

A Consensus Framework for Smart City Architectures



IES-City Framework

(Internet-of-things Enabled Smart City Framework)

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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. The 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 which inhibit widespread deployment of effective, powerful smart city solutions:

1. Inadequate information and knowledge transfer: Most smart city deployments are based on custom systems which 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[5]. There is a lack of consensus on both a common language/taxonomy and smart city architectural principles [67]. 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 [51].

Additional barriers include lack of resources, 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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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.
– UrbanTide and Scottish Government, 2014 [100]”

A smart city 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 existed before [59]. Achieving that vision requires moving beyond many current implementations in which the degree of integration of core subsystems within smart cities is often limited by patchworks of legacy and fixed solutions connected by custom integrations. This public working group sought to benefit from lessons learned by pioneers of smart city implementations to distill a composable Smart City Framework [60][66][57]. This framework is intended to facilitate the emergence of Interoperable, Composable, and Harmonized technologies that can be used to realize the vision.

“Interoperable” implies the ability to substitute or integrate parts from a diverse economy of offerings. As the reader will see in the descriptions of the CPS Framework described in section 4.2.2 CPS Framework, there are many measures by which interoperability must be achieved. Each concern of a stakeholder that a given technology can address represents another dimension of interoperability.

“Composable” implies that continuous integration and improvement should be achieved through graceful addition of functions as opposed to wholesale replacement or substantial re-engineering. 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 [49].

“Harmonized” technologies can make compatible the incompatible. From offerings in different domains to those designed in different standards bodies, the ability of different specifications to result in interoperable and complementary solutions are essential to achieve the other two goals of the framework.

The principle goal of this framework is to provide useful tools to enable stakeholders of smart city implementation projects to perform more and faster implementations through lowered barriers to interoperability. It 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. “Pivotal Points of Interoperability (PPI)” and “Zones of Concern (ZofC)” are concepts introduced in this framework that provide means to lower barriers to interoperability between the various ecosystems currently being deployed.

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 [58]. 80% of critical infrastructure in the US is owned by industry [34]. These have national security implications.

80% of critical infrastructure in the US is owned by industry [34]. These have national security implications.

The recent progress of applications in smart cities has been explosive. In just one example, this is evidenced by the large engagement achieved in NIST’s Global City Teams Challenge (GCTC) [31]. There are many teams of implementers and cities pioneering applications all over the globe. There are also many consortia and standards organizations developing frameworks of various scopes appropriate for Smart City integrations [40]. These groups would benefit from the ability to work together through a common language and shared architectural principles.

As well as industry interest, governments have a keen desire to benefit from the efficient integration of “smart” into their cities. A recent report [32] predicts that by 2018, twenty 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 Office of Science and Technology Policy recently announced a “Smart Cities Initiative to Tackle City Challenges with Innovative Approaches.”[4] 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 [62][52][64][56].

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How

To meet the needs of all stakeholders, therefore, this public working group is a *technology and business model neutral* forum for capturing 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;
- comprised of technical experts and stakeholders from industry, academia, and government worldwide;
- made its deliverables freely available on the web [32];
- held regular working meetings virtually 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 [31] that encourages “action clusters” to form and collaborate to demonstrate technologies at city scale, and the NIST CPS Framework [1] 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 (PPI) (see inset to the right).

To determine these PPI the participants reviewed the following:

- Analysis of current architectures
- Success stories about how seamless integrations and portability of applications across cities were achieved
- Standards that support the modular integration of function at city scale
- Standards that support updates, publication and access to information coming from different sources describing what is going on in the city
- Best practices on how to integrate PPI into existing infrastructures
- Educational materials and tools that facilitate consumer/commercial understanding and usage of smart city capabilities and technologies

A corollary concept to PPI is that of Zones of Concern (ZofC). ZofC allow for the emergence of service providers which can offer a bundle of services that allow the concerns represented by one or more PPI to be addressed. For example, a common authentication service, third party authorization service, and privacy enhanced data exchange can comprise a ZofC service offering.

Pivotal Points of Interoperability

If you standardize everything, you freeze out innovation. If you standardize nothing, you get non-interoperable clusters that are not easily integrated. The principle of Pivotal Points of Interoperability is to find consensus standardized interfaces that deal with composition of CPS without constraining innovation.

Zones of Concern

At certain interfaces within any smart city architecture there exist unique sets of concerns which emphasize PPI at the architectural interface. Zones of Concern represent these sets of PPI that allow for the aggregation and presentation of services that support these.

Who

The smart city market is a growing and global one with significant competitiveness implications for both industry and municipalities. The sponsors of this activity are introduced below:

NIST, as lead partner, is coordinating this activity through its Cyber-Physical Systems Program, part of the NIST Engineering Laboratory, to pursue its responsibilities for assisting industry in the development of measurements, measurement methods, and basic measurement technologies; and assuring the compatibility of United States measurement standards with those of other nations.

ANSI's role is primarily outreach and awareness-raising to encourage technical experts to participate in the initiative and to use the working group's output in subsequent standards activities in which ANSI plays a role as coordinator of the U.S. standardization system and U.S. member to international standards bodies.

ENEA is analyzing (especially but not exclusively based on Italy) and elaborating specific aspects related to standards and smart cities (with a special focus on Interoperability issues) as a contribution to the technical white paper. For this purpose, ENEA is coordinating an Italian Convergence Table, involving research and industrial communities and cities, for identifying common principles in a national perspective and promoting and disseminating standards and interoperability approaches for smart cities.

MSIT's (Ministry of Science and ICT) role is to provide its expertise gained from Korea IoT Cluster Projects such as Busan Global Smart City and Daegu Daily Healthcare Centre, which are facilitating convergence of various IoT services based on an International IoT/M2M Standard (oneM2M) platform. In addition, as the government of South Korea, MSIT supports its role for enabling numerous IoT businesses and start-up companies to build up profitable services and establishing IoT ecosystem with the smart city frameworks derived from this activity.

ETSI's technical groups such as SmartM2M, and the global standards initiative oneM2M in which ETSI is a founding partner, are working on IoT service platform specifications that can be applied to Smart City scenarios. In addition, ETSI is active in various EU initiatives such as AIOTI (The Alliance for Internet of Things Innovation) which is examining the need for technical specifications and making recommendations for additional standards to be developed in order to support the ICT technologies in Europe.

ETSI hopes that through this collaboration in the IES-City framework it may enable global cooperation and knowledge sharing as well as the development of global technical specifications and recommendations to help accelerate the numerous Smart City deployments around the globe.

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 working toward their mission of market transformation and participation in this program through LEED and other key [programs](#), offering 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.

The **FIWARE Foundation** is targeted to boost creation of an ecosystem around the FIWARE platform, which provides a rather simple yet powerful set of APIs (Application Programming Interfaces) 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 enabling multiple FIWARE providers to emerge faster 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 a reference architectural framework for smart cities that it can help implement as open source and promote.

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. When governments look at how to adopt Smart City solutions, the path to adoption is not clear-cut. Every city has its own unique needs based upon the regional geography, population demographics, and the composition of the local economy. The communications industry is in a unique position to assist governments to overcome the challenges of urbanization and address the current and future well-being of metropolitan populations.

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 of system development and deployment is in the early stages of a significant, fundamental evolution in scale, complexity, interconnectedness, and interactivity.

To this point, timely although authored in 2005, the Software Engineering Institute (SEI) drafted a technical report, titled, *Ultra-Large-Scale Systems: The Software Challenge of the Future*[6], 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; (4) or to ever fully develop methods and tools to design and constructional aspects of an ultra-large-scale system. Rather, the report suggests that ultra-large-scale systems must be *cultivated* into function existence by continuous integration and optimization of its component systems of systems. Systems of this level of complexity, especially the components of such emerging systems of systems project types, have been studied additionally as: cyber-physical systems [11][12], socio-technical systems[13],

complex, large-scale, integrated, open systems [14], and multi-scale systems [15]. The new and salient aspects of design, construction, and operational challenges that these emerging complex, interactive systems types entail may be summarized by the following systems of systems characteristics (for a more detailed list in the CPS Framework see section “1.1.2 What is different about CPS” in [1]):

- “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.” [35]

In response to these challenges, the literature of these related emerging systems of systems project types 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 emerging project types is how to manage complexity (including interoperability) in a system of systems with many continuously changing components.

This IES-City Framework helps to manage complexity in such emerging systems of systems project types by introducing two key notions: Pivotal Points of Interoperability (PPI) and Zones of Concern (ZofC).

The figure that follows, Figure 1: IES-City Framework Structure illustrates how integration is facilitated through PPI and ZofC in the realization of user requirements.

