic Intent	**Technology**	**Readiness Parameters**
Data	Open data/information platform	- Current sources of open data from government services
ICT Infrastructure/Technologies	Internet network	- Substantial percentage of households with internet access - Availability of fixed broadband subscriptions
	Broadcasting	
	Sensors networks	- Availability of sensors network infrastructure - Substantial percentage of smart phones and tablets
	Computer/laptop	
Governance and Service Delivery Models	Integrated management center	
	Emergency response	

	Services deliveries	- 24/7 ICT services - Information security of public services and systems - Availability of services to support persons with specific needs, regardless of ability and affordability
Stakeholder Engagement	Citizen education	- Availability of education program for citizens on smart city applications
	Web portal/mobile apps/online services	- Most web portals/apps are universally accessible (also compliant to disabled persons) - Availability of programs for online citizen engagement

3.2.3 Conclusions

There are many existing projects that provide guidance on how to assess readiness with comprehensive smart city maturity models. They often involve strategic, technologic, policy aspects and define steps of lifecycle of project and readiness indices.

In the IES-City Framework, the readiness definition is coarser and less detailed. Its intent is to provide a simple tool to assist stakeholders in determining, at a first pass, whether a city has an existing infrastructure that will make applications from the categories straightforward to integrate. Once a smart city project is engaged, of course, the more detailed analytical tools may be appropriate to aid in the specification and implementation process.

A list of interesting readiness frameworks is presented in Appendix Section A.4.

3.2.3.1 Key Messages

The awareness of the gap between existing infrastructure and needed infrastructure is an important point in planning smart city strategies. This gap can give a measure of the economical, technical, political, and strategic efforts for evolving a city in a smart direction. Under this perspective, the list of readiness parameters provided by the tool for each category of application can be compared with the current state of infrastructure of a city. This comparison can give a sense of the investments and time needed to implement them, allowing also a prioritization of them, and thereby helping to elaborate a smart city strategy.

A recommended next step is to validate the list of readiness parameters with domain experts and with real cities.

3.3 Measure Benefits and Application Deployment Examples

3.3.1 Goals

The goal of this section is to develop the framework or structure that will provide the metrics and tools that can be used by cities to parameterize the necessary investment of public resources for a smart city designation. Such investments are expected to bring win-win situations to all involved stakeholders, thereby benefiting the city government, private sector enterprises, and people. This structured approach to evaluating possible technologies for deployment throughout a city will allow government leaders to build a more livable and productive community.

3.3.1.1 What was the Goal?

By enhancing the deployment of these IoT-enabling technologies, it is expected that the cities will experience greater economic activity [100][101]. The benefits are expected in all segments of the city, including the public sector, private sector, and the citizenry.

The public sector is heavily influenced by growth in economic activity. Benefits could include increased and better jobs in the science, technology, engineering, and mathematics (STEM) fields, local GDP growth, increased exports, inward investment, decreased cost of serving citizens, strengthened economic resilience, improved environmental quality and social equitability and cohesion, and less negative externalities [102].

The private sector also stands to benefit from the increased deployment of innovative technologies. New markets and revenue potential become available. Through innovation, new service ideas and business models are developed and pursued. New capabilities lead to new approaches to performing existing services, thereby yielding increased productivity [103][104].

Citizens are rewarded in the sense of improved service delivery in terms of quality, efficiency, and cost in areas such as transportation, energy, water, and other resource utilization [105]. By empowering citizens through enhanced information about their lifestyles, greater productivity and creativity become a reality [100]. With advanced data collection and analysis of citizens' health, activity, and behaviors data, a dynamic understanding of public health and safety can be achieved.

3.3.1.2 Why Was It Done?

Ultimately, the reason for deploying these IoT-enabling technologies is to provide greater quality of life to people. Greater quality of life will allow the cities to become more competitive globally [107].

Recently, the growing trend is toward more people moving into urban areas. These growing populations present a huge challenge to city planners and leaders. More people mean increased consumption of valuable resources such as water and energy and further burdening of an already aging and stressed infrastructure. They need more fire protection, police, health care, and education, often before the tax revenues are available to pay for them [32].

With the current situation of shrinking budgets and limited resources, cities are constrained in providing quality services to the growing population. For example, cities continue to build new roads, buildings, and infrastructure. Instead of striving for physical growth, cities should be measured by the following:

- how wisely they use energy, water, and other resources.
- how well they maintain high quality of life for their people.

- how smart they are in enabling economic prosperity and social equitability on a sustainable foundation.

In short, cities must become much smarter in how they use available capacity and resources to maximize benefits to people [106].

Despite these challenges, growing cities represent a huge opportunity. After all, the urban population is growing because people can expect to find better jobs and make more money in cities than they could in rural areas and small towns [106]. City dwellers' economic opportunity is magnified by the network effect of having thousands of people around them. Many will find value in the skills and labor they provide. Cities themselves can benefit when they provide the infrastructure that enables those individuals to grow economically and improve the quality of life.

More open and connected city operations provide for better and timely communications between different departments. With timely information flow, better city planning, and forecasting become a reality, and more effective deployment of city resources becomes the standard, yielding cost and resources savings. The availability of real-time information allows system operators to assess real-time conditions to govern their operations. This allows them to be able to predict and prevent problems before they become costly events.

3.3.1.3 How Was It Developed?

To develop a set of metrics for identifying benefits for cities to help them decide whether to make investments in smart city applications, we have identified three primary benefits categories based on the foundation of three pillars of sustainability--economic benefit, environmental benefit, and social benefits. These categories apply to all segments of the city including public sector, private sector, and citizenry.

From the theme areas, more detailed evaluation criteria were established by conducting a thorough review and evaluation of a comprehensive set of existing city performance indicators and hundreds of real-world case studies.

3.3.2 Descriptions

3.3.2.1 Benefit Metrics

To evaluate the benefits thoroughly, a wide range of benefits has been identified for three domains: public sector, private sector, and citizenry.

Table 5: Summary Benefits Metrics

Domains	Categories	Subcategories	Metrics
Public sector	Economic benefits	Integration	Improve economic integration
		Employment	Create more job opportunities
		Leverage of private funding	Provide public-private partnership opportunities
		Prosperity	Promote local GDP Growth

			Attract foreign direct investment (FDI) or promote inward investment
			Promote exports to other countries
			Develop opportunities for more revenues
		Cost saving	Reduce cost in governance operation and maintenance
			Decrease cost in serving citizens
			Reduce cost by being able to pick from the widest variety of solutions possible
		Economic resiliency	Reduce economic loss
		Pricing	Pricing advantage
	Environmental benefits	Energy conservation	Reduce community-wide energy consumption and greenhouse gas (GHG) emissions
			Promote community-wide use of clean energy
		Water conservation	Reduce community-wide water consumption
			Increase community-wide wastewater recycling and reuse
		Waste reduction	Reduce community-wide solid waste generation and disposal
			Increase community-wide solid waste diversion/recycling rate
		Raw materials conservation	Reduce raw materials consumption by public sector
			Promote use of eco-friendly materials as alternatives by public sector
		Environmental quality	Reduce community-wide air pollutants emissions
			Reduce and prevent water contamination releases to public area
			Reduce and prevent hazardous waste releases to public area
		Ecology system protection	Protect the habitat for animals and other species
			improve livable environment for city
		Natural hazard prevention	Reduce the occurrence and impact of natural hazards or man-made disasters

			Enhance alert of natural hazard or man-made disaster
	Social benefits	Public service	Improve public service deliveries
		Governance	Improve decision-making process and operation efficiency of governance entity within one department or across others
			Enhance governance transparency
			Reduce duplication of city effort from different departments with enhanced procurement process
		Equitability	Improve social equitability
		Attraction	Increase city's attraction to residents and visitors
Private sector	Economic benefits	Business development	Promote business development and increase revenue opportunities
			Engage and leverage the small and medium enterprises (SME) community
			Accelerate new business start-ups
		New market opportunities	Catalyze development of new products and new service ideas
			Create new business models
			Incubate innovative technologies and accelerate new product disruptions
		Employment	Create more job opportunities for private sector
		Cost savings	Reduce products investment cost
			Reduce operation and management cost
		Productivity growth	Promote production productivity of companies
	Environmental benefits	Energy conservation	Reduce energy consumption and GHG emissions by private sector
			Promote use of clean energy by private sector
		Water conservation	Reduce water consumption by private sector
			Increase wastewater recycling and reuse by private sector
		Waste reduction	Reduce solid waste generation and disposal by private sector

			Increase solid waste diversion/recycling rate by private sector
		Raw material Conservation	Reduce raw materials consumption
			Promote use of eco-friendly materials as alternatives
		Environmental quality	Reduce air pollutants emissions by private sector
			Reduce and prevent water contamination released by private sector
			Reduce and prevent hazardous waste released by private sector
	Social benefits	Service delivery	Catalyze development of new products and services
		Management	Increase the efficiency of the enterprise management
			Reduce the duplication of effort from different company departments
Citizenry	Economic benefits	Cost saving	Reduce cost in purchasing products or services
			Decrease cost in paying for utilities, including electricity, natural gas, water, etc.
			Reduce the frequency and cost of repairs
		Economic resiliency	Reduce economic loss
		Productivity	Increase productivity of employees
		Empowerment	Increase employees' satisfaction
			Increase empowerment of citizens
		Economic activity	Increase economic activity
		Time saving	Reduce the processing time of services
	Environmental benefits	Energy conservation	Reduce citizen energy consumption and GHG emissions
			Promote use of clean energy by citizens
		Water conservation	Reduce residential water consumption and wastewater production
			Increase residential wastewater recycling and reuse

		Waste reduction	Reduce solid waste generation and disposal by citizens
			Increase solid waste diversion and recycling rate by citizens
		Raw materials conservation	Reduce raw materials consumption by citizens
			Promote use of eco-friendly materials as alternatives by citizens
		Built environment quality	Reduce indoor air pollutants emissions
			Prevent domestic water pollutions
			Reduce and prevent domestic hazardous waste disposals
			Improve environmental quality of public space and local streets
		Environmental incidents alert	Public alerts for critical environmental or man-made incidents
		Creativity	Enhance creativity of citizens
	Social benefits	Livability	Improved health and well-being of citizens
		Equitability	Reduce poverty rate
		Citizen engagement	Provide opportunities to enhance public participation in public affairs or activities
		Public safety	Reduce both violent and property crime rate
			Improve public safety and security via video surveillance, fire and smoke alarms, and other ICT-enabled devices.
			Enhance cybersecurity
		Social cohesion	Enhance social cohesion and harmonization
			Improve community connectivity
		Skills development	Provide lifelong skills development opportunities to citizens, industrial employees, or government employees.
		Privacy protection	Improve the privacy of citizens

3.3.2.2 Integration into the Application Framework Tool

To integrate this dimension into the tool, a third output was included—a list of benefit metrics for the selected input category and subcategory (Figure 14 shows a screenshot from this output, and Table 4: Example of Set of a Complete Readiness Table for a Sub-category).

List of Benefits Parameters for the following kind of Smart City applications		
Category:	Built environment	
Sub-Category:	Smart Home	
Sector	**Kind**	**Benefits**
Citizens	Economic Benefits	- Cost saving: Decrease cost in paying for utility includes electricity, natural gas and water, etc. - Cost saving: Reduce the frequency and cost of repairs - Productivity: Increase productivity of employees - Empowerment: Increase satisfaction of employees - Empowerment: Increase empowerment of citizens - Economic activity: Increase economic activity
	Environmental Benefits	- Energy Conservation: Reduce citizen energy consumption/GHG emissions - Energy Conservation: Promote use of clean energy by citizens - Water Conservation: Reduce residential water consumption - Water Conservation: Increase residential wastewater recycling and reuse - Waste reduction: Reduce solid waste generation and disposal by citizens - Waste reduction: Increase solid waste diversion/ recycling rate by citizens - Raw Materials conservation: Promote use of eco-friendly materials as alternatives by citizens - Built environment quality: Reduce in door air pollutants emissions - Built environment quality: Prevent domestic water pollutions - Environmental incidents alert: Public alerts for critical
	Social Benefits	- Livability: Improved health and well-being of citizens - Social cohesion: Improve community connectivity

Figure 14: Example of Benefits Output from the Tool

Table 5: Example of Set of a Complete Benefits Table for a Particular Subcategory

List of Benefits Parameters for the Following Kind of Smart City Applications		
Category:	Built environment	
Subcategory:	Smart Home	
Sector	**Kind**	**Benefits**

Public sector	Economic benefits	- Employment: Create more job opportunities - Leverage of private funding: Provide public-private partnership opportunities - Prosperity: Develop opportunities for more revenues - Cost saving: Decrease cost in serving citizens - Cost saving: Reduce cost by being able to pick from the widest variety of solutions possible
	Environmental benefits	
	Social benefits	- Attraction: Increase city's attraction to residents and visitors
Citizens	Economic benefits	- Cost saving: Decrease cost in paying for utilities, including electricity, natural gas, water, etc. - Cost saving: Reduce the frequency and cost of repairs - Productivity: Increase productivity of employees - Empowerment: Increase satisfaction of employees - Empowerment: Increase empowerment of citizens - Economic activity: Increase economic activity
	Environmental benefits	- Energy conservation: Reduce citizen energy consumption and GHG emissions - Energy conservation: Promote use of clean energy by citizens - Water conservation: Reduce residential water consumption - Water conservation: Increase residential wastewater recycling and reuse - Waste reduction: Reduce solid waste generation and disposal by citizens

		- Waste reduction: Increase solid waste diversion and recycling rate by citizens - Raw materials conservation: Promote use of eco-friendly materials as alternatives by citizens - Built environment quality: Reduce indoor air pollutants emissions - Built environment quality: Prevent domestic water pollutions - Environmental incidents alert: Public alerts for critical environmental or man-made incidents
	Social benefits	- Livability: Improved health and well-being of citizens - Social cohesion: Improve community connectivity
Private sector	Economic benefits	- Business development: Promote business development and increase revenue opportunities - New market opportunities: Create a new business model - New market opportunities: Incubate innovative technologies and accelerate new product disruptions - Employment: Create more job opportunities for private sector - Cost savings: Reduce operation and management cost
	Environmental benefits	
	Social benefits	

3.3.2.3 Benefits for Smart Applications Deployment: Examples

3.3.2.3.1 Public Sector: Environmental Benefits

Mitigate Resource Depletion:

Smart lighting (energy efficient product): As part of the Accelerated Conservation and Efficiency (ACE) program of New York City, smart lighting solutions, including LED upgrades and advanced lighting controls, have been installed in many agencies;' buildings. LED lighting offers many benefits including low maintenance costs and high longevity, as well as better quality lighting.
Smart building (integrated smart energy solutions): Smart building is one of the research projects of Aspern Smart City Research. Installed with photovoltaic panels, hydride panels, solar thermal panels, heat pumps, and various thermal and electrical storage facilities, the smart buildings are genuine prosumers (i.e., they can use, store, and produce energy at the same time). Advanced ICT systems facilitate the optimal management of the energy production, distribution, consumption, storage, and transmission.
Smart grid (energy system optimization): Real-time operational smart grid for this European project is based on the integration and development of advanced ICT tools that can provide the coordinated work of customers, aggregator, and distribution system operator (DSO). The result of the ROSE project is a platform integrated with Smart Aggregator and the DSO to send the D/R signals to customers. It is a new paradigm of heterogeneous systems interoperability with the Smart Aggregator component based on Real-Time Semantic Engine, fed by endogenous data grid and web social network source appropriately distilled.
Smart energy system: The project "Energy Lab Nordhavn-New urban energy infrastructures " will develop and demonstrate future energy solutions. They use Copenhagen's Nordhavn as a full-scale smart city energy lab and showcase how electricity, heating, energy-efficient buildings, and electric transport can be integrated into a smart, flexible, and optimized energy system.
Smart utility meter systems: The GigaBit Smart City Project deploys a smart meter system into local existing fiber networks to enable automated services and management dashboards, thus enabling local governments and companies to move to more data-driven energy decision making. This can reduce time, save money, and conserve resources at the same time.
Smart plugs: Pittsburgh has installed pilot "smart plugs," which are inserted between a wall outlet and electrical devices and which transmit power output data via Wi-Fi to a mobile or desktop portal. With the smart plugs and management system, the city can monitor its energy consumption in buildings and determine what devices are top consumers of electricity, as well as control the devices remotely. The results include saving money and energy.
Transactive energy: The transactive energy for smart cities (Buffalo) project utilizes PowerMatcher, software developed in the Netherlands. The project adds an ISO/IEC/IEEE P21451-1-4 (Sensei-IoT*) XMPP Interface to PowerMatcher to provide cyber protection and facilitate data sharing. This network will spur innovation and create jobs to help consumers to obtain energy savings and to enable owner control over who has access to their data. This will result in energy reduction from homes and buildings by 30%, increase the use of solar power by 20%, and increase customer awareness of the benefits by 50%.

Microgrid Cloud: Micro-grid Cloud, an IoT-based integrative sensing, communication, computing, and control framework, is designed to perform continuous monitoring, analytics, and optimization of community microgrid operations. It is a joint projected developed in the City of Hartford and the Town of Windham. It enables aggregated local energy sources and storage for demand response and energy saving; reduces energy outage and interruption risks; and significantly reduces the carbon footprint by supporting a high penetration level of renewable energy.
Resource impact estimation tool (open data to inform future smart city design): To understand the climate change impacts for future building development, Kansas City is developing a resource estimation tool, PlanIT Impact. The tool can create specific estimations that can be adjusted in an immersive, 3D digital space for optimal iteration and analysis, thus allowing linkages to weather data and utility information of an area, along with the potential energy usage. This can be a powerful tool/platform to solve the problems of climate change and water scarcity. It will also promote employment and save operational costs.
Smart irrigation management: Smart Water Management (company) provides adaptable irrigation solutions to be cost effective and to protect property environments.
Smart cities utility infrastructure (remote sensors): Every year, millions of gallons of water are lost through leaks in aged water pipes around the world. Unaccounted water loss is as high as 40% in cities around the world. Cities such as Los Angele (CA), Las Vegas (NV), and Atlanta *GA) use an AT7T network (LTE), sensors, sounding technologies, and smart dashboards to identify water leaks. Sensors installed in the water distribution infrastructure will utilize wireless networks to send information such as temperature, pressure, and leak detection. The leakage can be automatically reported to the control center.
Interactive web service (resource conservation): Urban EcoMap - Amsterdam and San Francisco is an interactive web service that displays environmental footprints (carbon dioxide emissions, water waste/transportation activities, etc.) for cities.
Underground smart infrastructure: Burlington City uses sensing and information technology to determine the state of infrastructure and provide it in an appropriate, timely, and secure format for the managers, planners, and users. Information processing techniques convert the data in information-laden databases for use in analytics, graphical presentations, metering, and planning. This project increases overall efficiency and resiliency of subsurface infrastructure and reduces service outages and emergency repairs. It also reduces environmental impacts such as energy use, as well as storm water and sewage discharge.
Smart waterfront: The Chula Vista (CA) smart waterfront project is the largest waterfront development project on the US West Coast. This project focuses on energy efficiency (targeting a 50% reduction), communications network technologies, and smart infrastructure solutions. The project will provide operational efficiency, sustainability, economic development opportunities, and citizen engagement for the city.

Pollution Reduction

On demand and shared transport: It is a new trend for car business to attract these new use cases for the car, realizing societal benefits from reduced car ownership and resulting congestion and pollution. For examples, Didi Taxi in China already has over 100 million users.

Customers can order a taxi service or rent a car through the app on their smartphone, as well as get the information about the estimated distance, fares, and time to their destination.
Responsive traffic management (improving traffic movement): New York City's "Midtown in Motion" is a technology-enabled traffic management system that uses real-time traffic information from a variety of sources to monitor and respond to various traffic conditions. It consists of microwaves sensors, EZPass readers, and traffic video cameras to collect traffic flow information.
Smart forests (Internet of Living Things): New York City has developed a concept of networked, smart urban forests to study the role of urban trees and vegetation in climate adaptation, human health, and urban aesthetics; to provide municipalities with economical and cost-cutting solutions for urban tree management and enhancement; and to engage citizens in both the use and stewardship of their urban forests. It involved many pilot applications such as an operational website and app for tree mapping and green walking route planner and a networked sensing system for an urban heat island study. This project will generate massive environmental data at high spatial and temporal resolution that can be stored for long-term records and used by government, academia, and the public for modelling, design, and decision making. Benefits will include improved public health, improved quality of life, and increased equality within cities. It will also help mitigate urban heat islands and help New York City adapt to future climate change scenarios.

Environment Quality

Smart water management models: The New York City Department of Environmental Protection (DEP) has deployed an extensive network of remote monitoring sensors across the city and watershed. The sensors can autonomously transmit water data to DEP operation centers, providing real-time 24/7 water quality and supply data. It can also alert DEP about potential water quality issues before water reaches a tap in the city.
Smart pump station: This project team in Cincinnati developed a "smart pump station" for waste water system that allows water utilities to receive, more reliable information, better manage water resources, reduce reactive maintenance, and improve water quality. This enables Cincinnati to collect actionable information from its water system in a timely manner to improve water quality and facilitate the management of its water resources.
Smart distribution system: This project is implementing a citywide sensor network to measure real-time water consumption, power requirement, and water quality in the Las Vegas area via innovative technology. Collected information will be centralized into a data platform to allow water utilities to access, analyze, and develop a system that is able to leverage system distribution pressures, temperatures, water quality information (e.g., pH, chlorine residual, turbidity, TTHM formation), and online customer consumption data. The project enables operational strategies beyond what a conventional hydraulic model can.
Smart wireless technology: Washington (DC) is deploying a fleet of asset management and tracking devices, sensors, and other communication gateways, along with a complementing analytics and data platform. The goal is to lower the life cycle cost to own and operate the infrastructure assets by identifying likelihood of failures early, and by fixing them before catastrophic failure. The project will use real-time data to continuously optimize unit and system process performances. Effective and efficient water/wastewater infrastructure management has

direct benefits to public health (reliable high-quality drinking water), public safety (fire safety), the environment (swimming, fishable receiving streams). improved quality of life, and more equitable social justice.