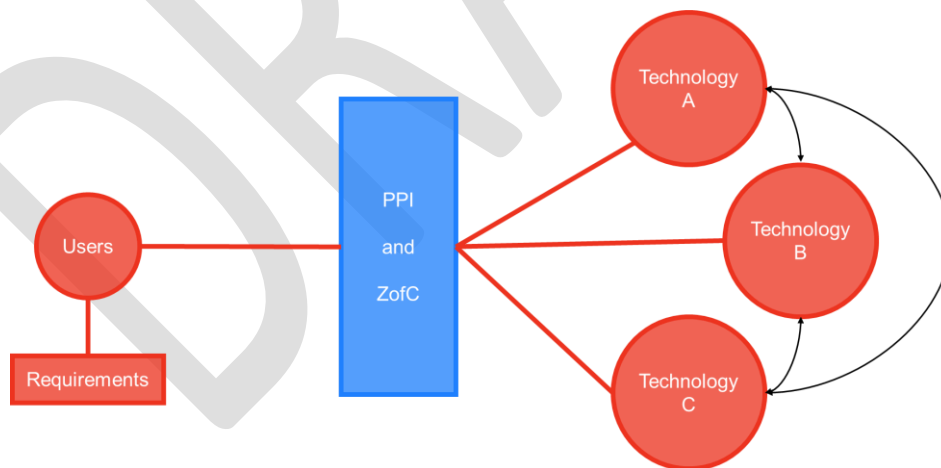


Figure 1: IES-City Framework Structure

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 of 2015, NIST published the NIST CPS Framework Release 1.0 [1][2][3] which provides an analysis and technical framework for describing and analyzing CPS. 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 common experiences in daily life. Increasingly we encounter more, *“...smart cars, intelligent buildings, robots, unmanned vehicles, and medical devices. 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 manifest all the differentiating characteristics of these emerging project types presented above. Per this NIST Cyber-Physical Systems Public Working Group initiative, 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 socio-technical systems, ultra-large-scale systems, and complex, large-scale, integrated, open systems will be based.

The CPS Framework introduces two powerful concepts – holistic concern-driven analyses and the grouping of system engineering activities. The holistic concern-driven analyses, *aspects and concerns*, introduces the notion that all requirements are potentially cross-cutting. That is to say, requirements reinforce or conflict with each other as design decisions must be made to achieve stakeholder goals. By treating these aspects – *functional, business, human, trustworthiness, timing, data, boundaries, composition, and lifecycle* – at every stage of the system engineering process, more complete systems result, since all dimensions are considered. The grouping of system engineering activities into *facets* – conceptualization, realization, and assurance – allows a simplification of the focus of the activities towards specific kinds of artifacts. These modes of thinking can be used in waterfall, spiral, V model, rapid development or reverse engineering processes, resulting in 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 [106][61]. Suffice it to say that 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 NIST CPS framework endeavors to provide the more general treatment [63].

To grasp the impact of ubiquitous CPSs you must imagine the changes that will occur in your city over the next ten years. CPSs will alter the city infrastructure and its role in improving the well-being, health and economic potential of its citizens.

Here are but a few examples of these deployments:

- The adoption by cities of high-performance building standards [20]

- Requirements that building owners must monitor and publicly report energy and water usage periodically [21], and in real-time [22].
- Wellness standards [23],
- Ecodistrict / neighborhood scale systems performance standards [24],
- Open telecommunications access protocols and infrastructure [25],
- The use of artificial intelligence to optimize systems efficiencies [26],
- Building information modeling for facilities design and operations based upon semantic web architecture [27],
- Standards to support automated usage of drones for applications ranging from security, shipping/delivery, telecommunications access, and disaster relief [28],
- Standards to support driverless vehicles [29],
- Supporting mindfulness and cognitive performance [30].

The buildings, transportation systems, infrastructure, and telecommunications ecosystems are evolving. Their uses, energy expenditures, resource consumption, and impact on human health, well-being, and productivity will simultaneously be monitored, analyzed, optimized, and integrated into vast interconnected socio-technical ecosystems throughout their lifecycles [39][36]. For example, there are the data monitoring, modeling, simulation, operationalization, and optimization standards that go into buildings and systems civil infrastructure only. In addition, there are other layers of industrial, commercial, and domestic networks of information and devices that service the economic, social, and physical needs of the populace. These networks and devices are all interconnected and sharing information and access in near-real-time [42][43][44].

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 [65].

The challenge with this approach is that being able to compose one smart city feature with another one, built according to a different ecosystem, confronts a large integration cost that must be born along with benefits provided just by deployment of a homogeneous technology [59].

The argument makes no judgement about the excellence of the various competing ecosystem teams – just that, because they will be different, there is an integration cost that doesn't go into providing the next service, and, sometimes this integration cost can be prohibitive to deployment. Additionally, the organizational dimensions of integration of differing approaches make integration challenging.

Yet, there are these ecosystems formed by various collections of enterprises and sometimes with government assistance, making it challenging to converge their approaches into a single architecture or design [105]. Such convergence would be desirable and is being pursued by the sponsors of this framework such as shown in the paragraphs for each organization at the end of this section.

Below, Matt Turck [40] 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.

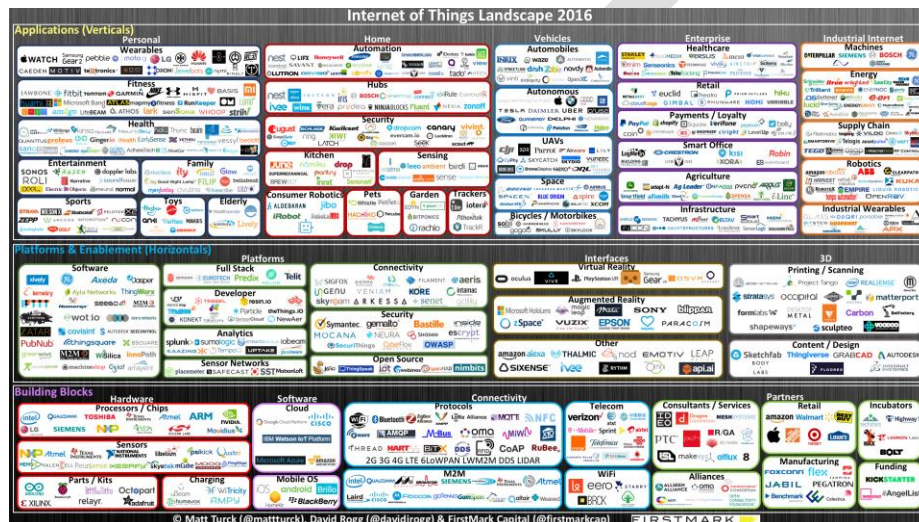


Figure 2: Internet of Things Landscape 2016

The sponsoring partners of this IES-City Framework have made independent efforts at facilitating convergence. This is not intended to be an exhaustive list of efforts and standards but is an introduction based on the efforts of our sponsoring partners. Here is a summary of their endeavors:

NIST: One approach that shows promise for facilitating convergence is the NIST-sponsored Global City Teams Challenge(GCTC) [31]. 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.”

This IES-City Framework aims to ameliorate the high cost of application integration through its efforts at analysis and presentation of what its authors have learned in studying these smart city applications and architectures.

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 2 ½ 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 the national competitiveness, ENEA is designing and developing a set of specifications, Smart City Platform Specifications (SCPS). The SCPS aim is to support the development of ICT platforms, horizontal with respect to the various vertical services in a Smart City, providing them with the necessary data exchange interfaces for avoiding the creation of non-interoperable silos.

These specifications are adopting the Pivotal Point of Interoperability approach defined by IES-City and will be the base for defining technical attachments for Smart City service public call for tenders, so mitigating the lack of 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 to help cities come together and express their standardization priorities in a focused manner and dialogue directly with representatives of Service providers, vendors and researchers. ISG CDP (City Digital Profile) was created in December 2017, and has already attracted several cities and places as contributing members. Other groups actively working on city related standards include ISG CIM (Context Information Management) that is tackling the complex issue of enabling multiple organizations to develop interoperable software implementations of a cross-cutting Context Information Management (CIM) Layer. TC ATTM are also working on Key Performance Indicators for Sustainable Digital Multiservice Cities. Several cities have identified Data management between multiple sources as a Pivotal Point of Interoperability, and this issue is being examined in ISG CIM, and also TC smartM2M with their work on SAREF (Smart Appliances REFerence ontology) interoperability language that is being adopted in oneM2M with their base ontology model.

FIWARE Foundation: Not only as a mean to cope with the diversity of technologies and products at IoT level but also as a mean to solve the need to integrate information from other sources beyond the Internet of Things, the FIWARE Foundation proposes the adoption of an open API for context information management: FIWARE NGSI. A Reference Architecture for Smart Cities can then be defined incorporating a main Context Broker layer supporting this API which provides the mean for managing information coming from different IoT networks as well as the interoperability within a City, and portability across Cities, of Vertical IoT-enabled Smart City solutions (for Waste Management, Traffic Management, etc.) and Smart City Governance Support solutions.

The proposed FIWARE NGSI API has experience a growing momentum of adoption in the last few years. Actually, GSMA [45] has identified this API as cornerstone in the definition of a target

Reference Architecture for IoT-enabled BigData systems. Similarly, TMForum [46] has adopted FIWARE NGSI as basis for a recommended Reference Architecture for Smart Cities. Quite significant, FIWARE NGSI has been selected as one of the mechanisms which more than 117 cities of 24 countries being part of the Open and Agile Smart Cities (OASC) [47] initiative have committed to adopt in order to support the interoperability of smart city solutions within a City and between Cities, as well as their portability across Cities. Also, very relevant, 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 recommended to EU member states when building Digital Services Infrastructures supporting services which have to work cross-border. Leveraging in all this momentum, ETSI created an Industry Specification Group aimed at creating open standards for Context Information Management (CIM ISG), taking FIWARE NGSI as basis for the specifications of a CIM API [48]. Evolution of the FIWARE NGSI API specifications is planned to be driven through this ISG in the future.

In collaboration with TMForum and leveraging on FIWARE NGSI, 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.

Last but not least, efforts within the FIWARE Community have been initiated towards creation of Common Context Information Models compatible with the FIWARE NGSI API. Collaboration with GSMA, TMForum, OASC, ETSI and other parties are taking shape.

MSIT: The Korean government has decided to promote smart city as one of the key agendas of the Fourth Industrial Revolution. The government has decided to focus on solving urban problems through the use of big data to increase sustainability for smart city business and increasing citizen participation. Specific directions for the promotion of smart cities are to create a new world-class smart city, to promote the Smart City Renewal New Deal project, to improve the smart city performance and to spread the business within and outside the country.

As a first step to implement this agenda, we have selected Busan and Sejong 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, efficient traffic management systems 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 which automatically turn on when a person is in need of help. The residents will be moving in to these trial cities starting in 2021 and the cities will be designed with fourth industrial revolution technology where the residents can actually feel the difference 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.

We expect that the specifications defined by IES-City will **serve** as an important reference in implementing smart cities in Korea.

The Telecommunications Industry Association (TIA) represents manufactures and suppliers of global communications networks through standards development, policy and advocacy, business opportunities, market intelligence, events and networking.

Recently, TIA became the official Administrator of US TAG Mirror Committee to IEC Systems Committee on Smart Cities; therefore, it is a new initiative, and there are lots of ongoing activities most of it is still unfinished. The scope of the IEC Systems Committee – 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 1) promoting the collaboration and systems thinking between IEC/TCs, the Systems Committee (SyC) and other SDOs in relation to city system standards 2) by undertaking systems analysis to understand the needs for standards and assess new work item proposals (NWIPs) related to city systems and 3) by developing systems standards where needed and by providing recommendations to existing Systems Committees, Technical Committees/Sub-Committees and other regional, global Standard Development Organizations. Overall common city goals include, for example, sustainable development, efficiency, resilience, safety and support for citizen's engagement and participation. However, an individual city will follow its own approach. 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 namely: Terminology WG, Market Relationship WG and Reference Architecture WG. TIA's current efforts on Systems Committee-Smart Cities and IoT Convergence are not new. Smart city is interconnected, Systems of systems and deploys comprehensive Networks of Networks. 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 by virtue of enriching the actionable insights for the city operation, management, governance and citizen engagement. The "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.

TIA is striving to influence Global Standardization paradigm with the American Stakeholders' perspectives and concerns to make global markets accessible to American industry and businesses.

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 working toward their mission of market transformation and participation in this program through LEED and other key [programs](#), offering 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.

LEED for Cities certification [program](#) was launched in December 2016, cultivating a new generation of high-performance cities. It certifies cities and communities based on performance and provides a common metrics for cities across the world to compare and compete. The program is offered on [Arc](#) platform, where cities can interconnect all city departments, their

visions and goals and track performance on actionable plans and projects; including their tracking climate action plan, sustainability plan, smart city activities or a resilience plan and much more; enabling a data-driven engagement.

1.3 A Look at Two Smart City Use Cases

Technologies, use cases, infrastructures, and communication needs coalesce in the smart city. How can one optimize the efficiency, effectiveness, and equality of access to such a smart city? To answer that question, it is instructive to imagine a typical morning in this brave new world. This section illustrates two perspectives: (1) a city resident dependent upon the CPS infrastructure; (2) a city administrator responsible for the evolving CPS infrastructure.

1.3.1 City Resident – Waking Up in a Smart City (2028)



Figure 3: Waking Up in a Smart City

Imagine your morning living in a smart city just ten years from now. Last night you set your smart phone alarm to wake you up this morning at 5:30 AM. Your child set an alarm for 6:30 AM. Your parent, who is visiting, set an alarm for 5:00 AM. You and your family members are among 700,000 people in the city who set similar 'smart' wake up alarms for the coming morning.

Data about when each of the 700,000 city residents wake this morning is anonymously collected and mined by the local utility to estimate the peak energy consumption load during the morning hours [50] – note that anonymization of this data is key to protecting privacy. This information is also used by the Department of Transportation (DOT) to optimize traffic signal timing in order to minimize rush hour traffic delays. The local healthcare providers also use this and other data, such as the age and gender and medical histories of the people who set their alarms, to predict the likely volume and type of need for various medical services today. The local utility and DOT and healthcare system use machine learning to analyze this data and create predictive models to estimate continuously changing needs and conditions and to

553 optimize services accordingly. These predictions are refined continuously throughout the day
554 as more data become available.

555 For instance, as you and the 700,000 city dwellers who set alarms wake up, your wearable
556 devices (smart watch, ear buds, shoes, under-garments) convey personalized real-time data
557 about your health to you and share anonymized data to the broader community.

558 For you personally, based upon your schedule for the day, and your past record of adhering to
559 your schedule and routines, your home automation system estimates when you and your family
560 members will *really* get up, what sequence of morning activities you will perform, when you will
561 want your coffee, when you will shower, and how much electricity and water you'll consume,
562 among many other considerations. Your home automation system will determine when to
563 adjust the temperature in your apartment to improve your comfort, when to adjust the
564 humidity, and when to increase the air change rate and introduce additional oxygen and reduce
565 the carbon dioxide and carbon monoxide in the air to help you wake up and get going. The
566 home automation system will begin heating the water for your shower just a few minutes
567 before it predicts that you will need the water.

568 The electrochromic glazing in your windows will change the electric current flowing through
569 them so that more blue light is admitted, engaging your circadian rhythm, and thereby
570 suppressing melatonin production and preparing you to wake up. Given that the ability of
571 human eyes to perceive blue light diminishes as humans age, as a result of yellowing of the
572 cornea, the inability to perceive blue light can disrupt the circadian rhythm of older people and
573 thereby lead to disruptions of their sleep-wake cycles, their wakefulness, and associated mental
574 health. In your smart apartment, your home automation system selectively tunes the
575 admission of light hues through the electrochromic glazing so that you receive slightly more
576 blue light than your child, and your parent receives significantly more blue light than you, so
577 that each of you is primed to have your best possible day by your technologies' harmonization
578 with the performance specifics of your endocrine and ocular systems.

579 As you wake and begin your day, your actual behaviors and biometric information are used by
580 your home automation system to correct and refine its predictive models of your behaviors.
581 Your home automation system is simultaneously exchanging data with other home automation
582 systems, building automation systems, and city-level and regional-level automation systems.
583 Your home automation system anonymously contributes information about your behavior to
584 the shared body of knowledge about resident behaviors that morning. At the same time, it
585 updates its model based on the collective data from other residents. Consequently, it can
586 understand how your behavior ranks you across categories such as age, gender, health, socio-
587 economic status, religion, intelligence, mental health, technical proclivity, likely social groups,
588 likely content, and activity preferences.

589 When you do wake, you feel refreshed because of the quality of bluish morning light, the higher
590 air change rate, the lower carbon monoxide content of the air, and the higher oxygen content
591 of the air. You walk into the kitchen and get a cup of coffee and a bowl of granola and yogurt.
592 Your visiting parent has gotten coffee and toast and is sitting in a chair reading a news article on
593 their tablet. The rate at which your parent is reading is detected by the device to be slower

than normal and the resident health assessment system sees this as a continuation of a recent pattern that indicates your parent may be suffering from deteriorating ocular or cognitive functioning. The system notifies your parent that it is time to visit the doctor for a checkup. It also notifies you of this recommendation because your parent has given you limited power of attorney for their health-related matters. Once your parent accepts this suggestion, the automated health management system creates an appointment with a health care provider based upon your parent's schedule.

Considering your own health, your wearables indicate that you have put on 7 pounds recently and that your heart rate and body temperature are elevated compared to your past data. The amount of shifting that you are doing in your chair indicates to your health management system that you may be uncomfortable. These combined observations indicate to the system that your weight gain may be both unhealthy and uncomfortable with your new body mass. Based on your social media posts, your health management system knows that you recently suffered the loss of your pet of 15 years and suspects that the grief of that loss led to the weight gain that is now adversely affecting your health and comfort. Your health management system suggests that you make an appointment with your therapist to discuss the loss of your pet and encourages you to try new, healthy recipes and increase your daily walk by 15 minutes.