3.3.2.3.2 *Public Sector: Economic Benefits*

Employment

Smart emergency response system: The Denton (TX) emergency response operations critically relies on the efficiency of emergency communication infrastructure. This project aims to mature and test the drone-carried on-demand broadband communication infrastructure for emergency use and to quantify its benefit compared with existing on-demand emergency communication technologies. Benefits include new jobs opportunities such as public service experts, robot operators drone operators, usability experts.
Living laboratory***:*** Copenhagen is a living lab for testing smart technologies, building on its unique accessibility to data and efficient public-private sector partnerships. Many world-leading companies choose Copenhagen for smart city projects. For instance, Cisco is testing and developing tomorrow's digital infrastructure, the Internet of Things in Copenhagen. Hitachi also has located its first big data research lab in Copenhagen.
Smart agriculture: IoT technology increases the fiscal sustainability of Montgomery County's agricultural reserve land and helped agriculture become a new path for economic opportunity for country residents. It helps the local farmers work more productively and support locally grown food and local businesses.

Integration

Integrated planning: The Genova Smart City initiative is aiming at improving quality of life of citizens through transforming the city into a smart city involving different partners, including research organizations, private enterprises, institutions, finance, and citizens. This initiative includes five components: energy (smart grid), transportation (smart transport system), buildings (smart metering, retrofitting), safety and security (IoT city infrastructure), and smart ports (automated port services).

Cost Savings

Smart utility meter systems: Envision Charlotte showcased its first-of-a kind program in energy, water, waste, and air to conserve resources and reduce operating costs.
Surveillance system: To improve public safety in school zones, to prevent crimes and car accidents, and to improve the sense of security, Busan Korea has created a safe school zone. This is achieved by scanning vehicles and pedestrian using video cameras that are embedded in street lights and vehicle-detecting sensors, as well as setting alarm signs using digital signage and ground LED light devices. The project also contributes by saving energy bills and lowering costs of city operations and management.
E-learning: The iSocial virtual learning environment for social skills development in adolescents with high functioning autism (HFA) benefits teachers, students, parents, and therapists by providing access to a quality evidence-based learning platform.

Smart central operation center: Traditional information has involved many disconnected and conflicting data sources. However, for predicting long-range trends and directions, data should be integrated with sensors, video, and voice. With the smart central operation center, detailed action is given in real time, and various departments and city stakeholders can coordinate in an interconnected way. For example, consider the following example involving IBM's Intelligent Operations Center (IOC)—attending an entertainment event at a stadium. IOC can improve overall navigation to the stadium, ease of parking, and waiting in line. IOC can also provide a complete interconnected view of stadium activities such as weather alerts, real-time security traffic flow to the stadium, etc.

3.3.2.3.3 Public Sector: Social Benefits

Service Delivery

Smart meters: Many residential households in Punggol, Singapore have installed display (IHD) units, a portable device that provides real-time information on their household electricity consumption, as a part of Singapore's nationwide intelligent energy system initiative.
Wireless water meters: New York City's automated meter reading (AMR) system consists of 817,000 individual water meters all over the city. Each of them is connected to a low-power radio transmitter that sends water readings to rooftop receivers at a certain frequency. The receivers transmit the data to a network operations center using a secure citywide telecommunication network. Customers can view their water usage data and pay bills online. By avoiding manual meter reading, the city has saved over $3 million per year.
Smart waste bins: New York City BigBelly uses integrated wireless sensors to detect trash level, alerting sanitation services to collect the waste. The unit is capable to fill with five times more waste than the ordinary garbage bin thanks to solar-powered compaction. BigBelly estimates their solution improves waste collection efficiency by 50-80%.
Waste tracking: Trashtrack is developed by MIT's SENSEable Cities Lab, using hundreds of small, smart, location aware tags to trace the movement of waste in the city's waste management system. Sensors are attached to consumer waste products, such as coffee cups or aluminum cans, which can report the location of the object in real-time. This project provides insights in understanding the "removal chain" in the city and can help to optimize resource management and promoting behavioral change of the people.
Smart parking: Singapore Parking guidance system provides drivers with real-time information on parking availability, which effectively reduces the amount of circulating traffic searching for parking spaces and promotes the efficient use of existing parking facilities
On-demand and shared transport: it is new trend for the automobile industry attract new use cases for the car as a driver or for passengers, realizing societal benefits from reduced car ownership and resulting congestion/pollution. Ohio State University (OSU) launched on-demand automated shuttles for solving the first-mile/last-mile problem on the OSU campus. The demonstration project will use a street-legal neighborhood electric vehicle with on-demand ordering capability, a pilot operation in a chosen pedestrian area on the OSU main campus, and a demonstration of socially acceptable collision avoidance. This replicable project will result in significant reduction in carbon dioxide emissions.

Public traffic information web portal: Singapore's ONE.MOTORING web portal serves citizens with online accessible traffic information collected by surveillance cameras installed on roads and GPS-enabled taxi vehicles. It will provide information such as current electrical road pricing (ERP)) rates, notification of the sections of road under construction, traffic news, travel time calculations, parking information, etc.
Traffic signal priority system: New York City's Transit Signal Priority (TSP) system, introduced by the Department of Transportation (DOT) and the Metropolitan Transportation Authority (MTA), aims to improve the efficiency and dependability of bus mass transit. Pattern selection (PS) and location-based traffic control software are built into the buses and traffic controllers, thus allowing them to communicate with each other via DOT's Traffic Management Center. A bus equipped with the TSP system can request priority service when it approaches an intersection and can change the normal signal operation to improve the traffic flow.
Smart signage system: New York City's 24/7 Smart Screens are based on an interactive platform that integrates information from open government programs, local businesses, and citizens to deliver real-time hyper-local information on events, merchants, and services for people, and to provide security alerts in surrounding area to keep people safe. The Smart Screens can be accessed via Wi-Fi on nearby smartphones, tablets, and computers.
Mobile application: The Emergency Medical Service (EMS) operated by Singapore's Civil Defense Force (SCDF) can be reached through a mobile application, "myResponders,", which has been designed to increase survival rate from incidents such as out-of-hospital cardiac arrest, guiding trained first-aiders in the area to respond before the SCDF arrives.
Tele-medicine: Tele-medicine, another major aspect of Singapore's Smart Nation initiative, aims to serve as a health-tracker, providing real-time health data of customers before medical examination. The program promotes the widespread use of wearable technologies such as fitness trackers, smart watches, and even smart clothing. These smart devices are designed to monitor the well-being of patient and transmit the data of vital signs such as blood pressure, heart rate, and body temperature to designated healthcare professionals.
Snow-plowing application: PlowNYC is a public-facing web app developed by the New York City Department of Sanitation (DSNY) to provide citizens real-time snow removal progress monitoring. The snow-removal-equipped GPS-enabled flip-phones can send GPS signals to the data center every 12 seconds, where information can be processed and released on the PlowNYC website and DSNY's management tool.

Governance Improvement

Data platform: The 5D Smart San Francisco 2030 District Project is a data visualization platform project that maps building energy consumption and GHG emissions data to a 3D-visualized model of downtown San Francisco, thereby empowering building owners with information that can be used for improving energy efficiency for buildings. The developer, Cityzenith, is developing a partner ecosystem worldwide to implement its 5D Smart City product to major cities, ICT companies, hardware and equipment providers, and international institutes. It can serve as a platform for government agencies, private commercial buildings owners, energy management solutions providers, network and telecommunications companies, and energy retrofit finance firms for knowledge/best practices sharing, data collection, collaboration, and commercial transactions.

Smart city platform: FIWARE MyCity is a smart city platform adopted by city of Eindhoven, Netherlands, aiming to accelerate the smart city wave. The smart city platform could bring in a dashboard with information and insights that supports and stimulate the development of smart solutions for public safety in the Stratumseind in Eindhoven. The goal is fewer public safety incidents, making it a safer place that attracts more people.

City data platform: Barcelona is developing an open, distributed, and public infrastructure of city data and providing strategies that involve citizens, businesses, communities, and the academic world with a clear policy promoting democracy. This project includes CityOS, Sentilo, Ecosystem of open city data, and DECODE.

City data platoform: London's data store provides over 600 datasets to citizens, business owners, researchers, or developers, helping them understand the city and develop solutions to London's problems.

City data platform: Chicago's data portal hosts over 200 datasets about city departments, services, facilities, and performance.

Smart Infrastructure: The CLOUD project of London is a giant viewing structure, composed of ETFE bubbles and thousands of LED lights. It is a new form of observation deck, immersing visitors in weather and digital data. It can be used as a data visualization platform displaying the Internet traffic patterns of London, energy consumption, transport activity, etc.

IoT Platform: Kansas City has designed and implemented an IoT platform to develop a smart city network, which can improve aspects of city life, including avoiding traffic jams, finding a parking spot, and getting a Wi-Fi connection at local venues. The projects include: smart Wi-Fi networks owned by Sprint, a unified smart city platform managed by Cisco, and a " living lab" development data portal managed by Think Big Partners, CityPost interactive digital kiosks, mobile citizen engagement, etc.

Equitability

IoT education and workforce development: Millions of connected sensors generate data that are used to improve quality of life and operational efficiency. This initiative is creating IoT recipes (e.g., hardware, software, data, use cases) modeled after smart city applications and deploying them to students through semester projects, workshops, hackathons, and active mentoring by industry experts.

Air quality sensing: LoRa technology has developed portable airbox devices to enable mobile air quality monitoring with a focus on PM2.5 sensing in Taipei city. The device is small-sized and lightweight, consumes low power, and has long-range data communication capacity. The technology provides a finer spatial-temporal granularity of air quality monitoring results for further data analysis and environment awareness, and builds a tight connection between government, academia, industry, and citizens. The data will be used for pollution emission sourcing, adaptation policymaking, city management, and urban planning. It will promote citizen engagement from personal to community scale on different aspects, such as environment education, science education, and "lifestyles of health and sustainability" (LOHAS) living.

Foolproof receipt booklet: In Nigeria and other countries, a very significant amount of government internally generated revenue (IGR) is lost to fraud. Miscreants and fake agents pocket government revenue to the detriment of the government and the citizens who have paid taxes and levies and are expecting government services. Anambra State (Nigeria) proposed to deploy a software solution to eradicate fake receipts used to illegally siphon government IGR. The solutions will generate coded receipts, thus ensuring that IGR is substantially received by the government. Employment opportunities will be created for agents who are required to collect IGR with the new system. Citizens' quality of life will improve as the government will have more revenue available to render services to the citizenry.

Public Safety

Mobile rechargeable power: San Francisco (CA) has deployed mobile rechargeable power units throughout city departments to intelligently manage and measure energy usage. This can result in reduced energy costs through shifting the time of consumption from daytime to nighttime and by using peak shaving to lower demand charges. The mobile chargers would be remotely monitored and available to be deployed in the immediate aftermath of a catastrophe. The solution uses FreeWire's Mobi Gen to deliver power wherever and whenever it's needed, whether to a building or directly to devices in the case of an emergency.

Smart water-level management (preventing floods): Chikuma City (Japan) has deployed water-level monitoring system using hypersonic sensors to detect the water level of a river and canals and collect the data through a wireless multi-hop network. This system can use past data (i.e., "big data") to predict the water level and publish the real-time water level and rainfall data on the city website. This project has significantly reduced the fatality by flooding.

Surveillance system: To improve public safety in school zones by preventing crimes and car accidents and by improving the public's sense of security, Busan (Korea) has created a safe school zone. This is achieved by scanning vehicles and pedestrian using video cameras that are embedded in street lights and vehicle detecting sensors and by sending alerts using digital signage and ground LED light devices. This system also contributes to lowering energy bills and costs of city operations and management.

Emergency warming system: A resilient warning system for tornadoes and flash floods has been developed in North Central Texas. This network is used for delivering hyper-local, user-driven, context-aware severe weather warnings. Mobile phones and hyper-local data enable customization to improve response and outcomes. The Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere CASA has established a Living Lab for Severe Weather Warning with an end-to-end warning infrastructure from radars to the public. This project has the potential to save lives and property in the case of severe weather events through the delivery of geographically targeted, user-defined alerts to users on mobile phones through custom-designed apps. This system will provide essential information to mobile users in severe weather events based on context.

Phased-array weather radar: Kobe (Japan) has deployed a phased-array weather radar system for obtaining real-time 3D data of rainfall. It has developed a real-time alert display and mail delivery system for localized torrential rainfall to predict heavy rainfall disasters in small local areas.

Business emergency operation center: Lafayette (LA) will prototype a municipal business emergency operations center based on a multi-agency, public-private partnership model to optimize information display, communications, and decision-making across private-sector entities, non-profit organizations, and citizens groups involved in disaster response and recovery. This project has the potential to greatly improve public safety and to preserve life, livelihood, and property by: 1) enhancing collaboration and partnerships between public sector agencies and private sector organizations; and 2) improving multi-agency information sharing and crisis decision-making at an affordable cost.

Streets surveillance system: Eindhoven (Netherlands) has deployed an integrated surveillance system, City Pulse, in the streets of the city to capture data in public space and combine the data with sentiment analysis on social media allowing for early warning of possible incidents. The connection layer for sensors is through a smart lighting grid where FIWARE is used to provide an urban platform.

Underground smart infrastructure: Beijing (China) has deployed software-defined cloud-driven wireless sensor networks for flexible monitoring of diverse underground infrastructure components, including manhole-cover fidelity, toxic gas levels and floodwater in tunnels, theft/destruction of communications equipment, and, eventually, water-and power-distribution infrastructure in the project cities. The project will provide significant benefits to city governments and residents in terms of safety, cost to monitor and address failures and other threats, and seamless operation of city services.

Smart crime-curbing system: Chattanooga (TN) is building a connected, real-time system to help curb crimes in urban areas, integrate real-time report and response with event detection of smart cameras, and standardize procedures for emergency response. The project involves city, police, and public safety officials, as well as application developers, electrical power board, enterprise center, company lab, and citizens.

Vision Zero fatality: The Seattle Department of Transportation (WA) is collaborating with Microsoft, the nonprofit DataKind, data scientists from the University of Washington, HERE maps, and many others to use data to create predictive models for crash probabilities, aiming to reduce bicycle and pedestrian fatalities and serious injuries to zero with a systemic approach. This Vision Zero Plan sets an aggressive goal to reach zero traffic-related deaths and serious injuries by 2030. Reducing crashes results in saving lives, reducing congestion, lowering costs, and reducing burdens on first responders.

Smart platform for data management***:*** Genoa (Italy) uses FIWARE (fiware.org)—a public, open-source platform that eases the development of smart applications—to improve the process of collecting and processing environmental data from meteorological sensors (e.g., radar, rain gauge, hydrometric, etc.) coupled with existing geo-referential data about major infrastructures and exposed people. The data will be used to provide weather “nowcasting” for preventing hydrogeological risk, and to provide mid-long-term forecasting to address risks related to climate change.

StormSense: Newport News (VA) uses state-of-the-art, high-resolution hydrodynamic models driven with atmospheric model weather predictions to forecast flooding from storm surge, rain, and tides at the street-level scale to improve disaster preparedness. The project can effectively predict the timing of flooding and flooded evacuation routes, as well as aid in rerouting emergency routes for public safety, thus saving lives and reducing property damages.

3.3.2.3.4 Citizenry: Economic Benefits

Empowerment

Artificial intelligence: Watson Health's cognitive systems understand, reason, and learn, and thus can drive more informed decision-making and help clinicians take better care of their patients, government program leaders take better care for their clients, and consumers care better for themselves.
Public participation program: In London (Great Britain), the Love Clean Streets Network consists of various sites and mobile applications operated by local authorities that allow citizens to report environmental crime, and for them to resolve it.

Cost Savings

On-demand and shared transport: These types of smart systems are realizing societal benefits from reduced car ownership and resulting congestion/pollution.
Innovation that help make use of existing yet underutilized resources: Airbnb is a peer-to-peer online marketplace that enables the renting out of unused private residential properties, with the cost of such accommodation set by the property owner.

3.3.2.3.5 Citizenry: Social Benefits

Quality of life

IoT-based healthcare services: Daegu City (Korea) is developing an IoT-based healthcare service to improve the quality of life of people and to provide a business incubation scheme with better regulatory support.
Hometown dashboard: Smaller towns and cities (under about 50,000 in population) often cannot afford to develop custom apps and in-house smart-community capabilities. They need a standard platform that is easily, cheaply, and quickly adapted to local needs. This platform should deliver a variety of functions that every hometown wants and needs and that improve quality of life (QoL) metrics for individuals, cohorts, and the community at large. The Hometown Dashboard project should help bring residents back to streets and shops of their own downtowns and improve the effectiveness of Main Street programs that encourage commercial revitalization and greater civic pride.
Environmental sensing: The PA2040 Environmental Sensing project in Washington (DC) is creating a network of environmental sensors distributed on campuses—throughout the District of Columbia (DC)—that are participating in the DC MetroLab partnership. This work enables general public access to environmental data such as temperature, wind, gas and particulate concentration, and even traffic flows, simultaneously from all over the city. Utilization of environmental sensor data will benefit predictive modeling and simulations, as well as mobile application developments targeting public health, transportation, wayfinding, and emergency response focus areas. The project will improve government operations and mass transit through better Wi-Fi access.
Electric vehicle-ready transit hubs: Residents of Baltimore, Maryland often face very significant challenges in transit services, because many parts of the city's public transit are limited, bus routes are confusing, and rail development is cost-prohibitive. Thus, the B'Smart project is

focused on planning and piloting transit hubs that are EV-ready (i.e., ready for electric vehicles) in Maryland, starting in Baltimore. It will combine the infrastructure elements of high-speed Internet and Wi-Fi with clean energy and clean, active transportation connections (e.g. for bus, rail, EV-charging, and car and bike share). These hubs will also serve as community centers for citizens by creating open public smart spaces.

Smart leisure strategy: The cities of Valencia (Spain) and Lindale (TX) are sharing the same goal of fostering leisure activities as a catalyst for community building in the city. Leisure activities will be leveraged on interoperable and replicable smart solutions for providing a better management, analysis, and promotion of city events while enhancing security of the citizens and parking management efficiency. This project will improve the quality of life of citizens, while strengthening the market position of local businesses.

Urban waste and cleaning service dashboard: Guadalajara (Spain) started a pilot project to create a visualization dashboard for generation, visualization, and tracking of key performance indicators (KPIs) for urban waste management and thoroughfare cleaning services. The relevant data are gathered through open APIs from various sources such as sensors, surveys, and external systems to generate a set of KPIs that can be used to assess fulfilment in municipal services. This project brings a change in the economic relationship of the municipality with utilities and service providers, from the fixed assignment of resources to dynamic adaption to the needs of the city. The benefits are Improving the quality of services delivery, and reducing the municipal cost, resulting in improvement of the quality of life of citizens.

3.3.2.3.6 Private Sector: Economic Benefits

New markets

Urban farming (vertical vegetables): The roofs of buildings and even walls can use soil-less hydroponic systems to grow vegetation more efficiently than growing food in remote farmland and transporting it to city centers. Companies such as Freight Farm up-cycle shipping containers delivering a plug-and-play working urban farm, all controlled from a smart phone. These urban farms can be placed in redundant space such as garages and rooftops. Aquaponic systems adopted by companies such as Sky Greens use the waste products from fish farms to fertilize the plants.

Train-as-a-service: Hitachi recently announced a “trains as a service” contract with Virgin in the U.K. for 65 new high-speed Hitachi trains. Under that deal, Hitachi maintains ownership of the trains, and is paid based on their trains’ reliability.

3.3.2.3.7 Cross-cutting Benefits

Augmented human mobility***:*** Cycling could be further popularized by innovations such as Copenhagen Wheel, an add-on to existing bikes conceived by the MIT Sensible City Lab that makes it easier to cycle by augmenting pedal power with a battery that captures energy as you brake or go downhill. The cross-cutting benefits could be also achieved by adopting many low-cost solutions such as separation of bike lanes, bike-sharing schemes, re-phasing traffic lights (green wave traffic) to fit the speed of vehicles/bikes, and planting trees along the road to slow traffic.

Smart Infrastructure: The CLOUD project of London (Great Britain) is a giant viewing structure, composed of ETFE bubbles and thousands of LED lights. It is a new form of observation deck, immersing visitors in weather and digital data. It can be used as a data visualization platform displaying the Internet traffic patterns of London, energy consumption, transport activity, etc.
IoT Platform: Kansas has designed and implemented an IoT platform to develop a smart city network, which can improve aspects of city life, including avoiding traffic jams, finding a parking spot, and getting a Wi-Fi connection at local venues. The projects include: smart Wi-Fi networks owned by Sprint, unified smart city platform managed by Cisco, and a " living lab" development data portal managed by Think Big Partners, City Post interactive digital kiosks and Mobil citizen engagement, etc.
Environmental sensing: PA2040 Environmental Sensing (Washington DC) project is creating a network of environmental sensors distributed on campuses throughout DC, which are participating in the DC Metro Lab partnership. This work enables general public access to environmental data such as temperature, wind, gas and particulate concentration, and even traffic flows, simultaneously from all over the city. Utilization of environmental sensor data to benefit predictive modeling and simulations and mobile application developments targeting public health, transportation, wayfinding, and emergency response focus areas. Also improve government operations and mass transit through better Wi-Fi access. See more at:
Web information streams enhancer: Perugia (Italy) is developing the WISE town project to collect information from different streams to identify issues that affect the city in several areas including urban renewal, garbage collection, public safety, transportation, social services, and environmental problems. This project will significantly improve the city management, promote citizen engagement and accountability, and facilitate better urban planning and optimization of maintenance, and allow real-time responses during emergencies.