At the ultra-large-system macro level, the health management system adds your anonymized data to a database and detects a pattern of increased pet deaths in your neighborhood due to cancer over the past year. The system cross references this information with city data about events in your neighborhood over the past five years and identifies six events that may correlate to an increase in cancer rates among pets and assigns a probability to each. The most likely cause is contamination of the soil in the dog park where an old, undocumented underground oil tank was disturbed when the utility ran fiber optic cable through the park two years ago. The system suspects that the oil tank remediation may have left contamination in the soil and notifies the city and Environmental Protection Agency that an investigation is warranted.

When your child awakes, your visiting parent is dozing in the recliner and you are responding to email. Your child prepares breakfast and watches a sports highlights show. The home automation and health automation systems recognize that your child's weight and food consumption are increasing in ways that are consistent with trends for children of that age. However, your child's interest in a sports highlight show is a new trend and indicates his/her tastes and interests are changing. Based upon cross referencing this interest with your child's schedule and your own history of activity and health, the system suggests you and your child may enjoy trying gymnastics. Furthermore, this change is consistent with trending data indicating that your child is entering an age/gender-appropriate growth spurt and an associated rapid maturation of cognitive functioning. To support this transformational development, the system determines that it will increase oxygen levels by 0.25% in the apartment for the predicted six-month duration of this developmental change and will drop average temperature by 1 degree. The anticipated benefits of these changes are more comfort and optimized rate of development. Of course, these predictions will be vetted in real-time as data are available.

When you take your shower, the system notices that your shower time has increased 20% over the last month and attributes this to you seeking comfort after the death of your pet. Your data is added to a database and the system knows that overall morning shower consumption is down in your building, up in the neighborhood, and down in the city overall. The decrease in water consumption in your building is attributed to new dashboards installed by the elevators that gamify water use reduction for the residents. The dashboards show the consumption of water per floor of the building each day and floors compete to see which floor can achieve the most reduction in water use each month. The floor that wins receives a 5% reduction in rent the next month. The consumption is up overall in your neighborhood because your neighborhood is hosting the city's annual marathon. Many residents of your neighborhood will compete and as people train and prepare for the marathon, they require more water and frequent bathing.

When you are done showering, you dress. The time that it takes you to dress, the balance that you exhibit while dressing, the efficiency of your movements, your choice of clothing, your heart rate, skin conductance, and level of cognitive functioning, are all monitored and correlated with several thousand other data points that are known to likely correlate to your biometrics and choice of clothing. Your home automation system suggests that you will be more comfortable if you choose a different shirt than the one that you've chosen, because of the humidity today. You accept the suggestion because the home automation system is usually correct. You leave the house and go to your job as a city administrator responsible for the mass transit system of buses and subway trains in your city.

1.3.2 City Administrator – The life of a citizen-oriented Smart City deployment: anticipating a flood

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

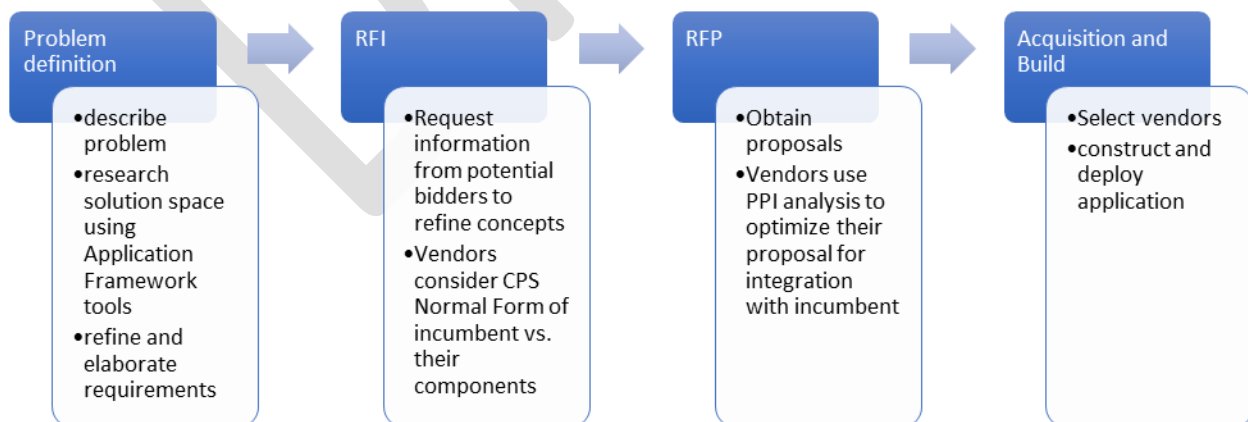


Figure 4: Smart City Application with Incumbent

1.3.2.1 Statement of the problem

You are a city administrator responsible for the integrated city infrastructure. You ride the bus from your apartment in downtown to your department's office in mid-town. On the bus, your phone populates a list of upcoming appointments and tasks for the day, as well as relevant news articles related to your primary concerns. There have been torrential rains this past week as a result of an approaching, slow-moving hurricane, and the predictive models of the EPA and NOAA suggest that there is a 67% chance that your city will be flooded with a foot of water within 72 hours. When you arrive at the office, you are consumed with preparation. The urban infrastructure that manages the city is challenged during an atypical event like this hurricane.

Your city has previously deployed a smart transportation application and you are familiar with the IES-City Framework tools, and 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. In the scope of these aspects were identified *pivotal points of inter-operability (PPI)* between the embedded systems, mechatronics, robotics, cyber-physical systems, and complex, large, integrated open systems that serve functional, business, human, social, and policy *concerns*. The aspects of concerns considered included: *functional, business, human, trustworthiness, timing, data, boundaries, composition, and lifecycle*. These aspects in turn provide guidance for how to compose new functions into the existing infrastructure.

During an event such as the anticipated flood, the weighting of concerns of the systems of systems that run the city briefly, but profoundly, shift. 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. This scenario is not the disaster it could be but rather an opportunity for your smart transportation system to evolve the emergency preparedness of your municipality – to further smarten the city!

1.3.2.2 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 how they addressed them.

You avail 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 sub-category 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 their respective *readiness* 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 next 72 hours in order 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 policy, 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 indicates 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, and suggested route guidance transmitted directly to driverless vehicles and drones. Your model plans a gradual transition from favoring transportation to and from these stores 72-24 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. Since 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 – on the fly – 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 and other priorities (i.e., 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 – they say can do it (note later a third team “C” will respond to the RFP)!

Of course, a design, modeling, and operations challenges such as this can only be successfully addressed because of methods developed to decompose the problem into addressable components. 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 Zone of Concerns (ZofC) for their Northbound (where applications connect) and Southbound (where IoT devices connect) interfaces. Several infrastructure vendors have supported these ZofC to provide a trustworthy infrastructure allowing 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.

1.3.2.3 How the Technology Providers will be able to Respond using PPI and ZofC

Based on the successful RFI, an RFP is composed based on the feedback received. The vendors that respond – “A”, “B” and “C” – cross-reference the PPI with their corresponding support for the concerns in their product offerings and looks for several bits of information, including:

- How many other PPI 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 PPI 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 and participates in the smart city framework consensus PPI protocol. 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 PPI to consider to maintain system functionality --- and this simplicity during a crisis is valuable;
- can trust the robustness of the PPI infrastructure --- since a shared set of PPI 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.

1.3.2.4 Describe how Standards Development Organizations (SDOs) can use PPI And ZofC to Converge their Efforts

Because every standards development organization (SDO) has its own constituency and history, the IES-City Framework can provide some unifying, yet un-constraining, principles to organize around. By utilizing and presenting their efforts with respect to PPI and ZofC, a common means of discussing similarity and differences can emerge. Additionally, by reviewing these commonalities, directions can be elected that result in convergence across the standards domains.

1.4 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 by stakeholders prior to commitment of substantial time and funds pursuing an actual deployment. This tool enables review of various smart city application categories and subcategories and their representative applications with regard to the breadth of functional requirements for these applications, the readiness of the municipality infrastructure to mount these applications, and the benefits to their citizenry from acquiring them. You will find this described in section 3 Smart City Application Framework.

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

The committee theorizes 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 (PPI) and an approach was developed to reveal them. PPI promises 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 notion of Zones of Concern (ZofC) which recognizes that there are distinct interfaces in any architecture where common requirements addressing common concerns can direct these PPI toward a readily integrable design. The pivotal idea is that there are three principally unique roles of supporting vendors in a deploying 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. You will find these described in Appendix B Use Cases and Analyses for Select Smart Cities.

2 Use of this Document

IES-City Framework is designed to support the needs of several stakeholders of smart cities – the city leadership, policy makers, 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.

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

Section 1 introduces to the IES-City Framework and the Smart City scope it seeks to address.

Section 2 is a guide to the framework document.

Section 3 describes the Application Framework – 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, needs for existing civic infrastructure, and the benefits these enhancements to city life can afford.

Section 4 provides a technical analytical methodology for comparing gross 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.

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.

2.2 Policy Makers and Regulators

Policy makers 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 recognizing the 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 (SDOs)s

Standards development organizations can benefit from the requirements analysis terminology provided by the NIST CPS Framework and use the methods of section 4 to recognize the 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.