(Digitally) Re-programmable space***:*** Urban space can be transformed for adaption to technological development, thus minimizing the overall urban footprint. Smart city centers are more easily adapted to new clean, knowledge-based, and lightweight industry, rather than the heavy, invasive technologies of 20th century. Vancouver (Canada) has reduced its allowable urban footprint; Glasgow (Ireland) has moved from a policy of expansion to concentration; and Melbourne (Australia) has repurposed 86 hectares of underutilized road and other spaces. Treasured historic city centers could become productive areas, as technology enables innovative ways of organizing work, occupation patterns, and places of production.

Infrastructure for social integration: Medellin (Colombia), in 1992, was considered one of the most dangerous cities in the world. But today, under recent mayoral administration (2003-2007), it opted for a different strategy, using architecture and urbanism as tools for social integration. Projects such as the Espana Library Park and the city's elevated cable car serve as key symbols of city's spatial, social, economic, and cultural transformation by connecting the city's low-income residents with the wealthier commercial center. This has dramatically changed Medellin in the past 10 years, both in its spatial dynamics and mentality and in the perception of its inhabitants.
Underground smart infrastructure: Burlington City (VT) uses sensing and information technology to determine the state of infrastructure and provide it in an appropriate, timely, and secure format for the managers, planners, and users. Information processing techniques

convert the data in information-laden databases for use in analytics, graphical presentations, metering, and planning. This project increases overall efficiency and resiliency of subsurface infrastructure and reduces service outages and emergency repairs. It also reduces environmental impacts such as energy use, as well as storm water and sewage discharge.

Systematic approach: EcoDistricts Protocol is creating a powerful collaboration platform to support the burgeoning marketplace of district-scale sustainability ideas and actions. It focuses on urban regeneration solutions that integrate smart and sustainable infrastructure, high performance green buildings, and robust community engagement and action. The protocol is built around two imperatives, Equity and Resilience, and a set of priority areas: Health + Well-being, Livability + Place, Mobility + Connectivity, Ecosystem Health, Resource Efficiency, and Economic Prosperity. To support the protocol, EcoDistricts plans to develop an online process and performance management enterprise solution to support cities as they implement projects that drive real change. The platform will help standardize data collection; gather and analyze data; leverage smart technologies; benchmark performance; and measure and report progress over time through a dashboard.

Officer Intelligent Agent for Quality of Life: New Orleans (LA) has created an ideal of having a "Intelligent Agent for Quality of Life" to improve the quality of service to citizens, and ultimately improve the quality of life for citizens in a cost-effective way and optimal manner by leveraging city, open, private, community-generated data (e.g., 311 data) and identifying quality of life issues. This project will improve the quality of life across several aspects, such as social/ public safety, health, socio-economic, knowledge, and education. It will also generate replicable methodology that can be applied in other cities or communities.

3.3.3 Conclusions

In the IES-City Framework, the benefits metrics provide stakeholders (SDOs, cities, vendors, and citizens) a sense of potential benefits when adopting specific smart city applications. Its intent is to initiate the process for users to screen and select the right applications with limited resources. A list of examples of those applications, which have been implemented or are under development in cities around the world, demonstrates the outcomes of smart city applications deployment in the real world. However, the real benefits of any specific application will depend on the circumstances of the city itself. Once a smart city project is engaged, more detailed analytical tools are needed to aid in the specification and implementation process.

3.3.3.1 Key Messages

It is often said, “If you can measure it, then you can manage it, and if you can manage it, then you can invest in it.” It is this philosophy that illustrates the importance of this effort. Ultimately, investments must take place to realize the development of smart cities. These measurements are a critical element in the strategy of improving the quality of life in our cities. Thus, the list of benefit metrics provided by the tool can be useful for investors to understand the usefulness and importance of each category of application, allowing them to make prioritized investment and implementation.

A recommended next step is to validate the list of benefits metrics with domain experts and with targeted users.

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4 Discovering Pivotal Points of Interoperability (PPI)

4.1 Goals

4.1.1 What Was the Goal?

The purpose for discovering PPI is to:

- Analyze existing exemplary smart city architecture and Internet of Things (IoT) technical descriptions including:
    - Standards, specifications
    - Architectures, frameworks, conceptual models
    - Platforms, protocols, environments
- Document their overlapping *concerns,* such as functionality, data, timing, trustworthiness, etc.
- Develop a means to reveal the common "properties" (solutions) specified in these overlapping concerns, such as cybersecurity choices, time synchronization, data formats/ontologies and thereby **reveal potential pivotal points of inter-operability**.

4.1.2 Why Was It Done?

The technologies that are being deployed for smart cities are complex and robust. They are often described by deep technical documentation—each with its own abstractions and style of writing and diagramming. As such, it is impractical for any single provider or acquirer to master all the instances that can be offered to determine if they can be composed with any offering from any other provider. The goal of this analytical activity was to make it possible for such comparisons to be made and thereby enable purchasers to have some degree of confidence that they will not be locked into a single source and/or hard-to-integrate technology.

4.1.3 Why Does this Matter?

The foundation of the approach to developing a consensus around PPI is to frame the integration of smart cities infrastructure as an instantiation of a system of cyber-physical systems. Cyber-physical systems are just one of the emerging project types that may be appropriate description models for the dynamics of smart cities.

By providing this comparative analysis technology, the opportunities for volume deployments of smart city technologies will be enhanced by substantially reducing barriers to acquisition. Standards developers and technology developers alike will be enabled to evolve their specifications in compatible ways to increase their marketability to their respective customers.

4.1.4 How Was It Developed?

The IES-City Framework utilizes a spreadsheet to capture the concerns addressed in any technology set with a responsibility for smart segments of society.

A comparative analysis method is used to map and compare the parameters and functions of the various smart city frameworks and organize the results to reveal potential pivotal points of interoperability. The method reduces the observed degrees of freedom of the implementation space so that systems developers can simplify systems design and lower barriers to interoperability.

What is unique about the present approach is that it can be done in a concise manner, is architecturally agnostic, and produces a "holistic-concern-driven" approach to the analysis so that all dimensions of interoperability may be considered.

To distill the rich technologies under analysis to a common basis for comparison, the CPS Framework's a*spects* and c*oncerns* are used. Referring to Figure 15: PPI Analysis Model, the technologies are reduced to rows of a spreadsheet by first considering the relevancy of a *concern* to the technology, and then by next considering which technical solutions are used to address the *concern* (see Section 4.2.2).

Figure 15: PPI Analysis Model

Additional discussion of these concepts is presented in the following subsections.

4.2 Elements of the Technical Analysis

The technical analysis of PPI is achieved by a process that relies on the following:

- Pivotal Points of Interoperability (PPI)
- NIST CPS Framework
- Zones of Concern (ZofC)
- Description of the Spreadsheet Tool

4.2.1 Pivotal Points of Interoperability (PPI)

One of the key challenges in the smart city space is the abundance of standards and technologies available to use for IoT and smart cities. Each such technology set is documented in large volumes of descriptions and processes, and appropriately so. This, however, makes these technologies exceedingly difficult to understand and mate with other such solutions.

Yet, there are some concepts and component standards that independent teams arrived at in common. For example, no one would be surprised that most smart city applications make use of the Internet standards as the technology choice for exchanging information.

The framework calls these “Pivotal Points of Interoperability.” If these PPI are known, integrating a new component into an existing deployment is simplified. For example, knowing that the syntax of data exchanged is either eXtensible Markup Language (XML) or JavaScript Object Notation (JSON) yields a small set of boundaries for integration if technology A (the incumbent) and technology B (the next great idea) chose differently. Similar simplifications occur because most implementations use Internet Protocol (IP), Transmission Control Protocol (TCP), REpresentational State Transfer (REST)/Publish and Subscribe (PubSub), and Transport Layer Security (TLS), to name a few. The concept is illustrated in the figure below, which shows the potential benefits to integration when PPI are known:

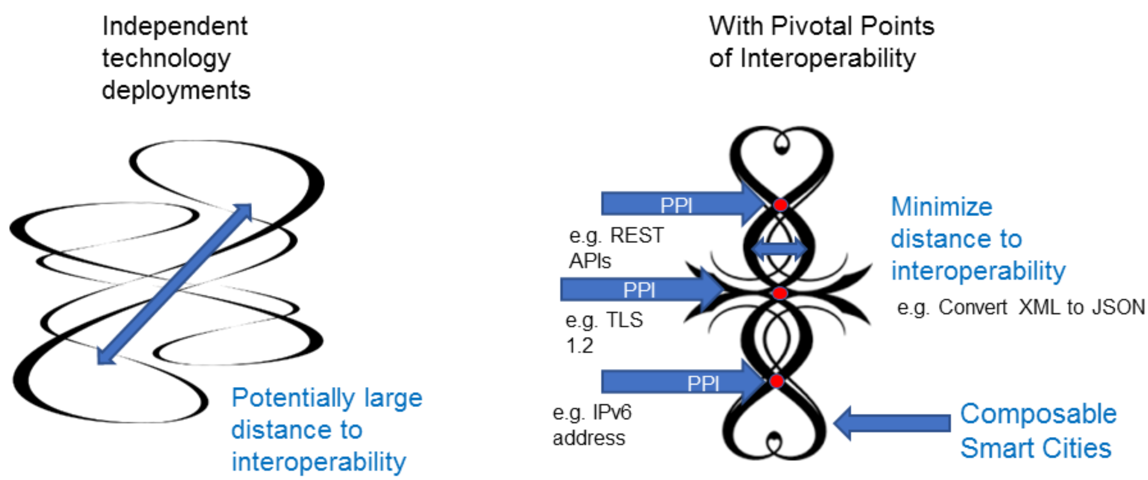

Figure 16: PPI Reduces Distance to Interoperability

Consider this example scenario:

> A city acquires its first smart city application from ecosystem team “A,” because they are the best of breed for this kind of application. The city now wants to add a feature from ecosystem team “B,” because they are the best of breed for this new addition. As shown in Figure 16 on the left, with only the documentation set provided by ecosystem team “A,” there is potentially a large complex technical space to navigate to make the offering of team “B” offering work with the offering of team “A.” Being at risk for the integration, team “B” must plan its pricing accordingly to capture the integration cost uncertainty. Call this a potentially large “distance to interoperability.” Yet, if there are well known PPI such as IPv6 end node addressing, TLS 1.2 for cybersecurity, and REST APIs for messaging, there is a reduced distance to interoperability. In the example, team “A” used XML encoding for the data in the packets; team “B” used JSON. It is well understood how to interconvert between XML and JSON [108].

It is a challenge, in the scope of smart city applications, to seek a comprehensive single standard. In fact, it is not desirable, because if you standardize everything, you limit the opportunity for discovery and innovation. Of course, if you standardize nothing, you get little or no interoperability.

The concept of discovering the PPI through analysis of prominent technologies in use in smart city applications promises to reveal common choices by technology providers acting independently. Note that this framework does not seek to declare PPI but simply reveal potential PPI through dispassionate analysis.

The following section describes how the NIST CPS Framework *aspects* and *concerns* can be used to study PPI.

4.2.2 CPS Framework

As stated previously, the NIST CPS Framework provides for a holistic-concern-driven analytical concept for conceptualizing, realizing, and assuring cyber-physical systems. The present framework uses the methodology described in the CPS Framework for decomposing complex architectures to *CPS Framework Normal Form* to expose potential Pivotal Points of Interoperability (PPI).

The reason this work is helpful for IES-City Framework is that it provides a means to condense the many pages of documentation of smart city and IoT technologies to a manageable and understandable summary. And this in turn allows for comparison and therefore reduces the barriers to integrating dissimilar approaches.

The following figure illustrates the structure of the framework:

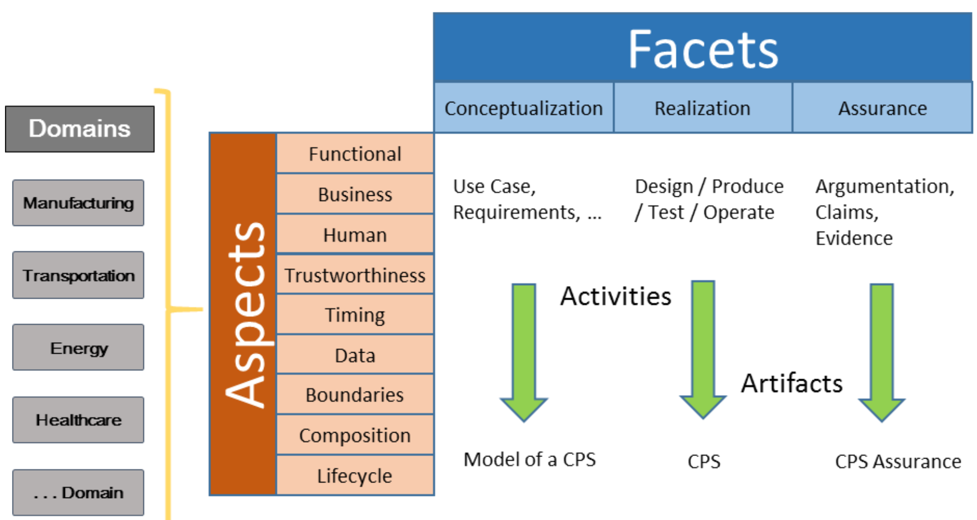

Figure 17: CPS Framework

The framework has two principle concepts—*aspects/concerns*, and *facets*. *Facets* are modes of thinking during a system's engineering process for a cyber-physical system. Note that a CPS can be a device, a system of devices, or a system of systems.

The three *facets* are *conceptualization, realization, and assurance*. There are many system engineering processes in use throughout the domains of CPS. Any given process, however, involves a sequence of activities that typically include use case development, requirements analysis, design and test, and verification, to name a few. For smart cities, community involvement and several stakeholder groups are often included. ISO/IEC/IEEE FDIS 15288 [108] identifies the large scope of such activities to select from. These activities sort cleanly into the three *facets* that group these activities and produce sets of linked artifacts that comprise a complete data set describing the CPS.

The a*spects* serve to group common *concerns* that must be addressed in any given CPS. They also drive their realization and are verified by their assurance case. To have the best requirements defining and satisfying the needs of a technical development, it is important to holistically consider a rich set of potential *concerns* at each activity during the conceptualization mode of development. This way, for example, cybersecurity is considered during business case development, use case development, CPS component decomposition, etc.

The IES-City Framework uses the set of *aspects/concerns* as a means of normalizing disparate technologies being reviewed for comparison, termed “CPS Normal Form.”

Each technology has its own method of presenting a specification. These methods will have diagrams and detailed documentation that may be highly stylized to the community for which they are being presented. Yet, for example, they may all be using IP addressing to identify nodes in a network, as mentioned previously. In CPS Normal Form, this would correspond to the “Function.Communications.NetworkInteroperability.OSI-Network*” concern*, and, use of IPV6 to identify end nodes in a communication network would be a property or requirement that satisfies the *concern* about network layer interoperability.

Table 6: CPS Framework Aspects summarizes these CPS Aspects and the kinds of concerns that they categorize.

Table 6: CPS Framework Aspects

Aspect	Description
Functional	*Concerns* about function including sensing, actuation, control, communications, physicality, etc.
Business	*Concerns* about enterprise, time to market, environment, regulation, cost, etc.
Human	*Concerns* about human interaction with and as part of a CPS.
Trustworthiness	*Concerns* about trustworthiness of CPS including security, privacy, safety, reliability, and resilience.

Aspect	Description
Timing	*Concerns* about time and frequency in CPS, including the generation and transport of time and frequency signals, timestamping, managing latency, timing composability, etc.
Data	*Concerns* about data interoperability including fusion, metadata, type, identity, etc.
Boundaries	*Concerns* related to demarcations of topological, functional, organizational, or other forms of interactions.
Composition	*Concerns* related to the ability to compute selected properties of a component assembly from the properties of its components. Compositionality requires components that are composable: they do not change their properties in an assembly. Timing composability is particularly difficult.
Lifecycle	*Concerns* about the lifecycle of CPS including its components.

Each *aspect* is further detailed in the CPS Framework to identify a hierarchy of concerns. For example, a critical topic for smart cities is the Trustworthiness *aspect*. Trustworthiness further describes *concerns* that deal primarily with the avoidance of harm and include security, privacy, safety, reliability, and resilience.

The complete set of *concerns* identified in the CPS Framework are summarized in a spreadsheet with 115 rows. Each technology can be analyzed:

1) As to whether the technology addresses a given *concern* and

2) What technology or standard was identified to address the *concern.*

By this means, each suite of technology descriptions can be distilled down to the 115 rows of the spreadsheet. By placing the choices of multiple technology sets side by side, otherwise difficult-to-compare technologies can indeed be compared, and PPI revealed.

4.2.3 Zones of Concern

Given this CPS Framework concept of concern-driven analysis, and a taxonomy of concerns organized by aspects, an interesting corollary can be derived – that of the properties of sets of concerns. These sets of concerns may be considered to address groups of related requirements that may apply in a given functional decomposition of a problem. For a given set of such concerns, the term "Zone of Concerns (ZofC)" is introduced. For example, where IoT sensor devices attach to a network, there are likely a set of concerns that deal with trustworthiness and lifecycle, and this set can be labeled an IoT sensor *trustworthiness* and *lifecycle* zone of concerns.

The ZofC concept simplifies describing groupings of concerns and the service sets that address them. This in turn enables designer, developer, or vendor teams and others to assemble complementary service sets that can be naturally composed to provide an aggregate capability as a component of an architecture. While this grouping of concerns as a named set makes it easier to compose such groups in describing an architecture, this concept is not intended to, nor does it define an architecture.

THE IES-City Framework enables vendors and city stakeholders alike to fashion their own ZofC definitions for greater ease of integration of market participants and therefore reduced barriers to the growth of smart city applications.

What follows next is an illustration of how ZofC can help organize two common interfaces that can be seen in most smart city architectures. It is by no means intended to describe or define any single architecture. However, it is intended to show how ZofC can be constructed and what some examples might look like.

4.2.3.1 An Example of ZofC: The Northbound and Southbound Interfaces

Smart city applications are often provided by an "ecosystem" or collaboration of vendors. In many smart city projects, the providers fall into three distinct categories:

- Infrastructure providers,
- Device manufacturers, and
- Applications developers.

Because these categories are often fulfilled by distinct and often different individuals and enterprises (including public, private, academic, and community), they naturally connect a layered architecture at two distinct points. These are termed the "northbound" interface for applications; the "southbound" interface is where devices attach [109]; and the layers between these two interfaces might be termed the "trustworthy infrastructure" (see Figure 18: Zones of Concern).

Many of the smart city architectures reviewed have these layers and interfaces in common. Note that the southbound interface does not necessarily imply a single physical/data link layer, as there will be many. However, there are common needs for device admittance into the network and overall management that will be similar independent of underlying connection. A review of some prominent references in the literature readily illustrate the existence of these common northbound and southbound interfaces where ZofC may be helpful (see sections C.1, C.2, C.3, C.4 and C.6 where these interfaces are readily observable from the diagrams).

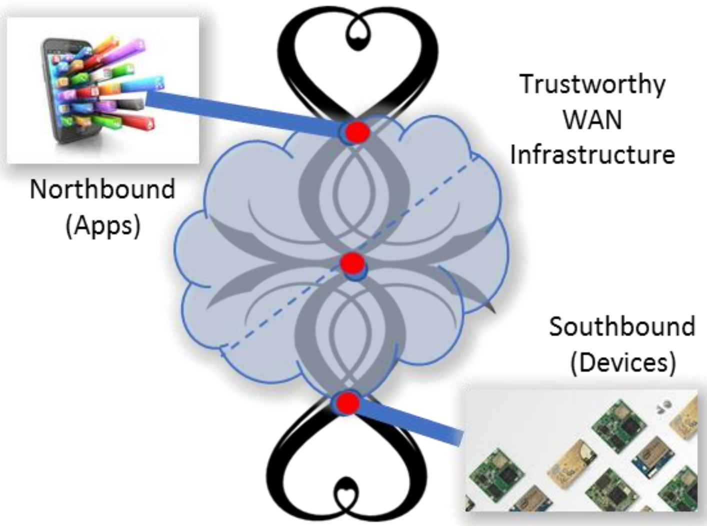

Figure 18: Zones of Concern

While this picture may appear as an oversimplification, interoperability will result if the services available at northbound and southbound have been arrived at by consensus (which may be described by open, informal or formal standards) and if one or more instances of the infrastructure exist to which devices can attach and applications can attach. This would allow applications to be device-agnostic and devices to be application-agnostic. The result is a smart city environment where it is not necessary to only sell end-to-end solutions but is also possible to assemble new function via piece parts.

The northbound and southbound conceptual ZofC do not imply that these are the only potential ones of note. For example, a service provider might bundle a series of trustworthiness services that satisfy needs at either the northbound or southbound interfaces shown above or even some other point of interface. Another service provider might provide device commissioning and management services.

4.2.3.2 ZofC in IES-City Framework

The IES-City Framework uses this concept for analyzing technology suites. From these analyses, stakeholders can study the ZofC represented at the northbound and southbound interfaces of an architecture.

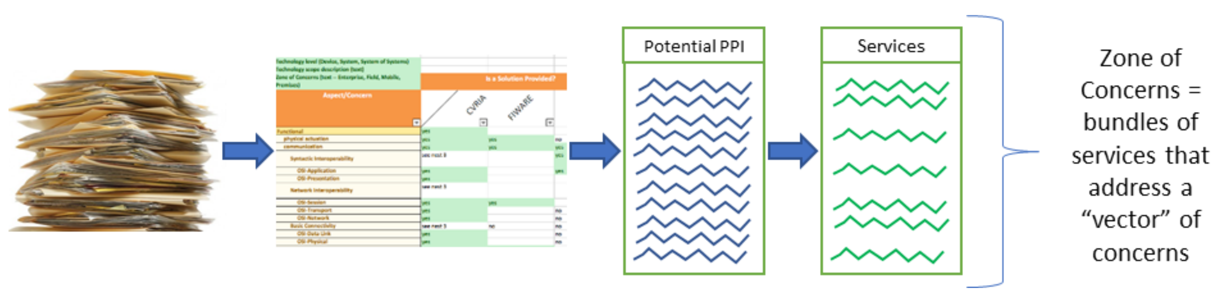

Figure 19: How to derive Zones of Concern

As technology suite providers analyze their suites against this list of *concerns* and identify the technology choices that were made to address the *concerns,* these common services can be identified.

4.2.3.3 Potential ZofC Use Cases

Additionally, here are some typical use cases for applications with ZofC. These examples do not intend to prescribe a design to any ZofC, but rather to illustrate how they might evolve depending on the individual choices of service providers.

Application provider to consumer: This use case has an application developer providing a mashup of several application programming interfaces (APIs) exposed at the northbound interface by one or more providers. The developer needs to know the end points of the data provider and the description of data and the access rules of that ZofC.

Application analytics to application: This use case has one application interacting with another application through the northbound interface. Like the application to consumer, each application needs to know the APIs exposed and the relevant rules and/or standards of the ZofC.

Sensor data stream to application: This is the common IoT smart sensor application. This use case has two parts—the sensor and the application. The sensor provides a data stream through the southbound interface, which has rules about network admittance, commissioning, persistence, and authentication. The application knows that the sensor data are present at the northbound interface because of the semantic exposition of data available at that interface. It is not necessary for the application to know it came from a specific sensor, only that it can access the desired data (e.g., local temperatures) and their metadata (e.g., locations, units of measure, and precisions).

Field device to field device application: In the case of critical infrastructure applications such as smart grid, it can be very important that field devices need to communicate directly with each other, without necessarily communicating through a cloud. Such devices will need to use the southbound ZofC, but this interface alone would be sufficient to enable a secure infrastructure for these messages.

The actual system composition, as well as the services and constraints available at each ZofC, are entirely left to the market participants. However, the analysis provided through the IES-City Framework can serve as a basis for discussion and interchange of ideas so that formal offerings of ZofC can evolve and be described in the smart city space.

It may be advantageous for SDOs and other standards setting consortia to leverage the concept of ZofC in to advance the specificity and hence interoperability of implementations based on their designs.

4.2.4 Descriptions of the PPI Analysis Spreadsheet

The comparative analysis of technology suites to reveal potential PPI uses a spreadsheet methodology. This spreadsheet is based on the previously discussed *aspects* and *concerns* from the NIST CPS Framework. Figure 20: PPI Analysis Spreadsheet shows a partial view of the spreadsheet template.

	CPS Framework: Aspects and Concerns	12/16/2017 11:49
Technology level (Device, System, System of Systems)		
Technology scope description (text)		
Aspect/Concern	**Description**	**Is Concern Discussed (y/n)?**
Functional	Concerns about function including sensing, actuation, control, communications, physicality, etc.	
physical actuation	Concerns related to the ability of the CPS to effect change in the physical world.	
communication	Concerns related to the exchange of information internal to the CPS and between the CPS and other entities.	
Syntactic Interoperability	Concerns about the presentation and exchange patterns of data	
OSI-Application	Concerns about application layer exchange patterns	
OSI Presentation	Concerns about the syntax of message encoding	

Figure 20: PPI Analysis Spreadsheet

For each row of the spreadsheet, a *concern* from the CPS Framework is listed. The technology under review would indicate the level of support for the *concern* in the ensuing columns:

- Aspect/Concern — Identifies the *concern* (provided by the template)
- Description — A textual description of the *concern* (provided by the template)
- Is Concern Discussed (y/n)? — An indication of whether the technology addresses this *concern*
- Discussion of Concern — Elaboration of how the *concern* is addressed
- Discussion Reference(s) — Reference to technology description
- Is a Solution Provided (y/n)? — An indication of whether a solution addressing the *concern* is specified for the technology
- Solution — Description of the solution
- Solution Reference(s) — References to the solution
- External References — Additional external references if needed
- Additional Notes — Additional notes if needed

For each technology, two tabs are filled out representing the *concerns* that dominate at the northbound and southbound Zones of Concern.

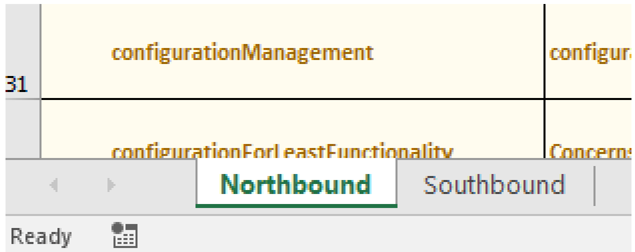

Figure 21: Northbound and Southbound Analysis Tabs

4.3 Comparison of the Individual Analyses

The artifacts produced in these analyses can be found in the links on the collaboration site (see Library [113]).

During the development phase of the framework, the following six analyses were completed:

CVRIA	Connected Vehicle Reference Implementation Architecture, developed by the US Department of Transportation to identify interfaces, use cases, and technical requirements. CVRIA covers interfaces between cars, clouds, infrastructure, and more [111][112].
AWS	Amazon, as one of the world's largest cloud infrastructure providers, offers a comprehensive set of service definitions and supporting implementation for IoT and smart cities.
oneM2M	oneM2M is a technology aimed at providing a universal IoT and smart city infrastructure. It is prevalent in Europe and Asia and sponsored by eight regional SDOs. It defines many details of a layered architecture with a simplified viewpoint.
FIWARE	The FIWARE Foundation is responsible for the development of a series of open-source "Generic Enablers" that are focused on the northbound interface but also support accessories to satisfy the southbound.
E015	E015 provides an interface documentation standard and is supported by an application catalog that simplifies the creation of supporting services and the acquisition of applications by potential municipalities.
OpenIoT	OpenIoT presents a minimal and efficient model of the northbound interface and primarily provides a gateway specification to enable implementations that support the southbound interface.

Together, these exemplars offer broad coverage of the kinds of technology suites being offered for implementing IoT and smart city systems of systems.

In addition to the six initial analyses, a comparison spreadsheet was constructed to allow for side-by-side comparison. In this initial effort, in order to compare the specific decisions made by each analyst, the reference links in the spreadsheets must be used to understand how the *concerns* were specifically addressed.

There was generally good correlation among the *concerns* addressed. However, it should be noted that the individual technology suites were targeted at different perspectives on the deployment of smart city technologies.

The authors believe that, based on these analyses, additional reviews can be performed to produce comparisons of an even greater set of details. As these technologies are compared, it should be possible for their authors and other stakeholders to migrate their works to have greater and greater overlap, further reducing the barriers to integration of unlike components into existing smart city infrastructures.

5 Conclusions and Recommendations

The IES-City Framework provides a unique and comprehensive view of smart city applications through the creation of specific tools. These tools are intended to allow city stakeholders of all kinds to reduce the barriers to deploying technology innovations and enhancements to city life.

It was the explicit intention of the partners of the IES-City Framework effort to produce short term and useful results that were designed to complement other important and ongoing activities that are also designed to enhance the growth of the smart city movement. The authors believe this goal has been achieved through this effort.

Due to the design of the tools produced, an extremely compact and digestible concentration of technical results was possible. By placing all these artifacts in spreadsheets, they are instantaneously available to a wide audience without the need of additional tools and methods.

The authors further assume that any discrete effort is limited in scope and depth by the duration and effort afforded it. Hence, the artifacts of the IES-City Framework can be expanded by following the descriptions in this document and utilizing the publicly available artifacts as a basis of extension. Additionally, the non-proprietary properties of the results make potential commercial incorporations and extensions of these artifacts practical and perhaps commercially attractive.

The creation of a smart city deployment, of course, goes beyond the initial requirements analysis afforded by the Application Framework analysis tool and the *concern*-driven analysis of the Pivotal Points of Interoperability analysis tool. However, these can provide the starting points for identifying the most relevant features and providing a shared taxonomy to build on.

Convergence on a consensus for PPI and ZofC might develop among the standards development community, and this would be an attractive outcome from the IES-City Framework effort.

In conclusion, the IES-City Framework participants are grateful to the partner team for encouraging this effort and to have had the ability to make this contribution to the growth of smart city deployments.

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Appendix A. Application Framework Categories and Subcategories

A.1 Analysis of ITU-T Common Requirements of the Internet of Things

The requirements from the previous recommendation are summarized in the following table:

Table 7: Summary of the Main Requirements from Recommendation Y.2066 from ITU-T Group 20

Common requirements of the IoT	Technical requirements, independent of any specific application domain
1) Non-functional requirements	
Interoperability	*Need to standardize an architecture reference model*
Scalability	*Handling: large number of devices (and so of data), of applications, and of users (and so large amount of processing and storage => cloud computing)*
Reliability	*Reliability in communication, service, and data-management capabilities of IoT*
High availability	*Required in service provisioning, data management, communication, sensing, and actuating things of IoT*
Adaptability	*Adaptability to the new technologies emerging in the future*
Manageability	
2) Application support requirements	*The functional requirements from the development of IoT applications in different application domains*
Programmable interfaces	
Group management	
Time synchronization	
Collaboration	*Among services or among devices*
User management	*Creation, authentication, authorization, and accounting of users*
Resource usage accounting	
3) Service requirements	*"Service" as a set of functions and facilities offered to a user by a provider*
Service prioritization	*To satisfy the different service requirements of different groups of IoT users*
Semantic-based services	*Semantic-based services*
Service composition	
Mobility service	
Reliable and secure human body connectivity services	
Autonomic services	*The IoT can enable automatic capture, communication, and processing of data of things based on rules configured by service providers or customized by IoT users*
Service management	
Discovery services	
Service subscription support	
Naming and addressing	
Virtual storage and processing	
4) Communication requirements	
Communication modes	*Support to unicast, multicast, broadcast, …*
Communication control	*Support to error control for communications and time-critical communications*
Intelligent communication	*Autonomic networking, content-aware communication, and location-based communication*

Heterogeneous communication support	*Various kinds of wired or wireless technologies (ZigBee, Bluetooth, …) and support for heterogeneous device-related communication technologies*
5) Device requirements	
Connectivity of things	*Connectivity between a thing and the IoT based on the identifier of the thing*
Device control and configuration	*Support of remote monitoring, control, and configuration of devices*
Monitoring of things	*Automatic notification of the status of things and its changes*
Device mobility	
Device integrity checking	
6) Data management requirements	***Functional requirements from storing, aggregating, transferring, and processing the data of the IoT***
Data storage	*Storing data of things based on predefined rules and policies*
Data processing	*Data fusion and mining based on predefined rules and policies*
Data query	*Querying stored historical data of things*
Data access control	*Access control of data by their owner*
Data exchange	*Data exchange with entities outside the IoT is required to be supported*
Data validation	*Integrity checking and life-cycle management of data of things*
Semantic annotation and access to data of things	
Semantic storage, transfer, and aggregation of data of thing	
7) Security and privacy-protection requirements	***Functional requirements during capturing, storing, transferring, aggregating, and processing the data of things, as well as to the provision of services which involve things***
Communication security	*Secure, trusted, and privacy-protected communication capability*
Data management security	*Secure, trusted, and privacy-protected data management capability*
Service provision security	*Secure, trusted, and privacy-protected service provision capability*
Integration of security policies and techniques	*Ability to integrate different security policies and techniques*
Mutual authentication and authorization	*Mutual authentication and authorization between the device (or the IoT user) and IoT*
Security audit	*Any data access or attempt to access IoT applications are required to be fully transparent, traceable, and reproducible according to appropriate regulation and laws*

The previous requirements can be mapped within the CPS Framework, thus complementing the list of requirements from case-study analysis.

Table 8: Mapping of ITU-T Requirements Within in the CPS Framework

Aspect	Concern	Abstract requirement (harmonized with ITU)
Functional	**Actuation**	Device control and configuration (support of remote monitoring, control, and configuration of devices)
	Communication	Communication modes (support to unicast, multicast, broadcast, …) Communication control (support to error control for communications and time-critical communications) Intelligent communication (autonomic networking, content-aware communication, and location-based communication.)

		Heterogeneous communication support (various kinds of wired or wireless technologies, such as ZigBee, Bluetooth, …) and support for heterogeneous device-related communication technologies)
	Monitorability	Device control and configuration (support of remote monitoring, control, and configuration of devices) User management (creation, authentication, authorization, and accounting of users)
	Functionality	Monitoring of things Service management
	Controllability	Device control and configuration (support of remote monitoring, control, and configuration of devices)
	Physical context	Device Mobility (so that the IoT can support mobility of things connected with devices) Mobility services (so that the IoT can support service mobility, user mobility, and device mobility in the service-provisioning perspective)
	Sensing	Device Mobility (so that the IoT can support mobility of things connected with devices) Autonomic Services (enable automatic capture, communication, and processing of data of things based on rules configured by service providers or customized by IoT)
Human	**Usability**	Programmable interfaces
Trustworthiness	**Security**	Communication security (secure, trusted, and privacy-protected communication) Data management security (secure, trusted, and privacy-protected data management capability) Service provision security (secure, trusted, and privacy-protected service provision capability) Integration of security policies and techniques (ability to integrate different security policies and techniques: consistent security control over the variety of devices and user networks) Mutual authentication and authorization Reliability
Timing	**Synchronization**	Time synchronization
Boundaries	**Behavioral**	Capacity to interact with system from other domains
Data	**Data semantics**	Semantic annotation and access to data of things Semantic storage, transfer, and aggregation of data of things
	Operations on data	Data storage Data processing (data fusion and mining based on predefined rules and policies) Data query Data access control Data exchange Data validation

	Relationship between data	Semantic storage, transfer, and aggregation of data of things

A.2 Application Categories and Subcategories with Sample Application Examples

Table 9: List of Smart City Applications Category/Subcategories

Category/Subcategory	Issues	Kind of applications (examples)
Built environment	• to manage and improve building performance, energy efficiency, safety, and comfort • to know, use, and manage the land resources into built environment	
Smart home	• to enable automatic and remote control of home systems and conditions • to create services to improve the awareness of home residents about energy and water consumption • to activate remote assisted-living services • to optimize the efficiency of heating systems, to reduce energy consumption and environmental impact, thus lowering utility bills	• home-monitoring and management systems • building-monitoring and management systems • energy-monitoring and management systems • water-monitoring and management systems • consumption-monitoring systems
Smart building	• to enable automatic and remote control of home and building systems and conditions • to create services to improve the awareness of building occupants about energy and water consumption	• building-monitoring and management systems • energy-monitoring and management systems • water-monitoring and management systems
Land use and management	• to collect and provide information about available land resources and how there are used • to management natural resource	• land-use classification systems • GIS-enabled land mapping • smart land-use planning systems
Water and wastewater	• to collect, manage, distribute, use, reuse, and recycling water • to reduce water consumption and contamination, to enable the effective utilization of water resources • to reduce costs and increase the reliability and transparency of water distribution	
Water collection and management	• to map and monitor the hydrology network • to monitor groundwater level • to predict and manage events (like storms) in time • to monitor water quality and take corrective action in case of any degradation of water quality • to analyze, predict, and manage water consumption	• weather-forecasting systems • systems for geo-spatial mapping of networks

	Water distribution	• to map, monitor, manage, and make efficient the water distribution network • to detect outage, breakage, leakage, ghost pipes in the network • to monitor water quality and take corrective action in case of any degradation of water quality	• ghost-pipe detection and management systems • water-leakages detection and management systems • outage management system • real-time hydraulic-modeling water distributions tool • water and wastewater SCADA • application for geospatial management of water-distribution network • quality water monitoring and correcting systems
	Water consumption	• to enable consumers to understand, monitor, and control their water usage	• online systems for understanding and monitoring water usage
	Wastewater management	• to monitor sewer-lines infrastructure • to improve wastewater treatment	• plant-monitoring and control systems • sewer- lines infrastructure-monitoring and control systems
Waste		• to favor recycling and reuse of the products in order to convert waste into a resource and create closed-loop economies • to involve citizens in city sanitation • to improve efficiency of waste collection and transportation systems • to improve the waste-disposal processes	
	Citizens engagement	• to create awareness on waste segregation and recycling • to provide visibility on city sanitation, route planning for garbage collection, resource optimization, efficient asset management, efficient maintenance, visibility of waste bins, air-quality measurements etc.	• online platform to sell and regain value from products • web portal to share and provide information
	Collection and segregation	• to optimize the pick-up routes and schedules • to reduce the manpower	• waste-collection scheduling systems (based on sensors and GPS devices) • automated waste-collection systems
	Waste disposal	• to evaluate the energy production from waste • to enable smart landfill management • to monitor pollution levels at landfills	• energy-simulation systems • landfill-management systems • pollution- and contamination-control systems
Energy		• to manage the demand/supply gap • to reduce energy losses, consumption, and carbon footprint • to provide reliable 24x7 energy supplies and reliable metering • to favor the creation of a single and smart electricity grid • to improve energy asset management, energy operations, and customer service for citizens and businesses	
	Energy supply	• to improve supply by integrating decentralized renewable energy sources	• demand-response management systems • energy-simulation systems

		• to provide advanced energy-supply service management: load management, demand-response, real-time monitoring, and control • to create large customer profiling	• real-time consumption-monitoring and control systems • carbon reporting and management systems • energy-service management systems
	Energy transmission and distribution	• to regulate load and capacity factors to maintain stability in the grid • to manage unpredictable energy production • to identify theft and pilferage • to track defaulters	• electric SCADA • solutions for substation automation • solutions for feeder automation • overloading management solutions • self-healing grid systems
	Energy demand	• to reduce energy demand from buildings and industrial plants • to identify target customers and define strategies for effective energy management • to activate smart-prices policies • to collect accurate information on energy usage	• electric infrastructure-management systems • GIS-mapping systems • network mapping and consumer-indexing systems • smart-streetlights systems • large customer profiling solutions • energy-service management systems • consumption-monitoring systems
Transportation		• to reduce pollution levels and/or greenhouse gas emissions and energy consumption • to reduce traffic congestion • to optimize trip planning and management • to optimize transport mode selection and allow seamless multimodality • to change the behavior of the drivers in the long term • to improve public safety	
	Travel demand/consumption	• to reduce the mobility needs for both individuals and goods and to reduce travelling time • to improve the use of public transport, also increasing its reliability	• online services to access to public transport and information • bicycle-sharing systems • carpooling/car-sharing applications • multi-channel citizen services to report maintenance issues • cash-less payment systems for multiple mode of transportation • GPS-based system for real-time tracking of public transport
	Traffic management	• to monitor and analyze traffic information and provide real-time traffic information and periodic traffic forecast • to improve efficiency in incident management • to improve efficiency of freight-vehicle operations • to provide efficient management of streets and off-street parking spaces	• GPS-based system for real-time tracking of public transport • GPS-based vehicle-tracking systems • Smart-parking systems • Smart-traffic-lights systems • freight ICT services • efficient incident-management systems • real-time roadway-traffic monitoring and analysis systems • video analytics-based scenario simulations systems
	Surveillance	• to remotely monitor the public transport	• video analytics-based surveillance

	and roads	systems • efficient incident-management systems
Education	• to increase access, improve quality, and reduce costs to education	
Learning outcomes	• to evaluate teacher performance • to monitor student attendance and performance	• education-analytics platforms • teacher-performance management systems • biometric-identification systems • student-performance management systems
Learning and teaching	• to facilitate distance education • to improve curriculum design and publication processes • to improve the quality of teaching	• e-Learning platforms • video-conference systems • curriculum-management solutions • online teacher-training solutions
Service management	• to improve quality and safety of school infrastructures • to reduce costs for personnel and infrastructures management • to reduce access costs to school	• online centralized-admission systems • online teacher recruitment • integrated school-management systems • surveillance systems • GPS-based tracking systems in buses
Health	• to improve quality of care, patient safety, and outcomes • to improve the effectiveness and efficiency of healthcare services • to reduce costs • to increase communication about health	
Health care systems	• to provide real-time information regarding hospitals and availability of beds, waiting times, doctor offices, and appointments, etc. • to have an integrated management of patient information • to provide citizens with direct access to their health information • to provide online access to health services	• logistic-management systems • administrative systems • patient-information management systems • online patient portals • online health portals
Health care delivery	• to improve diagnosis and enhance patient care • to monitor dissemination of epidemics • to reduce health problems • to provide remote assistance to patients • to forecast the care demand	• remote diagnostic and support systems • critical decision support systems • medical-simulation systems • remote monitoring and assistance systems • diagnostic-analytics systems
Communication	• to increase health-information dissemination	• Internet information portals • communication systems
Socio-economic development	• to meet social needs and to increase standards of life within urban areas • to improve enterprises' efficiency and competitiveness	
E-Governance	• to improve efficiency, effectiveness, transparency, and accountability of communications and transactions between government and public	• e-Government applications • open-data platforms

		administration, citizens, and businesses	
	Social Innovation and Inclusion	• to increase engagement of citizens in the city functioning • to favor access to city's services and opportunities.	• Citizen-reporting platform for contacting local authorities • Social-networking applications
	Economy and business	• to create a multi-sectorial economy, smart industries, and smart manufacturing	• e-Commerce solutions
Public safety, policing, and emergency response		• to anticipate and respond rapidly to emergencies and threats • to improve safety and security within urban areas	
	City surveillance and crime prevention	• to detect misbehavior of individuals • to monitor social events and crowd behavior • to support human capacity in surveillance • to enable citizens to provide information about criticalities	• mobile emergency services • cybersecurity tools • incident-control systems • surveillance systems • integrated response and emergency systems
	Communication	• to increase citizen awareness and education	• online platforms and services
	Prevention and managing of natural disaster	• smart systems of crisis management to support decision making, early warning, monitoring, and forecasting emergencies and environmental situation • centrally operated units of police and Integrated Rescue System (IRS)	• modelling and simulations in preparation process of crisis management • simulations, supporting decision making during the real emergency
	Flood monitoring and forecasting	• handling emergency flooding conditions in the near-present • preparing for the flood-related disasters of the future	• systems for remotely alerting residents • flood-monitoring network