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. They can additionally study impacts, assess betterment of living, developing research frameworks and otherwise 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 cornucopia 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 they are implementing to better manage their resources and deliver services to their citizenry.
- Identifying the needs and priorities of a city and assess on 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 determine whether the goals (benefits) have been accomplished

First a couple of key definitions for this section.

Solution: We define solution as the ensemble of administrative, policy and technological actions that solves a socially-related challenge. Solutions can seek to better the environment, save money to the taxpayer, infuse innovation, or any combination of the above (note that some might be mutually exclusive.) Examples range from automating the wastewater routing systems to benefit the environment to the provision of eGovernment services to save money, increase efficiency, and provide services for rural citizens.

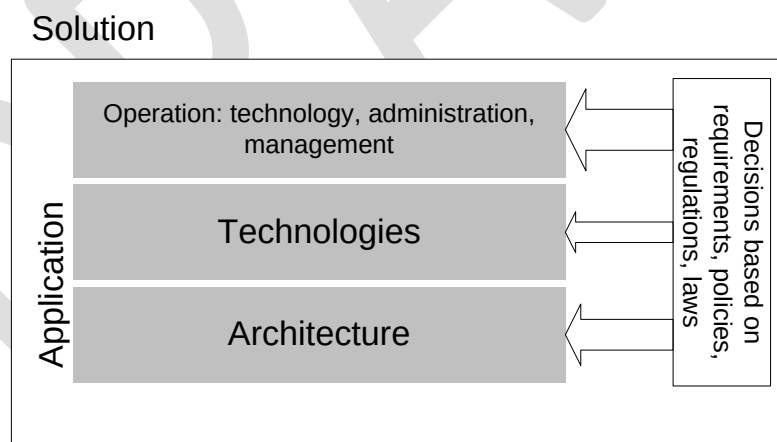


Figure 5: Solutions and Applications for Smart Cities

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 line of 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 its citizenry.

The promise of Smart City technologies is the ability to access dramatically more current and comprehensive information by which to make decisions, particularly at the operational level. Realtime traffic, energy and resource data enables administrators to intervene and manage city services and resources in direct response to normal operation, under system stressors (accidents, weather, over utilization,) and under constantly changing citizen demands due to urbanization, for example (health & safety, water and energy).

Determining which Smart City applications provide cost-rational and proven benefits is a challenge. In the technical realm, the flood of internet-enabled sensors and applications by which to manage and monitor civic systems, resources and services can overwhelm experts in the field let alone non-technical public officials or operational management. Therefore, a matrix of available Smart City technologies would provide a guide by which civic leaders and their technical teams could develop their unique vision. It would also help in having of common understanding of core issues to carry out joint informed decisions.

Likewise, an objective description of the benefits each technology can realistically be expected to yield would provide meaningful guidance to civic leaders who must assign scarce financial and human resources to their Smart City initiatives.

Finally, while the promise of Smart Cities affords an exciting set of new civic capabilities, the political, legal, financial and technical implications of deploying these new solutions 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, in addition to defining, designing and implementing Smart City solutions, able to solve their community's problems in a smart way, 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 to enable less-costly feasibility analyses on which to base decisions on deeper investigations.

Table 1: Dimensions of the Application Framework

Dimension	Description
Breadth: List of applications and related metrics	It consists of both a framework (metrics + tool) for evaluating the breadth (elaborated on the basis of existing models) and the list of evaluated applications

Readiness: A framework for assessing City's Readiness	A List of Metrics + a tool to Assess the Readiness of Cities to Absorb Smart City Applications (elaborated based on existing maturity models)
Benefits: A Framework to Measure Benefits	Metrics + tool for measuring benefits that can be derived from Assimilated Applications

The sub-sections that follow describe the individual analyses for each dimension. 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 but capture a useful sampling of information about smart city deployments from several different perspectives.

3.1 Evaluate Breadth

3.1.1 Project goals

This subgroup has two main objectives:

- definition of an approach for evaluating the breadth of applications: this approach will be developed starting from some existing models
- definition of a framework for evaluating the breadth of applications: practically this framework will be 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 which will also represent the breadth of an application. This framework and approach is 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).

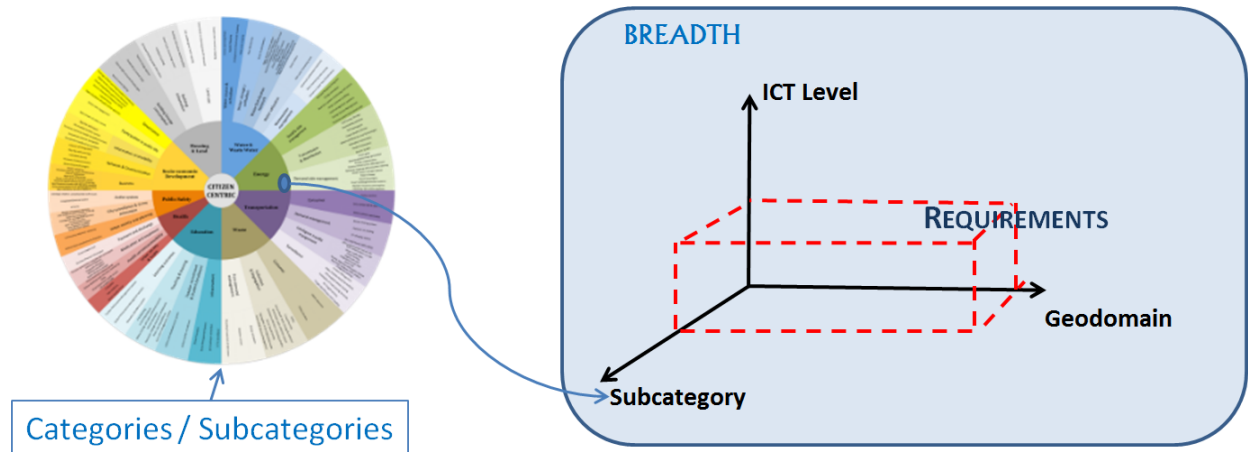


Figure 6: The meaning of Breadth of Smart City Applications

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 Point of Interoperability.

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

- technical and other stakeholders that, prior to developing an application, need to know the requirements that such an application must satisfy;
- city managers that 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 that desire to evaluate the breadth of an application that they have developed.

3.1.1.3 How was it developed?

The steps that will 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 **sub-categories** (e.g. governance, participation in public life, ...)
- a set of “contexts” to fix the features, like:
 - geo-domains (Home, Building, City, Land, Country, Mainland)
 - ICT Architecture level (User Interface, Application, Data, Sensor/Actuator), where:

- 998 ▪ Sensor/Actuator refers to the physical devices which provides

999 sensing, actuation, control and monitoring activities,

1000 ▪ Data refers to the level in which data are aggregated, stored,

1001 analyzed,

1002 ▪ Application refers to the level which provides the needed

1003 “intelligence to the system”, providing controlling, monitoring,

1004 decision, prediction capabilities

1005 ▪ User Interface refers to the user interfaces and GUI enabling an easier

1006 use of the system
- 1007 2. Utilization of literature and case studies to identify the requirements of each context

1008 and its link with each category and subcategory. For example, the subcategory “Traffic

1009 Management” (included in “Transportation” category) will yield a set of requirements

1010 such as large communication network, scalability, capability of manage heterogeneous

1011 data from different sources, etc...

1012 Other requirements will be inherited from the context of use of the application.

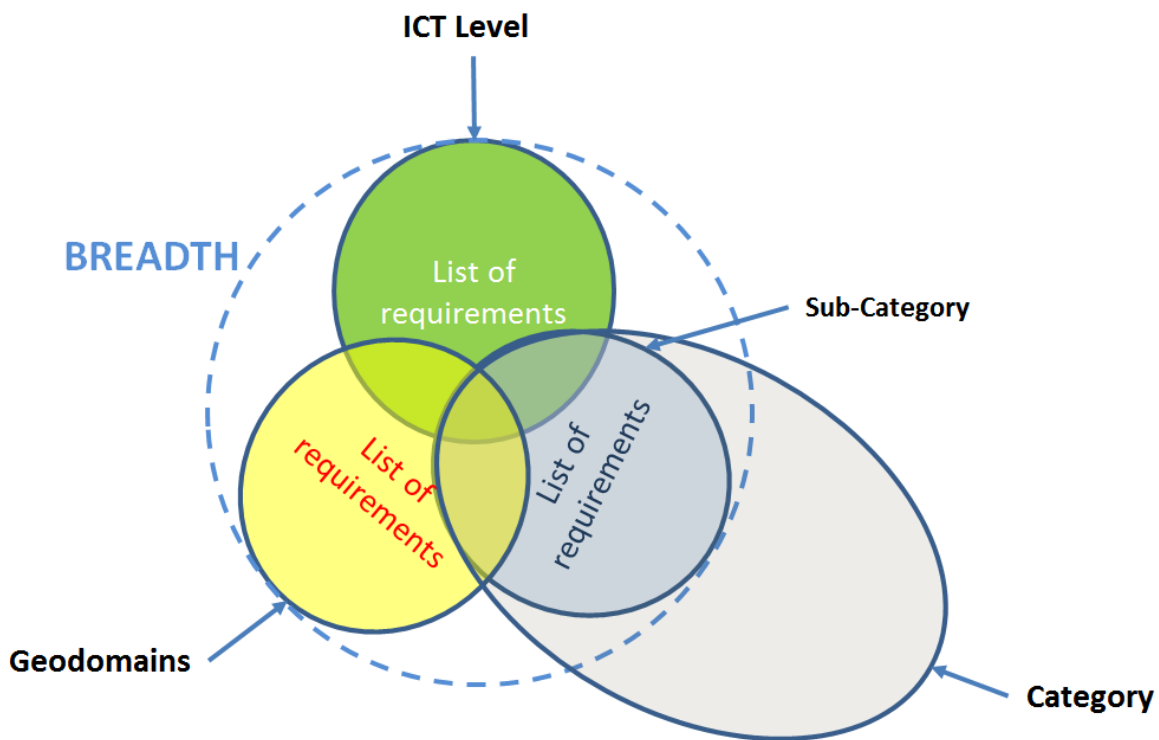


Figure 7: The final list of requirements from the coordinates

Design and development of a software tool implementing the previously defined evaluation approach.