A.3 Sample CPS Framework Decomposition of a Subcategory

Table 10: Requirements Associated to the Category "Built Environment" Subcategory "Smart Home"

	Subcategory	Aspect	Concerns	Abstract requirements	Specific implementation requirements	ICT architecture level	Geo-domain
	Smart home	Functional	**Actuation**	capacity to analyze and elaborate received data and make decisions	actuation capabilities smart appliances, turning off electronics devices automatically, security device management,	sensor; data; application; user-interface	home

				lights and thermostats management, motorized shades		
		Functionality	remote access	audio/video equipment		
		Controllability	to remotely control and provide access to the systems	Internet connection remote control software		
		Performance	to provide feedback in time to act	fast and reliable network real-time systems		
		Physical context	to exactly identify location of people	placement sensors motion sensors		
		Sensing	to exactly identify location of people, persistent communications to get data from home automation and energy systems, to elaborate data received from home automation and energy systems	placement sensors motion sensors persistent communications technology decision support systems		
	Human	**Usability**	to provide human-readable, unambiguous, and aggregated data	variety of Interfaces available		
	Business	**Utility**	to provide effective information to reduce costs to improve quality of life of residents	fast and reliable network real-time systems		
	Trustworthiness	**Safety**	persistent monitoring to provide data in time to act	fast and reliable network, real-time systems,		
		Privacy	to define privacy policy	privacy protection mechanisms		
		Security	to preserve authorized	firewall		

			restrictions on access and disclosure, to prevent modification or destruction of system, to ensure non-repudiation and authenticity, to ensure timely and reliable access to and use of a system	antispyware antivirus		
	Timing	**Logical time**	to take into account the sequence of the events			
		Managing timing and latency	to send data in a timely manner			
		Synchronization	to send data with a common time scale			
	Data	**Data semantics**	to correctly understand the meaning of the data			
		Operations on data	to harmonize data from different sources			
		Relationship between data	to connect data from different sources			

Some other requirements are associated the other two "coordinates" of the breadth, which are the "ICT levels" and the "Geo-domains." These relationships are shown respectively in Table 11 and Table 12.

Table 11: ICT levels and Related Requirements

Aspects/Concerns		ICT Architecture Level Implementation Requirements			
		Sensor/Actuator	Data	Application	User Interface
Functional	Communication	sensors communication protocols (standard-based) sensor network communication protocols (standard-based)			User-centric design applications accessibility
	Monitorability			dashboard authentication mechanisms	

Trustworthiness	Security	sensor network security protocols	digital signature cryptography	entity authentication mechanisms intrusion detection systems intrusion prevention systems	
Timing	Managing timing and latency			managing time and latency systems	
	Synchronization	sensor synchronization algorithm			
Data	Data semantics		standard data models		
	Operations on data		electronic data format (standard-based)	public interfaces	
	Relationship between data		public, shared, and standard data models	public interfaces	

Table 12: Geo-domains and Related Requirements

Geo-domain	Aspects	Concerns	Requirements
Home	Functional	**Communication** capacity to exchange information internal to the system	Home-management systems sensor network
	Boundaries	**Behavioral** capacity to interact with system from other domains	software interfaces
Building	Functional	**Communication** capacity to exchange information internal to the system and between systems	sensor network local-area network
	Boundaries	**Behavioral** capacity to interact with system from other domains	software interfaces
Aggregation	Functional	**Communication** capacity to exchange information internal to the system and between systems – Multi-departmental network access	Campus area network
	Boundaries	**Behavioral** capacity to interact with system from other domains - capacity to add or remove modules without the need to redesign the whole network	Software interfaces Simplified network management
District	Functional	**Communication**	sensor network local-area network

		capacity to exchange information internal to the system and between systems	campus-area network
	Boundaries	**Behavioral** capacity to interact with system from other domains	software interfaces
City	Functional	**Communication** capacity to exchange information internal to the system and between systems	metropolitan-area network
	Boundaries	**Behavioral** capacity to interact with system from other domains	software interfaces
Country	Functional	**Communication** capacity to exchange information internal to the system and between system	backbone wide-area network cloud
	Boundaries	**Behavioral** capacity to interact with system from other domains	software interface

A.4 List of Smart City Readiness Frameworks

Table 13: Smart City Readiness Frameworks

Framework	Producer	Reference
Smart Cities Readiness Guide	Smart City Council	Smart Cities Readiness Guide (2015)
Smart Cities Maturity Model	Scottish City Alliance	Smart Cities Maturity Model and Self-Assessment Tool Guidance Note for Completion of Self-Assessment Tool (October 2014)
FTTH Council MENA - Readiness of Smart Cities White Paper	FTTH MENA Smart Cities Operations and Applications Committee	Assessing the Readiness of Smart Cities and Major Real Estate Developments – White Paper (2014)
PAS 181 Smart City Framework	BSI Group	PAS 181 Smart City Framework: Guide to Establishing Strategies for Smart Cities and Communities (2014)
The Networked Readiness Index framework	World Economic Forum	The Global Information Technology Report (2016)
Smart City Index	Ernst & Young	Italia Smart – Smart City Index (2016)
ISO 37120:2014 Sustainable Development in Communities	ISO	ISO 37120:2014(en) Sustainable Development of Communities — Indicators for City Services and Quality of Life

Appendix B. Use Cases and Analyses for Select Smart Cities

B.1 Smart City Case Studies

The descriptions and data (and some of the text) has been provided by organizations affiliated with the specific projects.

B.1.1 Smart Solutions for a Greener Copenhagen

Copenhagen (Denmark) is one of the most livable cities across the world. The city planning favors cyclists and pedestrians and encourages inhabitants to enjoy city life with an emphasis on culture, community, and cuisine. Copenhagen set an ambitious goal to be the world's first carbon-neutral city by 2025. With easily accessible data, advanced public digitalization, a longstanding tradition of public-private partnerships, and ambitious national climate targets, Copenhagen is a world-leading smart city solutions laboratory. In Copenhagen, at least 50% of people will go to their workplaces by bike, resulting in a reduction of city's carbon dioxide emissions by over 20%, and at least 80% of cyclists feel safe and secure in Copenhagen in traffic [114].

Major achievement/key measures: Describe major projects/services that are in their planning stages, have launched, or have been completed, and describe policy-oriented strategies to be implemented along with cross-cutting efforts of the smart cities development.

1. **Smart transportation solutions:**
   - Green wave traffic control
   - Optimized route planning based on real-time traffic information
   - Free parking space detection
   - Chip-based cost-effective bike theft prevention and tracking of municipality's material
2. **Open data:**
   - Copenhagen open data platform is city's portal for data on traffic, infrastructure, cultural activities, and much more (Available at [115] and [116]).
   - City Data Exchange enables purchase, sale, and sharing of a variety of data types among all kinds of users in city such as citizens, public institutions, and companies. This innovative platform—established by Hitachi with support of the Copenhagen Municipality, CLEAN (A Danish clean-tech cluster), the Capital Region, etc.—is aiming to provide a citywide marketplace for the purchase and sale of data.
3. **Living laboratory:**
   - Street lab is the test area for Copenhagen's smart city solutions in real urban space, which will be a showcase for the newest technologies of IoT and smart city applications. First-phase projects include: smart parking, waste management, air quality and noise monitoring, water management, mobility monitoring, city Wi-Fi for tourists, real-time big data city flow, cost-efficient data connections, asset tracking, services for citizens and tourists [116].
   - EnergyLab Nordhavn – New Urban Energy Infrastructures will develop and demonstrate future energy solutions in the next four years. It is a full-scale smart city energy lab and

demonstrates how electricity, heating, energy-efficiency buildings, and electric transport can be integrated into a systematic, flexible, and optimized energy system [118].

Impacts/benefits: Describe the anticipated economic benefits (new products, jobs, economic growth, exports, contributions to the tax base, etc.) as well as impacts on energy, health, safety, environment, or other quality of life aspects.

- 11-32% optimized traffic flow and 1.7 million L fuel reduction
- 180,000-ton carbon dioxide emission reduction
- 50% reduction in bike thefts
- 1% increase in tourism
- Foreign investment attraction**:** Thanks to this outstanding environment, many world-leading companies choose Copenhagen for smart city projects. For instance, Cisco is testing and developing tomorrow's digital infrastructure, the Internet of Everything in Copenhagen. Hitachi also has located its first big data research lab in Copenhagen.
- Job creation €104 million

B.1.2 Smarter Hong Kong, Smart Living

Hong Kong (China) envisions becoming a world-renowned smart city with proactive developments of ICT. In 1998, the Hong Kong Special Administrative Region Government published the first Digital 21 Strategy, which was updated in 2001, 2004, and 2008. The Digital 21 Strategy serves as a blueprint to steer and guide smart city development of Hong Kong.

Challenges and solutions: Identify the challenges the city is addressing and describe the proposed solutions.

- The city will be more sustainable and smarter, through intelligent and interconnected infrastructure, networks, and management systems.
- The community will be more prosperous and equal, through an open and efficient collaborative digital ecosystem.
- Citizens and visitors will be more engaged with (and understood by) businesses and government agencies via smart and interconnected touch points, such as mobile applications and website portals.
- Business will be more innovative in anticipating changing customer needs and expanding beyond Hong Kong borders both physically and digitally.

Major achievement/strategies: Describe major projects/services that are in their planning stages, have launched, or have been completed, and describe policy-oriented strategies to be implemented along with cross-cutting efforts of the smart cities development.

- Develop Hong Kong as a hub for technological cooperation and trade: Hong Kong plays a role as a two-way platform for mainland enterprises, and it fosters a vibrant ICT industry supported by programs, such as Closer Economic Partnership Arrangement (CEPA).

- Build an inclusive, knowledge-based society and empower everyone through technology, by adopting various approaches including: Government Wi-Fi program (GovWiFi), which increases mobile and broadband penetration; Web Accessibility Campaign, which was designed to facilitate access to online information and services for all, especially for persons with disabilities; "I Learn at Home" program, which was launched to assist children from low-income families to be able to undertake web-based learning courses at home; and eElerly portal, which encouraged older citizens to make better use of ICT.
- Ignite business innovation through exploitation of technology and by establishing innovation and collaboration platforms, as well as promoting cloud platforms and knowledge sharing for small and medium enterprises.
- Support a thriving Hong Kong ICT industry and R&D, through ICT talent development, data center, and cloud computing development, and through digital media center of excellence development.
- Transform and integrate public-service delivery to a new level through ICT: 1) e-Government services: create multi-platform solutions for existing and future public services for all government departments; 2) mobile applications; 3) smart city infrastructure: promote deployment of sensing or IoT devices and encourage data sharing across government departments.

Impacts/benefits: Describe the anticipated economic benefits (new products, jobs, economic growth, exports, contributions to the tax base, etc.) as well as impacts on energy, health, safety, environment, or other quality of life aspects [119].

B.1.3 Smart Singapore

The Smart Nation Program of Singapore was developed in 2014 to push the country towards the vision of being the world's first smart nation. This program is seeking to facilitate ICT, networks, and data to increase the quality of life, to create more opportunities, and to support stronger communities, in response to growing urban challenges of increasing population, aging infrastructure, and resource sustainability.

Major achievement: Describe major projects/services that are in their planning stages, have launched, or have been completed, and describe policy-oriented strategies to be implemented along with cross-cutting efforts of the smart cities development.

1. **Transportation and urban mobility**

Singapore has implemented a sophisticated Intelligent Transport System (ITS) to enhance traffic flow and ensure traffic safety. It works together with other transport initiatives, such as free public transportation in pre-morning peak hours, a well-functioning public transport system, congestion charges, and a vehicle quota system, to enhance the overall transportation system in the city. ITS provides various smart transport services to citizens, such as 1) ONE MOTORING web portal to provide citizens with online accessible traffic information collected by surveillance cameras installed on roads and GPS-enabled taxi vehicle, as well as information on current ERP rates (electrical road pricing), sections of road under construction, traffic news, travel-time calculator, parking information, etc.; 2) "Your Speed Sign" for displaying the real-time speed of vehicles and alert drivers when they are violating the speed limit; 3) Parking guidance system to provide drivers with real-time information on parking availability, which effectively reduces the amount of circulating traffic searching for parking spaces and promotes the efficient use of existing parking facilities; and 4) Bus information system, a centralized system to determine real-time bus location, and hence provide more accurate bus-arrival information for more than 4700 public buses over 360 routes.

2. Emergency and response

The Emergency Medical Service (EMS), operated by the Singapore Civil Defense Force (SCDF), can be reached through a mobile application, "myResponders," which has been designed to increase survival rate from incidents such as out-of-hospital cardiac arrest, guiding first responders to respond before the SCDF arrives. Tele-medicine, another major aspect of the Smart Nation initiative, aims to promote the widespread use of wearable technologies such as fitness trackers, smart watches, and even smart clothing, which are designed to monitor the well-being of patients and to transmit the data of vital signs, such as blood pressure, heart rate, and body temperature to designated healthcare professionals.

3. Environment

Water shortages are ongoing challenges for Singapore due to its limited land area and ever-increasing demand. Therefore, it is crucial for the country to innovate and develop capabilities to improve water-use efficiency and enhance water conservation in the area. Singapore Power provides a mobile application that allows citizens to view their utility bills, make payments, understand their utility usage, and submit meter readings, thus leading consumers to audit their home usage and better manage their water consumption.

Smart waste management was also launched to help the waste collection team to optimize their route planning and constantly keep the public spaces clean. The sensors attached on bin lids collect information on contents and location and can then notify the waste management team through a central server.

4. Energy

One of the major goals of Smart Singapore is to promote energy efficiency and eco-friendliness. Smart lighting systems with motion detectors can automatically turn off or adjust the luminance of lights in buildings. For more efficient energy use, Singapore's Intelligent Energy System (IES) attempts to improve network operations and facilitate active participation among consumers. The initiative phase 1 began in 2010, focusing on developing the enabling infrastructure and the testing of smart meters that were equipped with communication capabilities. In 2012, as a part of IES project under phase 2, smart meters were installed at some residential households in Punggol. They were given in-home display (IHD) units, a portable device that provides real-time information on their household electricity consumption.

5. Citizen interaction and communication mechanisms

Singapore has emphasized the significance of connectivity between the government, industries, and citizens. It started promoting the e-Government platform as early as 1980s, and ITC began to converge, transforming the concept of service delivery in 1990s. E-Government programs are developed to deliver services to citizens, businesses, and government [120].

B.1.4 Smart London

London (Great Britain) is home to one of the most significant centers of commerce, creativity, and culture in the world. It is diverse, connected, international, and cosmopolitan. To solve London's future growth challenges, the city is considering innovative approaches, including new business models and new ways of financing for implementing integrated solutions in the city.

Challenges: Identify the challenges the city is addressing and describe the proposed solutions.

As an ancient city, London's infrastructure is struggling to cope with the increasing demands upon it. It costs an estimated 2 billion pounds per year due to the congestion on London's roads, with Londoners spending 70 hours on average in traffic jams. The aging population has also brought huge pressure on the city's health care and social welfare systems.

Major achievement/key measures: Describe major projects/services that are in their planning stages, have launched, or have been completed, and describe policy-oriented strategies to be implemented along with cross-cutting efforts of the smart cities development.

1. Enabling open-data transparency: The London Datastore was one of the first platforms in the world to publish open data and make it publicly accessible. This Datastore receives over 30,000 visits a month and more than 450 transport apps have been created using open data. This encourages the development of products and new business models, as well as the creation of better, more cost-effective services for all Londoners.

2. Leveraging London's research, technology, and creation talent: London is aiming to become a talent and world-class research base to solve its future challenges and to create new market opportunities, businesses, and jobs. Programs such as Smart London innovation challenge, London Green Fund, and Smart London Export program aim to help emerging solutions be rapidly commercialized.

3. Promote the use of smart grid technologies: Through the Low Carbon London program, London is proactively using smart grid technologies to help the city meet the increased energy demand and optimize energy consumption.

4. Offering a "smarter" London experience for all: Establish a Smart London Platform; invest in wireless networks in public spaces; and help visitors and Londoners to navigate the city easily [121].

B.1.5 Smart and Equitable New York City

New York City, New York (United States), leverages smart technologies to achieve the goals set by Mayor de Blasio's ambitious One NYC plan. The city envisions becoming a smart city with a dynamic, thriving economy; equal opportunities for all citizens to reach their potential and to succeed; and strong resiliency against shocks, both natural and man-made.

Challenges and Solutions: Identify the challenges the city is addressing and describe the proposed solutions.

New York City is facing great challenges of increasing population and aging infrastructure, as well as meeting the energy and water demand of millions of New York residents.

Major achievement: Describe major projects/services that are on their planning stage, launched, or have been completed, and describe policy-oriented strategies to be implemented along with cross-cutting efforts of the smart cities development.

Energy and Environment:

- Smart indoor lighting: As part of the Accelerated Conservation and Efficiency (ACE) program of New York City, smart lighting solutions, including LED upgrades and advanced lighting controls, have been installed in many agencies building. LED lighting offers many benefits including low maintenance costs and high longevity, as well as better quality lighting.
- Wireless water meters: New York City's Automated Meter Reading (AMR) system consists of 817,000 individual water meters all over the city. Each of them is connected to a low-power radio transmitter that sends water readings to rooftop receivers in a certain frequency. The receivers transmit the data to a Network Operations Center using a secure citywide telecommunication network. Customers can view their water usage data and pay bills online. Thus, New York City has saved over $3 million per year by avoiding manual meter readings.
- Water quality monitoring: New York City's Department of Environmental Protection (DEP) has deployed an extensive network of remote monitoring sensors across the city and watershed. The sensors can autonomously transmit water data to DEP operation centers, providing real-time 24/7 water quality and supply data. It can also alert DEP with potential water quality issues before water reaches a tap in the city.
- Smart waste management: New York City Big Belly uses integrated wireless sensors to detect trash level, alerting sanitation services to collect the waste. The unit is capable to fill with five times more waste than the ordinary garbage bin thanks to solar-powered compaction. Big Belly estimates their solution improves waste collection efficiency by 50-80%.

Transportation:

- "Midtown in Motion" is a technology-enabled traffic-management system that uses real-time traffic information from a variety of sources to monitor and respond to various traffic conditions. It consists of microwaves sensors, EZPass readers, and traffic video cameras to collect traffic flow information.

- The Department of Transportation and the Metropolitan Transportation Authority introduced the Transit Signal Priority (TSP) system to improve the efficiency and dependability of bus mass transit. Pattern selection (PS) and location-based traffic control software are built into the buses and traffic controllers, thus allowing them to communicate with each other via DOT's Traffic Management Center. A bus equipped with the TSP system can request priority service when it approaches an intersection and can change the normal signal operation to improve the traffic flow.

Safety and interaction:

- New York City 24/7 Smart Screens are interactive platforms that integrate information from open government programs, local businesses, and citizens to deliver real-time hyper-local information on events, merchants, services for people, as well as provide security alerts in the surrounding area to keep people safe. The Smart Screens can be accessed via Wi-Fi on nearby smartphones, tablets, and computers.
- PlowNYC is a public-facing web app developed by New York City's Department of Sanitation (DSNY) to provide citizens with real-time snow removal progress monitoring. The snow-removal-equipped GPS-enabled flip-phones can send GPS signals to the data center every 12 seconds, where information can be processed and released on the PlowNYC website and DSNY management tool --it is a low-tech but high-impact solution [122].

B.1.6 Smart Orlando

The City of Orlando, Florida (United States), is well known for attracting businesses of all types. As a world-famous tourist attraction, it experiences a significant inflow and outflow of citizens and visitors. Orlando has applied information communication technology (ICT) and many smart city approaches to provide citizens and visitors with efficient services and perform city operations in an integrated and smart manner. The vision is to keep pursuing economic prosperity, through further encouraging tourism, as well as attracting business and investment.

Challenges and visions: Identify the challenges the city is addressing and describe the proposed solutions.

The city is experiencing rapid population expansion as well as increasing tourism growth, thus resulting in a tremendous burden for the energy and water demand and civic infrastructures. Traffic control, business expansion, and safety are examples of demands that followed city growth.

Major achievement/key measures: Describe major projects/services that are in their planning stages, have launched, or have been completed, or policy-oriented strategies to be implemented along with cross-cutting efforts of the smart cities development.

1. **Transportation and urban mobility**

- Bus information service: Orlando launched a public bus system, LYNX, which provides massive public services connecting Orange County with surrounding city, towns, and counties. LYNX provides web-based services to customers for accessing information on ticket price, transit service areas, crashes, construction sites, roadblocks, real-time tracking of bus schedule and location, and an interactive map to allow users to find closest routes and bus stops.
- Parking information service: Orlando provides a parking information service through a mobile app, called Orlando parkIN', where users can get parking information on pricing, locations, operating hours, number of spaces available, etc. through an interactive map.

2. **Emergency and response**
   - OCAlert.net is an alert system that allows Orange County Government to contact citizens through emails, calls, and messages during an emergency with real-time updates and instructions on where to go, what to or not to do, and other important information under emergency situations. Alerts include life-threatening weather warnings, amber alerts, highly disruptive roadblocks, evacuation, shelter in place, environmental alerts such as lake, water body, air quality, etc.

3. **Energy and environment**
   - Power pass program is a pay-before-consumption program that allows customers to pay-as-you-go or pay-in-advance for utility services, which can result in lower electricity and water consumption. Users can view their utility usage through an online dashboard, MyUsage.
   - Smart waste information: The "Solid Waste Pickup" tab in the Orlando Information Locator provides information on garbage pickup days, recycling day, yard waste pickup day, etc.
   - Orange County Water Atlas helps researchers, resource managers, and the general public better understand and conserve water by providing general information, improvement projects, regulation, and detailed data on water quality, water levels, and flows, as well as habitats and ecology of local lakes, ponds, rivers, and watersheds.

4. **Citizen interaction and communication mechanisms**
   - Online education programs are offered by the City of Orlando in collaboration with the University of Florida and the University of Central Florida to provide education subjects such as household hazardous materials, lake-friendly pet practices, lake water quality, illicit discharge prevention, and storm water runoff and pollution, etc. [123].

B.1.7 Smart Vienna

Vienna (Austria) is aiming to become a vibrant metropolis and one of Europe's most attractive cities based on long-term and structural measures of the city in all fields of life: quality of living, sustainability, and prosperity, as well as quality and quantity of educational options and workplaces.

Challenges and solutions: Identify the challenges the City is addressing and describe the proposed solutions.

- The resource issue is strongly contingent on cities, as energy consumption, carbon dioxide emissions, and mobility patterns, and hence the quality of life of their citizens are at the center of attention. Thus, Vienna boasts a long-standing tradition of resource conservation and protection. Examples of this are the impressively high share of public transport, the ramified district heating network with its cogeneration and waste incineration installations, or numerous examples of resource-conserving production in Vienna's industrial plants.
- Vienna also copes with specific challenges that stem on the one hand from urban growth and on the other hand from necessary processes of change. Examples include the further restructuring of energy systems, the organization and financing of building rehabilitation including thermal rehabilitation, and the changing demands made on the mobility system, which is marked by a steep increase in the shares for walking and cycling.
- Better fine-tuning of process between city and surrounding region is another challenge for the future.

Major achievements: Describe major projects/services that are in their planning stages, have launched, or have been completed, and describe policy-oriented strategies to be implemented along with cross-cutting efforts of the smart cities development.

- **E-mobility on demand:** This project focuses on a gradual switch towards a comprehensive transport system. Public transport is effectively complemented by electromobility and e-car sharing.
- **Open government:** Vienna considers ICT as a central driver of innovation and a special asset of the city. It is committed to the open government principle and the related concepts of participation and transparency, as well as data security. Innovative applications can provide digital services in many areas such as energy, health, culture, environment, transport, or housing through mobile end devices. This also calls for improved **WLAN provision.**
- **Alternative methods of measuring prosperity:** Workplaces in Vienna correspond to the criteria of "good work" (i.e., employment is for an indeterminate period and fulltime (if requested by the workers); payment corresponds to a "living wage" standard; and collective bargaining regulations are complied with). Access to the labor market is low-threshold and equitable, in particular for less-advantaged parts of Vienna's population. Women and men contribute equally to the economy of Vienna as a smart city.
- **Education:** Vienna is transforming many elementary schools into whole-day school, enlarging the range crèches and kindergartens, and pursing the objective of an integrated school for all children aged 10 -14 years. In Vienna Campus Plus model, kindergartens, schools, and leisure education are concentrated in one location, thus ensuring the optimized use of all resources [124].

B.2 Business Cases for Implementing IoT-enabling Technologies

By 2050, more than 60% of the global population will dwell in cities. Existing mega-cities, such as New York City, London, Tokyo, and Shanghai, are facing the tremendous pressures of increasing urbanization, ballooning population, aging infrastructure, and climate change. Therefore, it is crucial for cities to work together in tackling urban issues such as traffic congestion, air pollution, energy crisis, water scarcity, food shortage, etc. IoT-enabling technologies are in great demand to make cities more efficient, sustainable, and resilient.

However, cities around the world need a great amount of investment in infrastructure upgrades, mass transportation expansions, energy transitions, etc. Public resources cannot manage it alone. Thus, financing becomes vital in facilitating infrastructure development around the world. It can help reduce initial cost, manage risks, and make mega-projects bankable.

B.2.1 Mobility Finance Business Case

Case Studies: City of London Crossrail Development

London's Crossrail is Europe's largest infrastructure construction project. When the project is completed, it will increase London's rail transport capacity by 10%, reduce people's commuting time, and bring employment growth of up to 30,000 jobs by 2026 in central London. It plays a vital role in meeting London's current and future transport needs and in facilitating economic growth of the UK, thus promoting sustainable development.

The capital cost of the project will be primarily financed in three ways: 1) through future ticket revenues generated by Crossrail services; 2) by business in London, developer contributions, and a Business Rate Supplement (BRS); and 3) by national taxpayers through grants of the Department for Transport (DfT).

Table 14: Cross rail Benefits and Costs Summary excluding 'sunk' cost [123]

Component (£bn; PV 1Q 2002 prices)	TfL (London Weighting VoT)	DfT (UK wide VoT)
User Benefits:		
– Time Savings	9.1	6.6
– Congestion Relief	7.3	5.3
– Other	0.5	0.5
– Indirect Tax Revenue	-1.4	-1.4
Total User Benefits	**15.5**	**11.0**
Costs:		
– CAPEX	-9.4	-9.4
– Operations/Maintenance	-3.9	-3.9
– Revenues	7.4	7.4
– Other	0.2	0.2
Total User Costs	**-5.6**	**-5.6**
Net Present Value	**9.9**	**5.4**
"Conventional" BCR	**2.76**	**1.97**

Not only will Crossrail bring direct benefits to London, but also the impact of this project on the wider economy will be substantial. The increase in GDP of UK derived from the development of Crossrail is majorly contributed by the growth of central London employment, which in return will generate higher earnings and profits for UK businesses, and create higher taxes to UK government. In total, Crossrail wider impacts are estimated to be 6-8 billion pounds in welfare terms, including increased tax receipts, which will exceed the initial project cost [125][126].

B.2.2 Building Energy Efficiency Business Case

An estimated number of 40% of the energy used and 1/3 of carbon emissions worldwide come from the building sector, thus improving energy efficiency of buildings is of great significance. Cities can optimize buildings' energy requirements to be 40-50% more efficient than conventional buildings by implementing effective green building technologies, building energy codes, and smart building solutions. Energy "saved" is energy "generated." Advanced building technologies will enhance energy and environmental performance from a whole building perspective over a building's lifecycle, thus promoting innovative implementation of sustainable site selection and planning, water and energy efficiency solutions, smart waste management, effective materials and resources utilization, and other intelligent building technologies.

While the environmental and human health benefits of green buildings have been widely recognized, our analysis reveals that a minimal increase in upfront costs of about 2% to support green design would, on average, result in life-cycle savings of 20% of total construction costs—more than ten times the initial investment.

Buildings can unlock huge energy-saving potential in energy consumption and costs when engineering and financing solutions are combined. Energy performance contracting (EPC) for building technology is one of the effective solutions. EPC is an innovative service offered by energy service companies to building owners. Customers can use the energy cost savings to pay for the installments of the advanced technologies without making any upfront investment [127].

B.2.3 Blockchain Technology Enabling the Design of Microgrid Energy Markets – An Example from Brooklyn

Generation from distributed renewable energy sources is constantly increasing. Due to its volatility, the integration of this non-controllable generation poses severe challenges to the current energy system. Thus, ensuring a reliable balance of energy generation and consumption becomes increasingly demanding. In our approach to tackle these challenges, we suggest that consumers and prosumers can trade self-produced energy in a peer-to-peer fashion on microgrid energy markets. Thus, consumers and prosumers can keep profits from energy trading within their community. This provides incentives for investments in renewable generation plants and for locally balancing supply and demand. Hence, both financial as well as socio-economic incentives for the integration and expansion of locally produced renewable energy are provided.

The efficient operation of these microgrid energy markets requires innovative information systems for integrating the market participants in a user-friendly and comprehensive way. To this end, the concept of a blockchain can be used for microgrid energy market without the need for central intermediaries. Seven market components were derived as a framework for building efficient microgrid energy markets. Then, the Brooklyn Microgrid project was evaluated as a case study of such a market according to the required components. The outcome of the analysis shows that the Brooklyn Microgrid fully satisfies three and partially fulfills an additional three of the seven components. Furthermore, the case study demonstrates that blockchains are an eligible technology to operate decentralized microgrid energy markets. However, current regulation does not allow to run local peer-to-peer energy markets in most countries and, hence, the seventh component cannot be satisfied yet [128].

B.3 Summary Analyses of Selected Smart City Deployments

This appendix provides some data acquired by the working group during the framework development. It is presented here to aid researchers in some of the details that might be considered in comparing and evaluating smart city deployments. The data was acquired by trying to address issues devised as questions that the reviewer sought to answer based on their research and knowledge of the application.

B.3.1 Property Set One

These analyses looked at properties of selected smart city deployments and captured the following:

- City and/or project name
- URL for project description/information

- City open data or open dashboard URL
- What is the city population?
- What is the scale of the project?
- Is it connected to neighboring (comparable) projects (whether formally or informally)?
- If so, please provide a brief description.
- At what stage is the city project?
- Have there been any funding issues for the project? If so, what were they and how were they solved?
- What are the key performance indicators (KPIs) for the project? How were they established? How were they evaluated?
- What are the key city systems involved in the project (e.g., housing, energy, health, mobility)? How were those partnerships/alignments facilitated?
- Are any community facilities involved? (hospital, home, school, park, clinic, etc.)
- Are any key infrastructures involved? (roads, gas, electricity, water, communications, etc.)
- Who are the key stakeholders (local authorities, businesses, agencies, citizens, etc.) and what are their roles? Are there any public or academic partnerships as part of this project?
- What role does ICT play in the project? (technologies deployed, where, why)
- How were technology choices made?
- Has the project made any specific technology choices based on "Technical Standards?"
- If yes, what are they?
- Are there any aspects of the project where good practice guidelines, certifications schemes, or standards would have helped? And if so, how? How could available relevant standards, guidelines, or certifications have helped in areas of defining the project?
- Have there been any issues about ICT interoperability (e.g., connectivity, data, application)?
- If so, what were they? How have they been solved?
- Is there an open data policy or requirement associated with this project? If so, how have those requirements been satisfied?

- How has the project addressed the topics of data security and citizen privacy? Is this project subject to federal compliance regulations (e.g., FedRAMP)?
- Was it possible to measure the cost/benefit of the project? If so, what methodology was used?
- What are the ongoing KPIs measured to indicate the success of the project? Do these KPIs include maintenance and depreciation (life cycle costs)?
- What one recommendation, documentation, or initiative would have made the smart city deployment experience simpler, faster, and/or more cost-effective?
- Are there any lessons learned that could be passed along to any relevant standards organizations?
- How did the project evolve during the development process? Did the KPIs or requirements change?

B.3.1.1 Busan open smart city pilot project

Property of project	Description
City and/or project name	Busan open smart city pilot project
URL to project description/information	http://www.k-smartcity.kr
City open data or open dashboard URL	http://opendata.busan.go.kr
What is the city population?	Over 1,000,000
What is the scale of the project?	District
Is it connected to neighboring (comparable) projects (whether formal or informally)?	No
If so, please provide a brief description.	Lot
At what stage is the city project?	Small-scale pilot project(s)
Have there been any funding issues for the project? If so, what were they and how were they solved?	The funding is not enough so the pilot scale is not big enough. They need investments from private corporations or municipalities and fund expansion from the government.
What are the KPIs for the project? How were they established? How were they evaluated?	Energy consumption decrease, car accidents decrease, traffic jam decrease, service utilization level, service satisfaction level
What are the key city systems involved in the project (housing, energy, health, mobility)? How were those partnerships/alignments facilitated?	Smart street light, smart crosswalk They are holding presentations to the stakeholders and establishing an organization for collaboration.
Are any community facilities involved? (hospital, home, school, park, clinic, etc.)	Nursing home - social care service using smart mirror Kindergarten, school - care services for disadvantaged

Are any key infrastructures involved? (roads, gas, electricity, water, communications, etc.)	Road related: street light Traffic related: crosswalk, traffic camera, parking lots
Who are the key stakeholders (local authorities, businesses, agencies, citizens, etc.) and what are their roles? Are there any public or academic partnerships as part of this project?	The most important ones: municipality, police, electric power provider Roles: administrative and operational cooperation to install urban facilities Public or academic: managers for traffic and CCTV network, police administrative, traffic control center
What role does ICT play in the project? (technologies deployed, where, why)	Data collection, sharing, analysis
How were technology choices made?	Vendor driven
Has the project made any specific technology choices based on "Technical Standards?"	Yes (describe in "If yes" below)
If yes, what are they?	oneM2M, global IoT service platform standard
Are there any aspects of the project where good practice guidelines, certifications schemes, or standards would have helped and if so, how? How could available relevant standards, guidelines, or certifications have helped in areas of defining the project?	OneM2M standard provides infrastructure platform that collects sensor data and enables services.
Have there been any issues about ICT interoperability (e.g., connectivity, data, application)?	n/a
If so, what were they? How have they been solved?	n/a
Is there an open-data policy or requirement associated with this project? If so, how have those requirements been satisfied?	Data security: encryption Citizen privacy: agreement on terms and service that enable personal data collection and use
How has the project addressed the topics of data security and citizen privacy? Is this project subject to federal compliance regulations (e.g., FedRAMP)?	It was possible depending on a service. Quantitative indices by analysis of data like energy consumption, traffic. Qualitative indices from surveys for satisfaction level
Was it possible to measure the cost/benefit of the project? If so, what methodology did was used?	Completeness ratio compared to the project proposal
What are the ongoing KPIs/measurements to indicate the success of the project? Do these KPIs include maintenance and depreciation (life cycle costs)?	n/a
What one recommendation, documentation, or initiative would have made the Smart city	n/a

deployment experience simpler, faster, and/or more cost-effective?	
Are there any lessons learned that could be shared with any relevant standards organizations?	In this second year of the project, there has been improvements for service adoption by relevant organizations and discussion about change of operational organization.

B.3.1.2 Goyang Smart City

Property of project	Description
City and/or project name	Goyang Smart City
URL to project description/information	
City open data or open dashboard URL	
What is the city population?	Over 1,000,000
What is the scale of the project?	Citywide
Is it connected to neighboring (comparable) projects (whether formal or informally)?	Yes
If so, please provide a brief description.	They are using the oneM2M-based open platform from Busan smart city.
At what stage is the city project?	Full-scale roll-out providing service
Have there been any funding issues for the project? If so, what were they and how were they solved?	This is a five-year project that does not end with just a trial/pilot. Goyang city will run services brought by this project. To run them, city needs other funds/budget. That budget has been already included in the total project fund.
What are the KPIs for the project? How were they established? How were they evaluated?	User (citizens, public servants, etc.) satisfaction NOTE: other KPIs should be updated here
What are the key city systems involved in the project (housing, energy, health, mobility)? How were those partnerships/alignments facilitated?	Environment Proactive communication between pilot deployment companies and city department in charge of operation on business model selection, IoT/ICT technology analysis for problem statements, etc.
Are any community facilities involved? (hospital, home, school, park, clinic, etc.)	Kindergarten, school, metro stations are willing to be involved. However, operational organizations for them are different, so having a consensus is not easy. Therefore, in this pilot project, for example,

	they chose kindergartens that are run by the city not the private ones.
Are any key infrastructures involved? (roads, gas, electricity, water, communications, etc.)	Trash bins, street lights
Who are the key stakeholders (local authorities, businesses, agencies, citizens, etc.) and what are their roles? Are there any public or academic partnerships as part of this project?	City authority
What role does ICT play in the project? (technologies deployed, where, why)	ICT/IoT enables new functionalities to city facilities, gathers data, feeds data to policy makers, and lets third-party providers bring new services. Those technologies are used for sensing, network communication, platform-based control/actuation
How were technology choices made?	Vendor driven
Has the project made any specific technology choices based on "Technical Standards?"	Yes (describe in "If yes" below)
If yes, what are they?	oneM2M, LTE, NB-IoT
Are there any aspects of the project where good practice guidelines, certifications schemes, or standards would have helped and if so, how? How could available relevant standards, guidelines, or certifications have helped in areas of defining the project?	The other pilot cities are good references to Goyang smart city. They are trying to adopt standard technologies, if applicable, to expand services and invite new service providers.
Have there been any issues about ICT interoperability (e.g. connectivity / data / application)?	Communication models on devices were different. In this project, there is one that was chosen and deployed in the project.
If so, what were they? How have they been solved?	All data from this pilot will be publicly available by open API from public data portal.
Is there an open-data policy or requirement associated with this project? If so, how have those requirements been satisfied?	Laws regarding privacy protection and other operational regulations are being carefully adopted.
How has the project addressed the topics of data security and citizen privacy? Is this project subject to federal compliance regulations (e.g., FedRAMP)?	They will measure it with cost-benefit analyses.
Was it possible to measure the cost/benefit of the project? If so, what methodology did was used?	Service deployment completeness level that was listed in the project proposal. This also includes maintenance and depreciation aspects.
What are the ongoing KPIs/measurements to indicate the success of the project? Do these	n/a

KPIs include maintenance and depreciation (life cycle costs)?	
What one recommendation, documentation, or initiative would have made the Smart city deployment experience simpler, faster, and/or more cost-effective?	There are a lot of sensors in the market, but due to regulations/laws there are limited number of sensors. Some of them are expensive. To enable globally interoperable smart cities, standard-based sensors with proved performances.
Are there any lessons learned that could be shared with any relevant standards organizations?	issues like maintenance cost and installation permission made changes to some of requirements and goals.