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 breath of such an application.

The **sets of requirements** have been identified from "Aspects" and "Concerns," as defined in the "Framework for Cyber-Physical Systems" [1].

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 sub-category 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", "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/sub-categories. Moreover, to facilitate the identification of the Sub-category an application belongs to, the table provides also 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) [68]. 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, Application Vendors. The tool further points to potential technological requirements which the administrator of policymaker will need to be aware of to allocate financial and human resources.

These stakeholders can get benefits from having a simple tool providing them 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:

IES CITY
Breadth Assessment Tool

Input

Please, choose the **Category** of your application

Please, choose the **Sub-Category** of your application

Please, select the reference **ICT Levels** (multiple choice is possible)

Please, select the reference **Geo-domains** (multiple choice is possible)

When you choose a category, its definition is shown

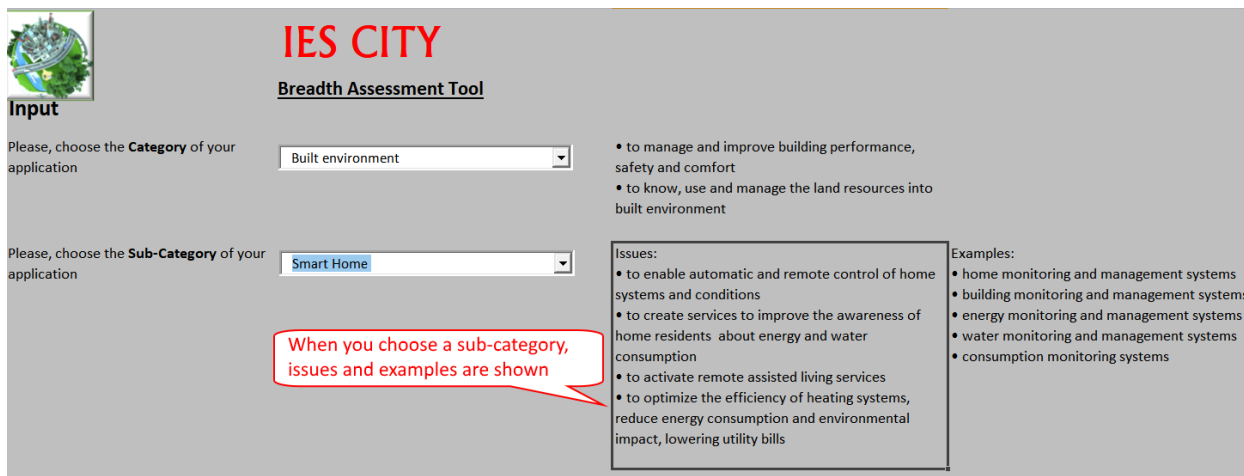
- to manage and improve building performance, safety and comfort
- to know, use and manage the land resources into built environment

Elaborate

Figure 8: Category choice

1064

1065



IES CITY
Breadth Assessment Tool

Input

Please, choose the **Category** of your application: Built environment

Please, choose the **Sub-Category** of your application: Smart Home

When you choose a sub-category, issues and examples are shown

Issues:

- 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, reduce energy consumption and environmental impact, lowering utility bills

Examples:

- home monitoring and management systems
- building monitoring and management systems
- energy monitoring and management systems
- water monitoring and management systems
- consumption monitoring systems

• to manage and improve building performance, safety and comfort

• to know, use and manage the land resources into built environment

1066

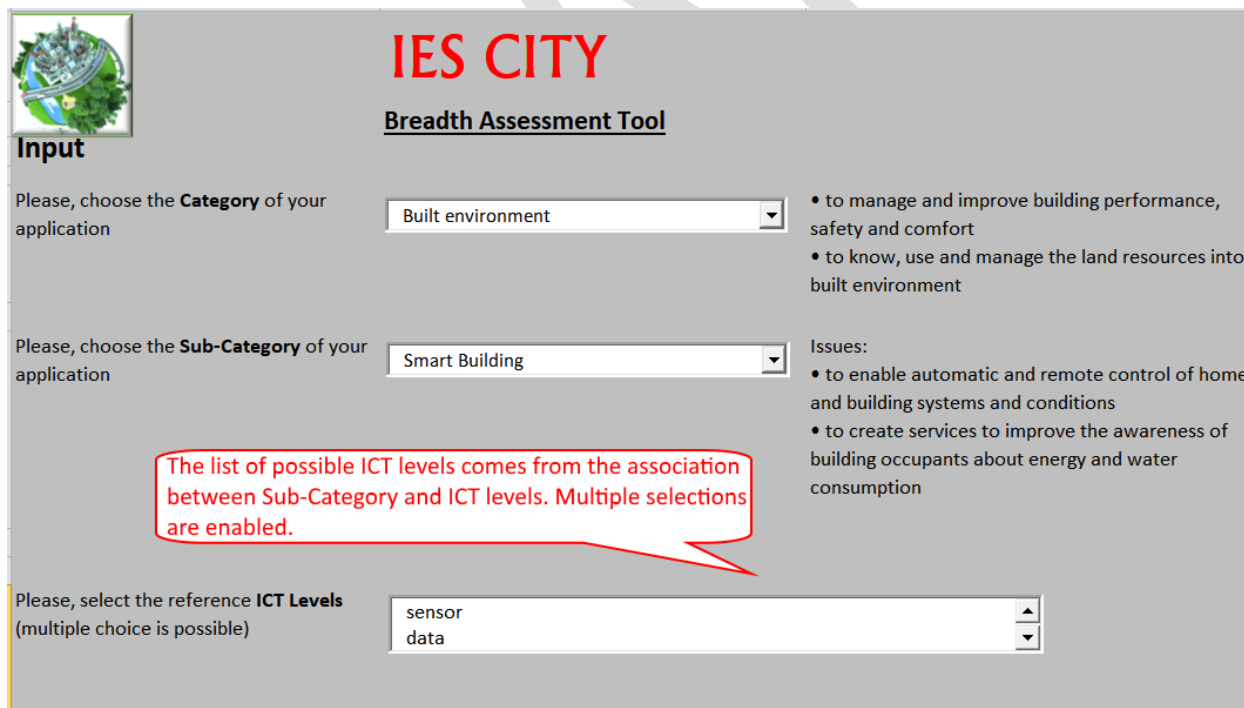
1067

Figure 9: Sub-Category choice

1068

- Then the geodomain and the ICT levels are chosen:

1069



IES CITY
Breadth Assessment Tool

Input

Please, choose the **Category** of your application: Built environment

Please, choose the **Sub-Category** of your application: Smart Building

The list of possible ICT levels comes from the association between Sub-Category and ICT levels. Multiple selections are enabled.