B.3.1.3 San Juan Barataria Smart City Project

Property of project	Description
City and/or project name	San Juan Barataria Smart City Project (Trinidad and Tobago)
URL to project description/information	
City open data or open dashboard URL	
What is the city population?	Up to 100,000
What is the scale of the project?	District
Is it connected to neighboring (comparable) projects (whether formal or informally)?	Yes
If so, please provide a brief description.	Connected to projects in Port of Spain
At what stage is the city project?	Small-scale pilot project(s)
Have there been any funding issues for the project? If so, what were they and how were they solved?	Yes, however funding issues were resolved using public-private partnerships and commercializing the services delivered.
What are the KPIs for the project? How were they established? How were they evaluated?	Key performance indicators: Improved accessibility, increasing energy efficiency, reduced greenhouse gases, improved satisfaction with key life interfaces How established: Established as part of planning and design processes and interaction with targeted beneficiaries Evaluated:

	On an ongoing basis, accessing delivery, execution, impact, outcomes. Project assessed for effectiveness, efficiency, financial viability, and environmental targets.
What are the key city systems involved in the project (housing, energy, health, mobility)? How were those partnerships/alignments facilitated?	The key city systems involved include energy, health, housing, solid waste collection, or waste management services, as well as public transportation services, water management, and tourism Alignment was facilitated through a steering committee involving all public-private partnerships as members of a consortium using a facilitative approach to remove bureaucracy. A clearly defined team charter identified roles and responsibilities and terms of references for endeavor. Project was facilitated by a quality management consulting team called Five Star Quality and Justice Associates.
Are any community facilities involved? (hospital, home, school, park, clinic, etc.)	Yes, the project involves community centers, creation of parks and recreational facilities powered by renewables, steel pan theatres, and senior citizens' activity centers all connected through technologies deployed by TSTT and Digicel.
Are any key infrastructures involved? (roads, gas, electricity, water, communications, etc.)	Yes, water and telecommunications. The projects bring to life the national information communication technology strategy and plan. The project integrates renewable technologies throughout to reduce cost and create a new sustainability product and attraction by integrating with infrastructure in place.
Who are the key stakeholders (local authorities, businesses, agencies, citizens, etc.) and what are their roles? Are there any public or academic partnerships as part of this project?	Yes Education: The project has connected with the University of the West Indies, Advanced Solutions Technical Institute and the Evidenced-Based Quality Institute for the Caribbean (EQiC) to deliver training, vocational qualifications, and other technical expertise to execution of project. Caribbean Well Services Limited addresses all water management and sewage treatment issues in an integrated platform that allows the

	management of water to be itself an attraction and promotes efficiency in flood and other water management. United Energy Petroleum, Kaizen, and TrintoPlan are responsible to all testing, chemical analysis, environmental impacts, ecofriendly emergency equipment, and design cold fire and fireblock deployment. Five Star Quality and Justice Associates and Microsearch Ltd Project Management provide quality assurance, change and transition management, and alignment. This team was also responsible for financier sourcing and negotiations. Lexington Caribbean, Southern Logistics Ltd, Frankal & Associates, Kaido, and Parks Enterprises Logistics, aggregate construction and design. Beyond Insurance Services provide risk management and insurance brokerage. ASTI is responsible for all fiber network training, as well as labor supply to fiber deployment companies. Environmental Management Authority is responsible for certificate of environmental compliance approvals, monitoring impacts, and third-party validation. Ministry of Planning Ministry of Housing provides units on listing and offer to customers who get financing from national mortgage company. Village Council and Civil society groups share needs insights and participate in execution team.
What role does ICT play in the project? (technologies deployed, where, why)	ICT is deployed throughout the project and facilitates the interoperability of the various smart city technology solutions. It is deployed where the clients interface, at the points of waste

	collection, creation, disposal. The solution included free Wi-Fi in public spaces, buses, etc.
How were technology choices made?	Combination based on needs and the capability of technology to meet needs. A criterion was developed, and a decision matrix used. Five Star consultants led in survey development and in facilitating execution. Public procurement practices were also used. Inter-American Deployment Bank (IDB) procurement practices were also observed.
Has the project made any specific technology choices based on "Technical Standards?"	Yes (describe in "If yes" below)
If yes, what are they?	ISO 37120, 27000, 14000, and a wide range of EET and technical standards.
Are there any aspects of the project where good practice guidelines, certifications schemes, or standards would have helped and if so, how? How could available relevant standards, guidelines, or certifications have helped in areas of defining the project?	ISO 37120, ISO 9001:2015 Guidelines. ISO 26000 Social Responsibility. These helped scope the project.
Have there been any issues about ICT interoperability (e.g. connectivity / data / application)?	Yes, on network capacity. Resolved by working with providers to deploy expandable solutions upfront and deploying fiber optic technology throughout. Improving use of the government communication backbone and using it as a basis to bring more interactive electronic services to customers in the community. They also expanded the deployment of TTconnect centers to community.
If so, what were they? How have they been solved?	This is one of our greatest challenges. The whole issue of cybersecurity is a challenge. Currently laws are being reviewed addressing open data and cybersecurity issues and challenges.
Is there an open-data policy or requirement associated with this project? If so, how have those requirements been satisfied?	The project has address cybersecurity in pragmatic ways (e.g., leaving security of device up to users to protect on platform, deploying generic protections and controls, working on legislation to address cybersecurity and compulsory response to server information

	request). The project is subject to all laws of Trinidad and Tobago.
How has the project addressed the topics of data security and citizen privacy? Is this project subject to federal compliance regulations (e.g., FedRAMP)?	Yes Cost of Quality Activity-based costing and cost-benefit analysis They have also used a series of feedback surveys addressing key indicators.
Was it possible to measure the cost/benefit of the project? If so, what methodology did was used?	Yes, but KPIs are reviewed according to the specific objectives and according to the areas identified as key result areas. They identified effectiveness indicators, efficiency indicators, viability indicators, and environment indicators. A scorecard is kept and maintained electronically and adjusted as monitoring information is tracked and entered. Monitoring data enters the system continually, but evaluation takes place once every quarter, and all information is reviewed and evaluated against the criteria and objectives. It is not merely a matter of checking off on a check box of indicators, as indicators may interact to gives us impact or outcomes desired. It's all about managing.
What are the ongoing KPIs/measurements to indicate the success of the project? Do these KPIs include maintenance and depreciation (life cycle costs)?	One recommendation Use a process approach throughout and take time to complete a macro-level diagram of inputs, major processes, outputs, measures, interfaces, competencies, and resources necessary. This step helped all from varying backgrounds to get on the same page and explained the project in terms understood by all. A second recommendation would be to get professional help to design and align initiative early.
What one recommendation, documentation, or initiative would have made the Smart city deployment experience simpler, faster, and/or more cost-effective?	Smart cities go beyond using ICT to effectively use resources to create value. For some it may mean ICT, but for others it can mean using the environment effectively. As such. they must allow cities to determine "smart" and define standards that allow for organic development based on their mission, purpose, and capability. Essentially, don't make it about technology but about smart application and adding value.

Are there any lessons learned that could be shared with any relevant standards organizations?	Yes, both requirements and PPIs change over time, as new methods also affect design and other changes as they evolve. Project is created with sufficient dynamism to allow for change without affecting robustness and ability to achieve outcomes.

B.3.1.4 Montgomery County, Maryland

Property of project	Description
City and/or project name	Montgomery County, Maryland
URL to project description/information	
City open data or open dashboard URL	http://data.montgomerycountymd.gov
What is the city population?	Over 1,000,000
What is the scale of the project?	Citywide
Is it connected to neighboring (comparable) projects (whether formal or informally)?	Yes
If so, please provide a brief description.	They are in the early stages of identifying funding sources for a joint air quality initiative with Washington, DC. They are also funded to replicate one of the projects in Pittsburgh, PA.
At what stage is the city project?	Small-scale pilot project(s)
Have there been any funding issues for the project? If so, what were they and how were they solved?	There have been and continue to be funding issues for the projects. They rely on corporate partners and federal grants to move the work along.
What are the KPIs for the project? How were they established? How were they evaluated?	Yes, they are based on the CountyStat headlines measures.
What are the key city systems involved in the project (housing, energy, health, mobility)? How were those partnerships/alignments facilitated?	Public safety, agriculture, and transportation are the current key systems. This was facilitated, because the program helping to coordinate these measures is part of the Office of the County Executive.
Are any community facilities involved? (hospital, home, school, park, clinic, etc.)	Yes, many.
Are any key infrastructures involved? (roads, gas, electricity, water, communications, etc.)	Transportation and public safety infrastructures.

Who are the key stakeholders (local authorities, businesses, agencies, citizens, etc.) and what are their roles? Are there any public or academic partnerships as part of this project?	These projects participate in the Global Cities Team Challenge and the MetroLab Network. As such, all of them have an academic/research component.
What role does ICT play in the project? (technologies deployed, where, why)	They use a diverse set of ICT resources in all parts of the architecture.
How were technology choices made?	City driven
Has the project made any specific technology choices based on "Technical Standards?"	Yes (describe in "If yes" below)
If yes, what are they?	
Are there any aspects of the project where good practice guidelines, certifications schemes or standards would have helped and if so, how? How could available relevant standards, guidelines, or certifications have helped in areas of defining the project?	
Have there been any issues about ICT interoperability (e.g., connectivity, data, application)?	
If so, what were they? How have they been solved?	
Is there an open-data policy or requirement associated with this project? If so, how have those requirements been satisfied?	
How has the project addressed the topics of data security and citizen privacy? Is this project subject to federal compliance regulations (e.g., FedRAMP)?	Not at this time.
Was it possible to measure the cost/benefit of the project? If so, what methodology did was used?	https://reports.data.montgomerycountymd.gov/countystat
What are the ongoing KPIs/measurements to indicate the success of the project? Do these KPIs include maintenance and depreciation (life cycle costs)?	Having consistent funding during the project
What one recommendation, documentation, or initiative would have made the Smart city deployment experience simpler, faster, and/or more cost-effective?	No
Are there any lessons learned that could be shared with any relevant standards organizations?	No

B.3.2 Property Set Two

Several smart city deployments were reviewed according to some key identified aspects as another means of understanding the challenges to achieving them. They are provided in this appendix.

The data is organized as a series of results of addressing the following set of questions:

- What were the technical standards for service platform, data model, and/or connectivity? What are the benefits to using that technical standard?
- What are the shortcomings of that technical standard in terms of smart city?
- What are the biggest portions of total deployment costs?
- What regulations/laws/etc. need to be changed/supported by government/municipality?
- How long does the project take? (assuming commercialization after the project)
- Is this a pilot project or already partially/fully commercialized? if commercialized, who runs the system/services?
- Does the city provide open-data API to be used by third-party applications? if yes, provide some examples.
- What were difficulties during deployment?
- Was there any reference smart city?

B.3.2.1 Busan, South Korea

Property of project	Description
What were the technical standards for service platform, data model, and/or connectivity?	Communications between devices and platform adopted oneM2M Release 1 standards.
What are the benefits to using that technical standard?	Service-specific platforms were merged into one, which provides the same specifications to integrate services and

	devices. It is expected to reduce operating costs later, too.
What are the shortcomings of that technical standard in terms of smart city?	It takes time for device and application developers to understand specifications and get enough implementation skills.
What are the biggest portions of total deployment costs?	Platform deployment and operation cost for pilot service support center
What regulations/laws/etc. needs to be changed/supported by government/municipality?	Law/act on ICT convergence facilities and services, ordinance on parking lots, amendment for technical standards
How long does the project take? (assuming commercialization after the project	May 2015 to November 2017 (30 months)
Is this a pilot project or already partially/fully commercialized? if commercialized, who runs the system/services?	No. When the pilot project is completed after Nov. 2017, Busan city government will continue to operate the system and services. So far it is being done by the project consortium.
Does the city provide open data API to be used by third-party applications? If yes, provide some examples.	-> open data portal is up and running (http://data.k-smartcity.kr). all the data of the services (e.g. parking, street light, traffic) is being provided.
What were difficulties during deployment?	Discussion and approval from the city government and public agencies for deployment. Discussion on sustainability planning.

Was there any reference smart city?	T-City test bed in Friedrichshafen, Germany; Santander, Spain; Amsterdam, Netherlands; Barcelona, Spain; etc.

B.3.2.2 Goyang, South Korea

Property of project	Description
What were the technical standards for service platform, data model, and/or connectivity?	oneM2M global IoT standard
What are the benefits to using that technical standard?	convenience and rapidity for IoT service development.
What are the shortcomings of that technical standard in terms of smart city?	Time for education of developers and protocol dependency
What are the biggest portions of total deployment costs?	Cost of personnel and materials
What regulations/laws/etc. needs to be changed/supported by government/municipality?	
How long does the project take? (assuming commercialization after the project	Two years (2016 to 2017)

Is this a pilot project or already partially/fully commercialized? if commercialized, who runs the system/services?	
Does the city provide open data API to be used by third-party applications? If yes, provide some examples.	Open-data API is provided (https://data.smartcitygoyang.kr)(e.g., quality of public water supply, parking, public bicycles, kindergardens, etc.)
What were difficulties during deployment?	Complying with relevant laws and regulations
Was there any reference smart city?	Barcelona, Spain; New York City

Appendix C. Technologies Analyzed

For each of a set of prominent smart city technologies, this section provides a brief overview of their capabilities and maturity. Of course, this is by no means a complete list. Indeed, it is anticipated that proponents of other technologies will find this presentation compelling and add to the library of analyses to further enrich an emerging set of PPI.

For each technology set contributed for the IES-City Framework, the proponents provide a summary in this section and their concerns spreadsheet. The spreadsheets are organized into tabs that allow for separate analysis of requirements and solutions at either the northbound, southbound, or both ZofC interfaces.

The technology sets and text are those provided by their specifying organizations. This was done to ensure that the description and analysis represented their opinion and not that of an external researcher. The IES-City Framework envisions this set of data to be "evergreen," adding analyses and descriptions as additional providers provide their work. Those incorporated into this document version are those that were made available to date.

C.1 oneM2M

oneM2M, a global partnership project involving eight regional standards development organizations (SDOs) for common IoT service layer platform, has been demonstrated in smart cities such as Busan, Goyang, and Daegu from South Korea. In 2017, the oneM2M white paper for smart cities, "Smart Cities Done Smarter" [http://www.onem2m.org/images/files/oneM2M_WhitePaper_SmartCitiesDoneSmarter.pdf] , was published. This paper explains the benefits of adopting oneM2M as a smart cities base technology. By nature, smart cities consist of different services/systems/technologies, and the real strength of oneM2M is that it can serve as the system for horizontal IoT middleware.

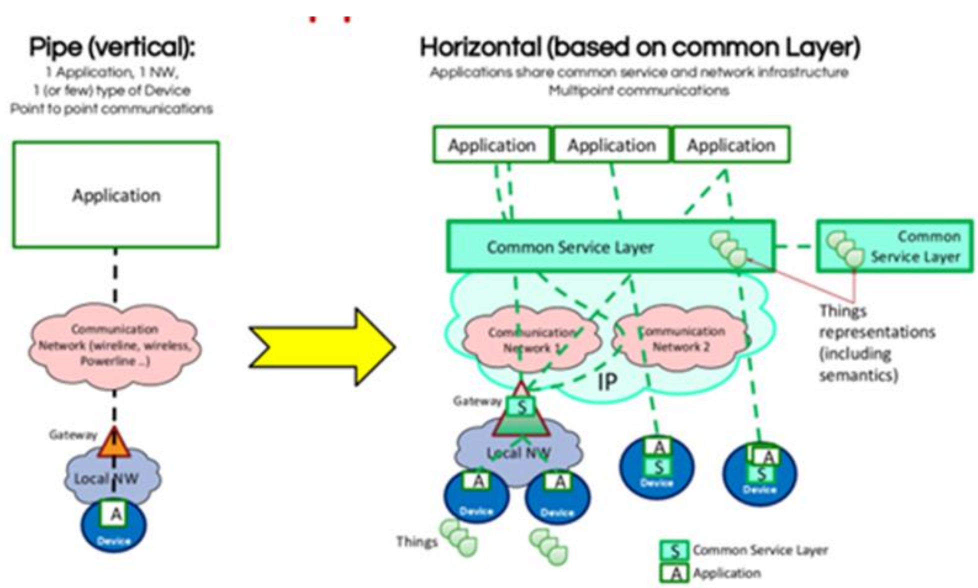

Figure 22: oneM2M High-Level View

In the specifications, oneM2M does not specify device northbound and southbound interfaces. Most of the APIs can be used in either case, so this analysis focuses on several API sets which are more relevant to one case.

For both, as the fundamental features of a smart city platform, oneM2M provides security and data exchange. The security features cover basically authentication, authorization, etc. Especially, oneM2M provides reach authorization schemes that will benefit different services. For data exchange, oneM2M supports historical data and time series data, which can be useful for back-end system integration like big data analysis.

To highlight southbound specific features, interworking with existing technology should be the most important one. For example, to manage field devices, oneM2M middleware provides LwM2M device interworking. This means that administrative applications still use oneM2M APIs to manage LwM2M devices already deployed in the field. This shows how existing devices can be integrated with the oneM2M system in smart cities. oneM2M interworking also covers OCF, OMA DM, and BBF TR-069. Several research studies show that there will be many more IoT devices using cellular communications. To enable this, oneM2M provides 3GPP network interworking technologies as well.

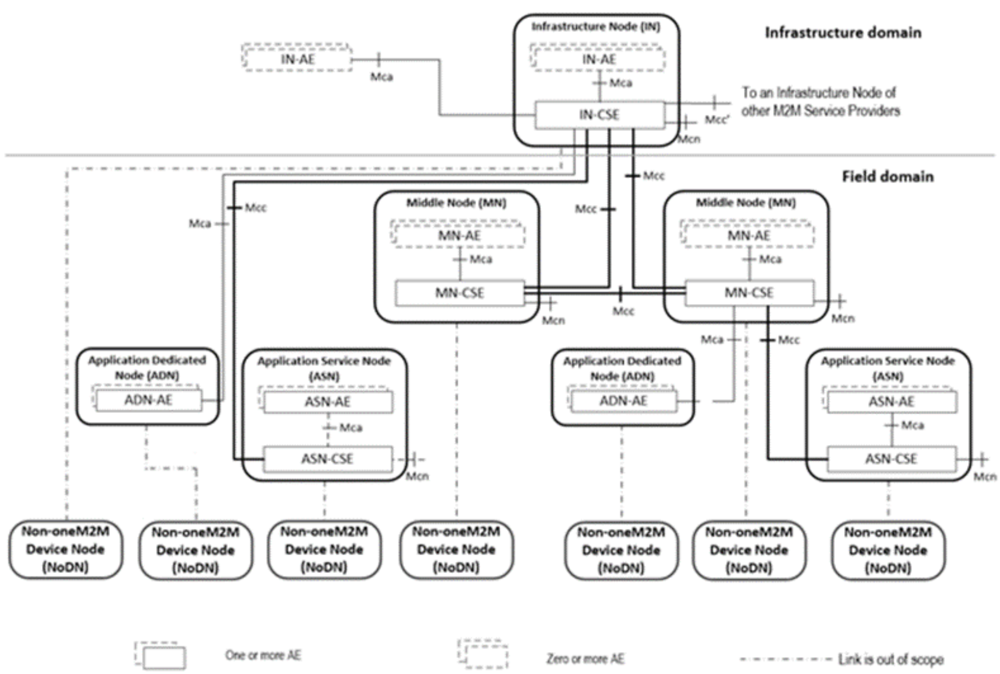

Figure 23: oneM2M Domain Interaction Model

Regarding the northbound APIs, semantics could be the prominent feature for smart city services. Semantic discovery, query, and mashup from oneM2M middleware, cross-domain services can be easily available. Analytics of different data sets should be possible, too. Another northbound-specific API is charging and accounting. The oneM2M server can log platform usages of applications and record them in standard format for accounting. This can be used to enable the oneM2M system as part of a data marketplace.

There are a rich set of northbound-specific APIs of oneM2M. For instance. subscription/notification and group management have been basic features since the first release. Recently, in release 3 specifications, other features, such as transaction management, are also supported.

Finally, oneM2M provides an official certification program that ensures conformance as well as interoperability among oneM2M-based products. This program is a useful benefit for those considering oneM2M as a candidate technology.

C.2 FIWARE

The figure below depicts the Smart City Reference Architecture proposed by the FIWARE Foundation.

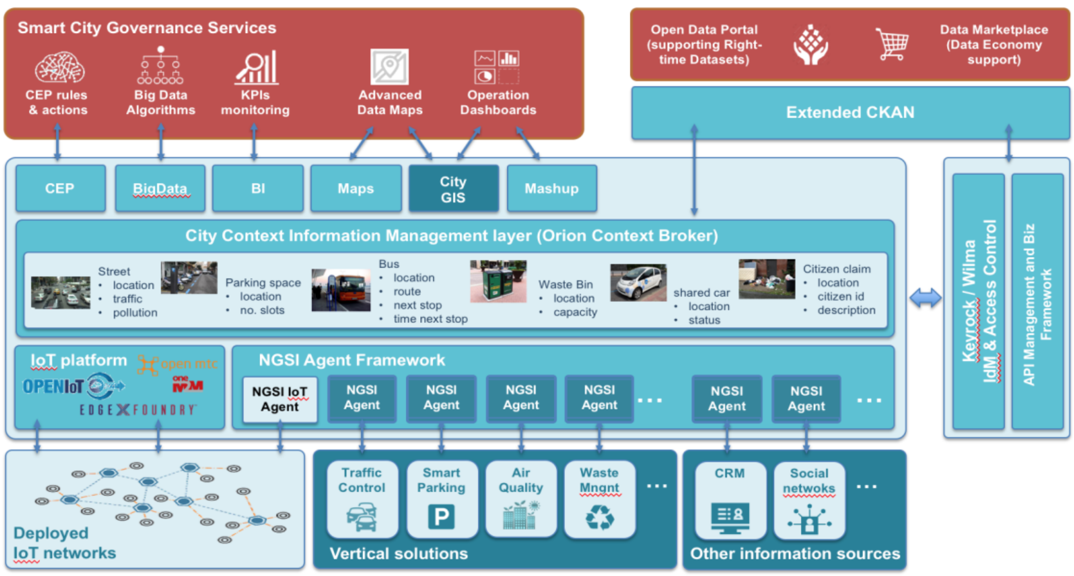

Figure 24: Smart Cities Reference Architecture Powered by FIWARE

The cornerstone component in the proposed Reference Architecture is a FIWARE-compliant Context Broker component. This component supports interfaces:

- Southbound: to IoT networks and different vertical smart city services management solutions deployed by the city, as well as to other information sources such as the city's CRM (Citizen Relationship Management) systems or social networks (Twitter, Facebook, …), thus gathering valuable context information from them. These systems may, in turn, also consume context information published by the Context Broker in order to trigger different actuations.
- Northbound: providing context information to smart city governance systems. These systems may, in turn, enrich context information through this interface (e.g., making insights derived from big data analysis available as context information).
- Eastbound: to other cities and third parties for the exchange of context information.

Context information managed through the Context Broker provides a holistic picture of what is going on in the city at any time. The Context Broker exports the FIWARE NGSIv2 API through all these interfaces, enabling it to gather updates on, or get access to, context information in real-time. This API is experiencing a growing adoption.

Multiple implementations of the Context Broker component can exist as far as they provide an API that is in compliance with the public and royalty-free FIWARE NGSIv2 API specifications. The FIWARE Community has developed and evolves an open-source reference implementation of the Context Broker named Orion.

Multiple products can be plugged and played together with the Context Broker component in a smart city reference architecture powered by FIWARE. They interface with the Context Broker using the FIWARE NGSI API. Members of the FIWARE Open Source Community contribute open-source platform products implementing several functions (big data analysis, complex event processing, business intelligence analytics, etc.) that come with modules enabling an easy integration with any FIWARE-compliant Context Broker product. Some of them rely on well-known open source platform products (e.g., Hadoop, Spark, etc.). These platform products are then considered FIWARE Generic Enablers supported by the FIWARE Community. Connection to the IoT can be implemented through FIWARE Generic Enablers provided by the FIWARE Community or by using alternative IoT platforms for which modules implementing integration through FIWARE NGSI are available.

The FIWARE Community has developed FIWARE Generic Enablers enabling enforcement of policies for controlling access to context data resources through the FIWARE NGSI API. Extensions to CKAN (one of the most widely used open-data publication platforms) have also been developed to bring support to the publication of real-time context information resources and related access control policies, thus enabling the transition from Open Data to real-time Open Data. Additional CKAN extensions, combined with FIWARE Generic Enablers supporting accounting and rating of FIWARE NGSI API calls, enable the monetization of city context data, enabling the transformation of cities into platforms for the data economy.

C.3 CVRIA Description for IES-City Framework

The U.S. Department of Transportation (USDOT) has researched and developed connected vehicle technology, which allows vehicles to communicate with each other, roadway infrastructure, traffic management centers, and travelers’ mobile devices. To ensure that this revolutionary technology is effective, the USDOT created the Connected Vehicle Reference Implementation Architecture (CVRIA), which establishes a framework for the integration and standardization of connected vehicle technologies.

The CVRIA forms the basis for a common language definition and early deployment concepts for connected vehicles. The architecture identifies key interfaces across the connected vehicle environment and prioritizes standards development activities. The CVRIA and its associated Systems Engineering Tool for Intelligent Transportation (SET-IT) support initial deployments and integration activities by taking different developments and research projects and illustrating how they all fit together.

The CVRIA also supports policy considerations for certification, standards, core system implementation, and other elements of the connected vehicle environment.

Because there are so many types of applications and underlying system definitions, an approach was defined to develop a System Architecture based on the fundamentals of ISO/IEC/IEEE 42010:2011, a standard for "Systems and software engineering — Architecture description." This includes steps to define, not just data and messages, but the full environment in which the stakeholder concerns are satisfied. This includes understanding the functionality; the high-level physical partitioning that may be required or that may be supported as alternative configurations; the enterprise or institutional relationships that will govern how those systems are deployed and used; and the communications protocols that are necessary for those interfaces to work. An architecture like this becomes a framework for developers, standards organizations, and implementers to all use as a common frame of reference for developing the eventual systems.

The CVRIA is a singular architecture composed of four viewpoints, each providing a different perspective to understand the architecture:

- **Enterprise:** Describes the relationships between organizations and the role that each organization plays within the connected vehicle environment.
- **Functional:** Describes abstract functional elements (processes) and their logical interactions (data flows) that satisfy the system requirements.
- **Physical:** Describes physical objects (systems and devices), application objects, and the high-level interfaces between these physical objects.
- **Communications:** Describes the layered sets of protocols that are required to support communications among the physical objects that participate in the connected vehicle environment.

Since the development of CVRIA, it has been the basis for early deployments in New York City, Wyoming, and Tampa, Florida. The tools provided by the architecture have served to identify interoperability issues among the different deployments.

In 2017, the US DOT merged CVRIA into the larger National Intelligent Transportation Architecture to create one complete "Architecture Reference for Cooperative and Intelligent Transportation" (ARC-IT). This ARC-IT reference architecture is available on-line at www.arc-it.net.

C.4 OpenIoT

The OpenIoT Architecture is comprised by seven main elements as depicted in Figure 25:

- **The Sensor Middleware (Extended Global Sensor Network, X-GSN)** collects, filters, and combines data streams from virtual sensors or physical devices. It acts as a hub between the OpenIoT platform and the physical world. The Sensor Middleware is deployed on the basis of one or more distributed instances (nodes), which may belong to different administrative entities. The prototype implementation of the OpenIoT platform uses the GSN (Global Sensor Networks) sensor middleware[1] that has been extended and called X-GSN (Extended GSN). Furthermore, a mobile broker (CUPUS middleware) is also used for the integration of mobile sensors and data streams to the IoT cloud.

- **The Cloud Data Storage (Linked Stream Middleware Light, LSM-Light)** enables the storage of data streams stemming from the sensor middleware, thereby acting as a cloud database. The cloud infrastructure stores also the metadata required for the operation of the OpenIoT platforms (functional data). In addition to data streams and metadata, the cloud could also host computational (software) components of the OpenIoT platform (e.g., the Scheduler and SD&UM outlined below) in order to benefit from the elasticity, scalability, and performance characteristics of the cloud. The prototype implementation of the OpenIoT platform uses the LSM Middleware[2], which has been re-designed with push-pull data functionality and cloud interfaces for enabling additional cloud-based streaming processing.
- **The Scheduler** processes all the requests for on-demand deployment of services and ensures their proper access to the resources (e.g., data streams) that they require. This component undertakes the following tasks: it discovers the sensors and the associated data streams that can contribute to service setup; it manages a service; and it selects/enables the resources involved in service provision.
- **The Service Delivery and Utility Manager** performs a dual role. On the one hand, it combines the data streams as indicated by service workflows within the OpenIoT system to deliver the requested service (with the help of the SPARQL query provided by the Scheduler). To this end, this component makes use of the service description and resources identified and reserved by the Scheduler component. On the other hand, this component acts as a service-metering facility that keeps track of utility metrics for each individual service. This metering functionality will be accordingly used to drive functionalities such as accounting, billing, and utility-driven resource optimization. Such functionalities are essential in the scope of a utility (pay-as-you-go) computing paradigm, such as the one promoted by OpenIoT.
- **The Request Definition** component enables on-the-fly specification of service requests to the OpenIoT platform. It comprises a set of services for specifying and formulating such requests, while also submitting them to the Global Scheduler. This component may be accompanied by a GUI (Graphical User Interface).
- **The Request Presentation** component is in charge of the visualization of the outputs of a service that is provided within the OpenIoT platform. This component selects mash-ups from an appropriate library in order to facilitate service presentation. It is expected that service integrators implementing/integrating solutions with the OpenIoT platform are likely to enhance or even override the functionality of this component on the basis of a GUI pertaining to their solution.

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[1] Karl Aberer, Manfred Hauswirth, Ali Salehi: Infrastructure for Data Processing in Large-Scale Interconnected Sensor Networks. MDM 2007: 198- 205.

[2] https://github.com/OpenIotOrg/openiot/wiki/Data-platform-(lsm)

- **The Configuration and Monitoring** component enables management and configuration of functionalities over the sensors and the (OpenIoT) services that are deployed within the OpenIoT platform. It is also supported by a GUI.

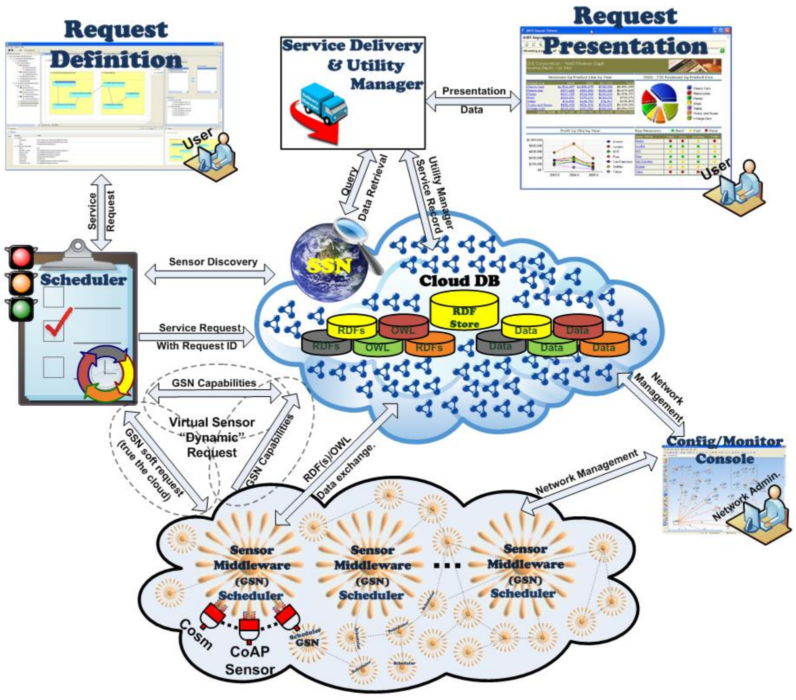

Figure 25: Overview of OpenIoT Architecture and Main Components

Given these components, a complete example of the platform's data and service flow is as follows:

- X-GSN nodes are "announcing" the available virtual sensors to the Directory Service and start to publish their data in SSN-compliant RDF format based on each X-GSN local configuration.
- A User requests from the Scheduler all the available sensor types that satisfy specific attributes (coordinates and radius) by using the Request Definition UI from the Directory Service. The request is sent to the Scheduler service.
- The Scheduler executes a combination of queries (SPARQL) to fulfill the previously user-specified query provided by the previous step. Accordingly, the Directory Service retrieves the data and replies back to the Scheduler with the available sensor types.
- The reply is forwarded to the Request Definition UI from the Scheduler and the retrieved information is provided to the User. The User, with the help of Request Definition UI, defines the request by implementing rules, provided by the tool, over the reported sensor types. This information, along with execution and service presentation preferences, is then pushed to the Scheduler. Accordingly, the Scheduler analyzes the received information and sends the request to the Directory Service.
- After having configured the request, the User is able to use the Request Presentation UI for visualizing a registered Service's data. In particular, through Service Delivery and Utility

Manager (SD&UM), all the registered applications/services related to a specific User are made available to the user. The user can select a specific service to be executed and visualized through the SD&UM and the Request Presentation components. The execution of the service corresponds to a collection of SPARQL scripts, which have been created by the Request Definition UI and stored by the Scheduler to the Directory Service SPARQL interface.

C.5 E015

The E015 Digital Ecosystem initiative (http://www.e015.regione.lombardia.it) was established in 2010 by major Italian associations of industries and companies (Confindustria, the Chamber of Commerce of Milan, Confcommercio, Assolombarda, and Unione del Commercio). The E015 reference model was conceived by Cefriel, since then in charge of the scientific coordination and evolution of the Ecosystem. In 2011, Expo 2015 S.p.A. became a full partner of the initiative. In 2013, the E015 Digital Ecosystem was publicly launched. In 2015, the Regional Government of Lombardy replaced Expo 2015 S.p.A. as the organization in charge of managing the E015 Digital Ecosystem and extended the duration of the initiative to 2021. In 2017, the E015 Digital Ecosystem became part of a regional law in Lombardy, as a strategic reference initiative promoting a “digital first” approach for assets sharing.

Thanks to common interoperability standards and participation processes (E015 guidelines), E015 Digital Ecosystem members, who have signed a free contract, can play two different roles:

- **Sharing E015 APIs**, describing their own APIs in terms of both functionalities and usage policies, in order to share their digital assets to unlock additional business value from them. The E015 APIs are validated by a Technical Management Board, and are listed into a catalog, in order to promote E015 APIs discovery.
- **Building E015 Apps**, enriching value-added integrated solutions for the end-users, asking for the E015 APIs listed into the E015 APIs catalog. Two examples of E015 Apps are the official Regional Government of Lombardy web app (http://www.l15.regione.lombardia.it) or the info-mobility portal of the Municipality of Milan (https://www.muoversi.milano.it/).

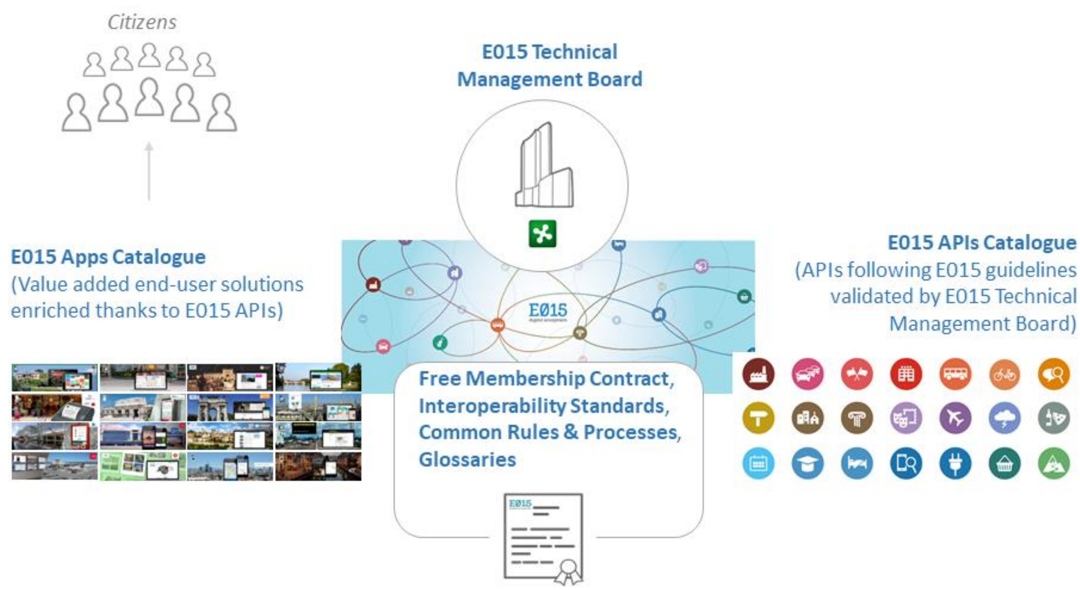

Figure 268: E015 Structure

C.6 Amazon

As a global, hyperscale cloud service provider (CSP), Amazon Web Services (AWS) takes a rigorous, risk-based approach to the security of our (IoT) services and the safeguarding of customer data. We enforce our own internal security assurance process on all our cloud services to evaluate the effectiveness of the managerial, technical, and operational controls necessary for protecting against current and emerging security threats impacting our security and resiliency. This mandatory security assurance process results in real security benefits and attests to our commitment to embed security throughout all phases of the development and operational processes of our services lifecycle. AWS offers hyperscale commercial cloud services that have been accredited against leading internationally recognized standards, such as FedRAMP Moderate and High, International Standards Organization 27001, Payment Card Industry Data Security Standard, and the Service Organization Control Reports, among other international, national, and sectoral authorizations. AWS is also the only hyperscale CSP that meets the rigorous security requirements supporting the classified environments of the intelligence agencies. Taken together, customers in any sector and of any size using AWS cloud services achieve security benefits by proxy because we apply the “high watermark” across all our services.

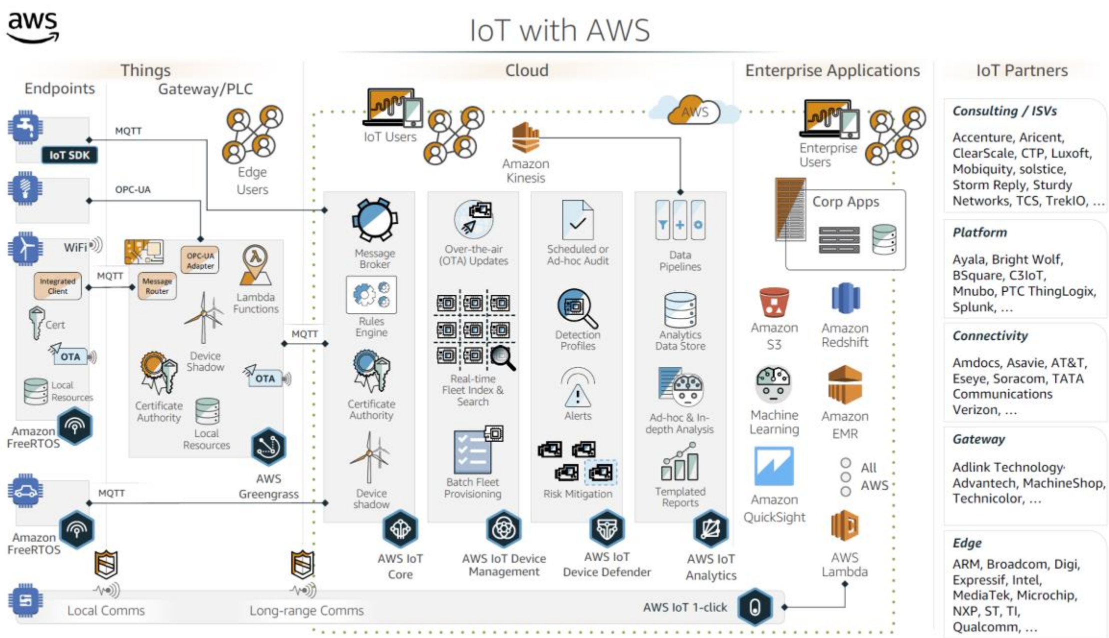

Figure 279: IoT with AWS

C.6.1 End-to-end Security as a Facilitator of IoT Adoption

The interconnectivity and interdependencies of “things” mean that organizations adopting IoT need to combine a breadth of sophisticated, individual components to achieve a holistic approach to, and view of, security. Achieving this can be challenging for most organizations because different players (e.g., device manufacturers, telecommunications companies, application developers, etc.) assume different roles and scope of responsibility in the IoT ecosystem. A competing dynamic for IoT security is the lifecycle of a physical device and the constrained hardware for sensors, microcontrollers, actuators, and embedded libraries. These constrained factors may limit the security capabilities each device can perform. With these additional dynamics, IoT solutions must continuously adapt their architecture, firmware, and software to stay ahead of the changing security landscape. The inherent “sum of the parts” composition of IoT can lend itself to a piecemeal security approach that is highly challenging due to the numerous players, parts, and connection points involved.

Securing such a matrixed technology environment is achievable by leveraging end-to-end solutions that can facilitate what may otherwise appear as an intimidating task. The foundation of an IoT solution should start and end with security. Because devices can send large amounts of sensitive data through the Internet and end users are empowered to directly control a device, the security of things must permeate every layer of the solution. AWS offers a suite of IoT services with end-to-end security in mind. As detailed in our technical comments, our offerings include services to operate and secure endpoints, gateways, platforms, and applications including the traffic traversing across these layers.

For instance, AWS IoT Core[3] provides authentication and end-to-end encryption throughout all points of connection, so that data is never exchanged between devices and AWS IoT Core without proven identity. AWS IoT Device Management[24] is a service that makes it easy to securely onboard, organize, monitor, and remotely manage large deployments of IoT devices across many locations and throughout their lifecycles to include updating device software over-the-air (OTA). AWS IoT Device Defender is a fully managed service that helps you secure your fleet of IoT devices. AWS IoT Device Defender continuously audits the security policies associated with your devices to make sure that they aren't deviating from security best practices.[5] The seamless integration of solutions simplifies secure end-to-end use and management of devices and data that constantly interact with each other via the Internet.

C.6.2 Open, Standards-based Approach as a Promoter of Interoperability

AWS supports NIST's open and standards-based approach to promote IoT adoption. When considering the billions of devices and connection points necessary to support a robust IoT ecosystem for consumer, industrial, and public-sector use, interoperability is vital. AWS IoT services adhere to industry standard protocols and best practices, which means that while we provide end-to-end capabilities, we are not creating self-serving restrictions to AWS protocol-only offerings. In fact, AWS IoT Core also supports other industry-standard and custom protocols, allowing devices to communicate with each other even if they are using different protocols. AWS is a strong proponent of interoperability, which is a foundational building block for a vibrant IoT ecosystem. Our services are extensible so that developers can build on top of existing platforms to support customers' evolving needs. We support a thriving partner ecosystem to expand the menu of choices and stretch the limits of the "art of the possible" for our customers as we work alongside other innovators and service providers.

C.6.3 Scalability as an Enabler of the "Art of the Possible"

Along with an exponential growth of connected devices, each thing in IoT communicates packets of data that require reliable connectivity and durable storage. Prior to cloud computing, IT departments would procure additional hardware and maintain underutilized, overprovisioned capacity in order to handle the increasing growth of telemetry emitted by devices. With IoT, an organization is challenged with managing, monitoring, and securing the immense number of network connections from these dispersed, connected devices.

This challenge is no longer a roadblock in a cloud-based environment. In addition to scaling and growing a solution in one regional location, cloud computing enables IoT solutions with the ability to scale globally and across different physical locations. IoT solutions can be deployed in multiple physical locations to meet the business objectives of a global enterprise solution and

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[3] https://aws.amazon.com/iot-core/

[4] https://aws.amazon.com/iot-device-management/?nc2=h_l3_ap

[5] https://aws.amazon.com/iot-device-defender/

lower communication latency for better responsiveness from devices in the field. Many IoT projects today are deployed as pilots and limited in scope mainly due to the complexities and costs associated with a large- scale deployment. This in turn can lead to a more significant risk of failure, which perpetuates the cycle of small-scale projects that do not adequately stress test the capabilities (and limits) of ubiquitously connected devices at city-scale.

The native capabilities and security of cloud computing—including on-demand scalability to meet workload surges, a cost-effective and pay-as-you-go use model, and reliable and resilient computing infrastructure—are among the key benefits that shift the prototype paradigm from "risk of failure" to "missed opportunity." We look forward to collaborating with NIST and other IoT partners to pilot at-scale, if not large-scale, initiatives to get advanced capabilities into the hands of public sector organizations whose mission is to protect and serve their citizens and communities.

C.6.4 Global Applicability as a Catalyst for Broad Use

Establishing globally applicable best practices carries several benefits across all IoT stakeholders including:

- Repeatability and reuse, instead of re-starting and re-doing
- Consistency and consensus to promote the compatibility of technology and interoperability across geographical boundaries
- Streamlining and harmonizing what could otherwise be competing standards or asynchronous country-specific processes
- Maximizing efficiencies to accelerate IT modernization and civic transformation

Governments can impede IoT adoption and its transformational benefits with incompatible or conflicting standards or governance models. The emphasis on global applicability, therefore, must remain central to the discussion, and in particular, the development of this Framework.

AWS is doing its part to bridge the gap to sophisticated, state-of-the art IT services through our "AWS Marketplace for Smart City Solutions"[4] launched in collaboration with NIST's Global City Teams Challenge. This marketplace of smart city solutions gives governments at all levels access to test and adopt vetted, ground-breaking technologies to support city goals around energy efficiency, air quality, intelligent transportation, public safety, public health, and other programs focused on improving quality of life for citizens. AWS has worked with cities around the world including the New York City Department of Transportation, Singapore Land Transit Authority, and Kansas City[5] to increase operational efficiencies, reduce traffic fatalities, and improve natural disaster preparedness and recovery, among other benefits attained.