Issues:

- 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

Please, select the reference **ICT Levels** (multiple choice is possible): sensor data

1070

1071

Figure 10: ICT Levels choice

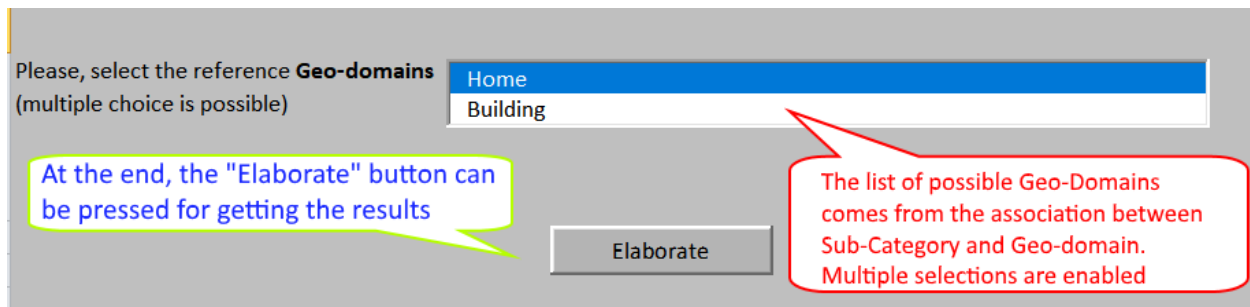


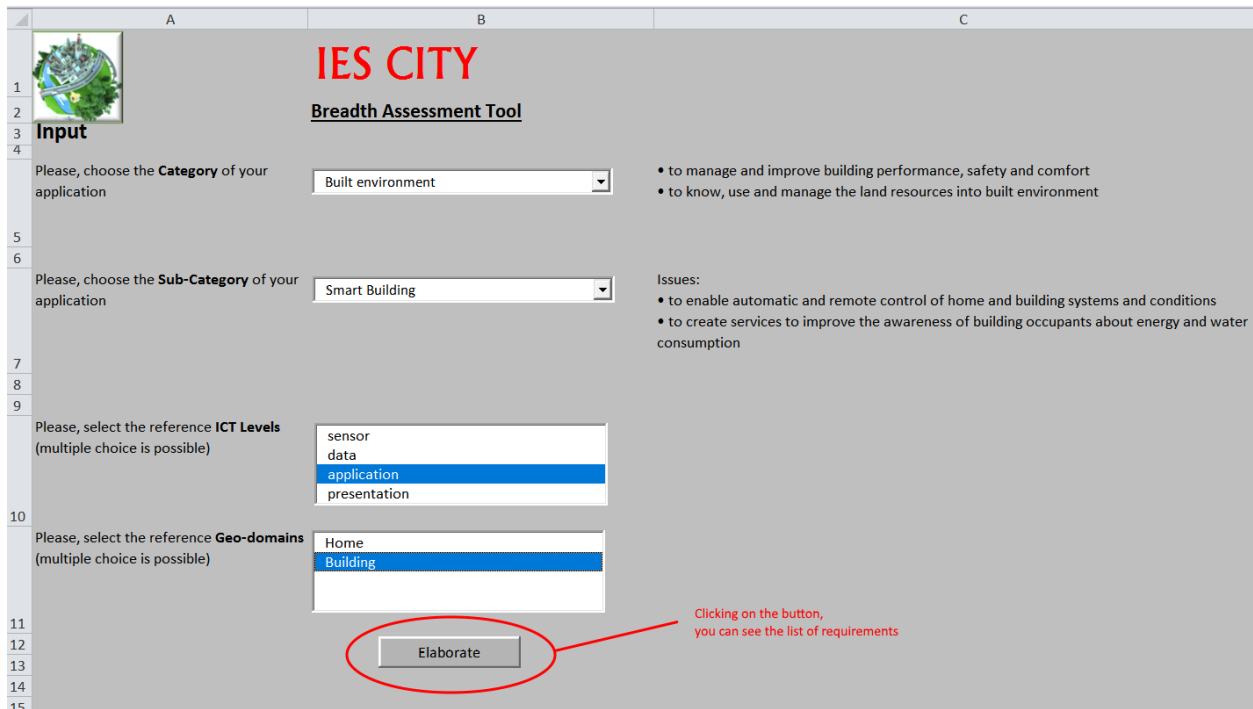
Figure 11: Geo-domains choice

Choosing the features of the application and clicking on the Elaborate button, the list of requirements, split in CPS Aspects and Concerns is shown (Figure 12)

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
Human	Monitorability		
	Usability	- to provide human readable, unambiguous and aggregated data	

Figure 12: 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.



IES CITY

Breadth Assessment Tool

Input

Please, choose the **Category** of your application

Built environment

- to manage and improve building performance, safety and comfort
- to know, use and manage the land resources into built environment

Please, choose the **Sub-Category** of your application

Smart Building

Issues:

- 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

Please, select the reference **ICT Levels** (multiple choice is possible)

sensor
data
application
presentation

Please, select the reference **Geo-domains** (multiple choice is possible)

Home
Building

Elaborate

Clicking on the button, you can see the list of requirements

Figure 13: Input sheet of the developed tool

A complete example of resulting list of requirements is the following one:

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1085

Table 2: List of requirements for an E-Governance application, involving the data level for the Country geo-domain

List of <i>Requirements</i> for the following kind of Smart City applications			
Category:	Built environment		
Sub-Category:	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 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	
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 to different stakeholders. The Smart City Framework Working Group has taken the role of processing 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 that will need to determine application requirements, assess different application requirements in order to explore benefits comparatively, and to explore the application where their current infrastructure and capabilities could be of immediate use.

Thus, the idea of this subgroup is 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 it belongs to, complementing them extracting other requirements other two features of the “application space”: the ICT levels on which the application works and its reference Geodomains.

The aim is to provide different kinds of stakeholders (for example Application designers/developers, City Manager and Application Vendors) with a simple tool able to produce 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 analysis made from other groups of the IES-City initiative.

3.1.3.1 Key messages

Within this sub-working-group 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 Project 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 are a much smaller set of key characteristics 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, that 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. eprocurement, indirectly highlighting most pressing needs, etc.).

3.2.1.2 Why was it done?

For example, assume a wonderful centrally distributed citizen alerting application that relies on a cell phones application for alert distribution. Yet, a municipality considering the merits of adding this service has spotty cell phone service and 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 get ready.

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 [100] summarized a set of organizing categories for readiness metrics:

- Strategic Intent
- Data
- Technology
- Governance & Service Delivery Models
- Stakeholder Engagement

This categorization was adopted as the gross 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 were derived from that work and are organized under the categories above.

This resulted in a matrix that allows for each category and sub-category 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 (matrix, tools, case-studies and data set?)

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.

1167

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 – for example building premises monitoring.
	Availability of WiFi 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 an information distribution means.
	Availability of sensors network infrastructure	The ability to add sensors to an existing sensor network infrastructure is needed.

Category	Metric	Notes
	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 & Service Delivery Models	Use of Integrated Management & Command Centre	An existing integrated management and command center is established.
	Centralized collaboration between emergency response, police, fire, water, 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 is 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 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	Website and application access portal(s) are established for at least some services.

Category	Metric	Notes
	support to continuously provide value to users	
Stakeholder Engagement	Adult 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.

1168

1169 3.2.2.2 Integration into the Application Framework Tool

1170 To integrate this dimension into the tool, a second output consisting of a list of readiness
 1171 parameters for the selected input category and subcategory (Figure 14 shows a screenshot
 1172 from of this output, and Table 4: Example of set of a complete readiness table for a sub-
 1173 category)

List of <i>Readiness</i> 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 14: Example of Readiness output from the tool

Table 4: Example of set of a complete readiness table for a sub-category

List of <i>Readiness</i> Parameters for the following kind of Smart City applications		
Category:		Built environment
Sub-Category:		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 & 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 which 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 so 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

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 - benefiting the city government, private sector enterprises and people. This structured approach

1203 to evaluating possible technologies for deployment throughout a city will allow government
1204 leaders to build a more livable and productive community.

1205 **3.3.1.1 What was the goal?**

1206 By enhancing the deployment of these IoT enabling technologies, it is expected that the cities
1207 will experience greater economic activity [101][102]. The benefits are expected in all segments
1208 of the city, including the public sector, private sector, and the citizenry.

1209 The public sector is heavily influenced by a growth in economic activity. Increased and better
1210 jobs in the Science, Technology, Engineering, and mathematics (STEM) fields, local GDP growth,
1211 increase exports, and inward investment, decrease in the cost of serving citizens, strengthen
1212 the economic resilience, improved environmental quality and social equitability and cohesion,
1213 and, less negative externalities [103].

1214 The private sector also stands to benefit from the increased innovative technologies
1215 deployment. New markets and revenue potential becomes available. Through innovation, new
1216 service ideas and business models are developed and pursued. New capabilities lead to new
1217 approaches to performing existing services yielding increased productivity [104][105].

1218 Citizens are rewarded in the sense of improved service delivery in terms of quality, efficiency,
1219 and cost in areas such as energy, water and other resource utilization and transportation[107].
1220 By empowering citizens through enhanced information about their lifestyles, greater
1221 productivity and creativity becomes a reality [101]. With advanced data collection and analysis
1222 of citizens' health, activity and behaviors data, a dynamic understanding of public health and
1223 safety can be achieved.

1224 **3.3.1.2 Why was it done?**

1225 Ultimately, the reason for deploying these IoT enabling technologies is to provide greater
1226 quality of life to people. Greater quality of life will allow the cities to become more competitive
1227 globally [109].

1228 Recently, the growing trend is toward more people moving into urban areas. These growing
1229 populations present a huge challenge to city planners and leaders. More people mean
1230 increased consumption of valuable resources such as water and energy and further burdening
1231 of an already aging and stressed infrastructure. They need more fire protection, police, health
1232 care and education, often, before the tax revenues are available to pay for them [106].

1233 With the current situation of shrinking budgets and limited resources, cities are constrained in
1234 providing quality services to the growing population. For example, cities continue to build new
1235 roads, buildings and infrastructure. Instead of striving for physical growth, cities should be
1236 measured by how wisely they use energy, water, and other resources, how well they maintain
1237 high quality of life for their people, and how smart they are in enabling economic prosperity
1238 and social equitability on a sustainable foundation. In short, cities must become much smarter
1239 in how they use available capacity and resources to maximize benefits to people [108].

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 [108]. 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 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 becomes 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 in deciding whether or not to make investments in Smart City Applications, we have identified the three primary benefits categories based on the foundation of three pillars of sustainability as Economic Benefit, Environmental Benefit, and Social Benefits for all segments of the city including public sector, private sector, and citizenry.

From the theme areas, more detailed evaluation criteria were established with 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	Sub-categories	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 FDI or promote inward investment
			Promote exports to other countries

			Develop more revenues opportunities
		Cost saving	Reduce cost in governance operation and maintenance
			Decrease cost in serving citizens
			Reduce cost by being able to pick from widest variety of solutions possible
		Economic resiliency	Reduce economic loss
		Pricing	Pricing advantage
	Environmental Benefits	Energy Conservation	Reduce community-wide energy consumption/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 department 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 Small and Medium Enterprises (SME) community
			Accelerate new business start-ups
		New market opportunities	Catalyze development of new products and new service ideas
			Create a new business model
			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 the companies	
	Environmental Benefits	Energy conservation	Reduce energy consumption / Greenhouse Gas emissions of private sector
			Promote use of clean energy of private sector
		Water conservation	Reduce water consumption of private sector
			Increase wastewater recycling and reuse of private sector
		Waste reduction	Reduce solid waste generation and disposal of private sector
Increase solid waste diversion/recycling rate of private sector			
		Reduce raw materials consumption	

		Raw Material Conservation	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	Cost saving	Reduce cost in purchasing products or services
			Decrease cost in paying for utility includes electricity, natural gas and water, etc.
			Reduce the frequency and cost of repairs
		Economic resiliency	Reduce economic loss
		Productivity	Increase productivity of employees
		Empowerment	Increase employee's 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/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/ 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 the cyber security
		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

1267 3.3.2.2 Integration into the Application Framework Tool

1268 To integrate this dimension into the tool, a third output consisting of a list of benefit metrics for
 1269 the selected input category and subcategory (Figure 14 shows a screenshot from this output,
 1270 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 15: Example of Benefits output from the tool

1273

Table 5: Example of set of a complete Benefits table for a particular sub-category

List of <i>Benefits</i> Parameters for the following kind of Smart City applications		
Category: Built environment		
Sub-Category: 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 more revenues opportunities - Cost saving: Decrease cost in serving citizens - Cost saving: Reduce cost by being able to pick from 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 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 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
	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	
Private sector		

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 Accelerated Conservation and Efficiency (ACE) program of New York City, smart lighting solutions including LED upgrades and advanced lighting controls has been installed in many agencies building. LED lighting offers many benefits including low maintenance costs, 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 - they can use, store and produce energy at the same time. Advanced ICT system facilitates the optimal management of the energy production, distribution, consumption, storage and transmission.

Smart Grid (energy system optimization): Real-time operational smart grid for Europe 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 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 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 and heating, energy-efficient buildings and electric transport can be integrated into a smart, flexible and optimized energy system.

Smart utility meter systems: GigaBit Smart City Project: deploy smart meters system into local existing fiber networks to enable automated services and management dashboards, thus local governments and companies can move to more data-driven energy decision making. This can reduce time, save many 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 transmit power output data via Wi-Fi to 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, as well as control the devices remotely. Thus, resulting saving money and energy.

Transactive energy: Transactive energy for smart cities (Buffalo) project utilizes PowerMatcher, a software developed in the Netherlands. The project adds a ISO/IEC/IEEE P21451-1-4 (SenseIoT*) 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 owner control over who has access to their data. This result in energy reduction from home

and building by 30%, increase use of solar power (20%), and increase customer awareness of the benefits by 50%.

[Micro-grid Cloud](#): Micro-grid Cloud, an Internet-of-Things-based integrative sensing, communication, computing and control framework, to perform continuous monitoring, analytics and optimization of community micro grid operations is a joint project developed in City of Hartford and Town of Windham. It enables aggregated local energy sources and storages for demand response and energy saving, also reduces energy outage and interruption risks, and significantly reduced carbon footprint by supporting 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 to create specific estimations that can be adjusted in an immersive, 3D digital space for optimal iteration and analysis, thus allow linkage 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 saving operation cost.

[Smart irrigation management](#): Smart Water Management (company) provide adaptable irrigation solutions to be cost effective and protect property environments.

[Smart cities utility infrastructure \(Remote sensors\)](#): Every year millions of gallons of water is 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 Angeles, CA, Las Vegas NV, and Atlanta, GA use AT7T network (LTE), sensors, sounding technologies, and smart dashboards to identify water leaks. Sensors that 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 (CO2 emissions, water waste/transportation activities, etc.) for cities.

[Underground smart infrastructure](#): Burlington City use 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, also reduce environmental impacts such as energy use, stormwater and sewage discharge. See more at:

[Smart Waterfront](#): Chula Vista, CA smart waterfront project is the largest waterfront development project on the US west coast. This project focus on energy efficiency (targeting 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 & shared transport: On-demand & shared transport: it is new trend to car business to attract new use cases for the car as a driver or passenger, and realizing societal benefits from

reduced car ownership and resulting congestion/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, traffic video cameras to collect traffic flow information.

[Smart Forests \(Internet of Living Things\)](#): NYC 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; provide municipalities with economical and cost-cutting solutions for urban tree management and enhancement; and engage citizens in both the use and stewardship of their urban forests. It involved many pilot applications such as operational website and app for tree mapping and green walking route planner, and networked sensing system for urban heat island study. This project will generate massive environmental data at high spatial and temporal resolution that can be used by government, academic and public for modelling, design and decision making, health living; long term records; improve the quality of life and increase equality within cities; also help mitigate urban heat islands and adapt to future climate change scenarios.

Environment Quality

[Smart water management models](#): remote monitoring sensors: NYCDEP 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 pump station](#): the project team in Cincinnati developed a "smart pump station" for waste water system that allow water utilities receiving more reliable information, better manage water resources, reduce reactive maintenance, and improve water quality. This enable 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](#): 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 able to leverage system distribution pressures, temperatures, water quality information (e.g., pH, chlorine residual, turbidity, TTHM formation), and online customer consumption data, to form 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 complimenting analytics and data platform to: lower the life cycle cost to own and operate the infrastructure assets by identifying likelihood of failures early, and fixing it before catastrophic failure, and use real time data to continuously optimize unit and system process performances. Effective and efficient

1401 water/wastewater infrastructure management has direct benefits to public health (reliable high-
1402 quality drinking water), public safety (fire safety) and environmental (swimming fishable
1403 receiving streams) quality. Also improve quality of life and social justice.

1404 3.3.2.3.2 *Public Sector – Economic Benefits*

1405 *Employment*

1406 Smart Emergency Response System: Denton emergency response operations critically relies on
1407 the efficiency of emergency communication infrastructure. This project aims to mature and test
1408 the drone-carried on-demand broadband communication infrastructure for emergency use and
1409 quantify its benefit compared with existing on-demand emergency communication
1410 technologies. Benefits include new jobs opportunities such as public service experts, robot
1411 operators drone operators, usability experts.

1412 **Living laboratory:** Copenhagen is a living lab for testing smart technologies, thanks to its unique
1413 accessibility to data and efficient public-private sector partnerships. Many world-leading
1414 companies choose Copenhagen for smart city projects. For instance, Cisco is testing and
1415 developing tomorrow's digital infrastructure, the Internet of thing in Copenhagen; Hitachi also
1416 has located its first big data research lab in Copenhagen.

1417 Smart Agriculture: IoT technology increased the fiscal sustainability of Montgomery County's
1418 agricultural reserve land and made agriculture become a new path for economic opportunity
1419 for country residents. It helps the local farmers work more productively and support locally
1420 grown food and local businesses.

1421 *Integration*

1422 Integrated planning: Genova Smart City initiative is aiming at improving quality of life of citizens
1423 through transforming city into a Smart City involving different partners, including research
1424 organizations, private enterprises, institutions, finance and citizens. This initiative includes five
1425 components: energy (smart grid), transportation (smart transport system) buildings (smart
1426 metering, retrofitting), safety and security (IoT city infrastructure), and smart ports (automated
1427 port services).

1428 *Cost Savings*

1429 Smart utility meter systems: Envision Charlotte showcased its first-of-a kind programs in
1430 energy, water, waste and air to conserve resources and reduce operating costs.

1431 Surveillance system: To improve public safety in school zone to prevent crimes, car accidents
1432 and improve sense of security, Busan Korea has created a safe school zone by scanning vehicles
1433 and pedestrian using video cameras which are embedded in street lights and vehicle detecting
1434 sensors, setting alarm sign using digital signage and ground LED light devices. Thus, also
1435 contribute in saving energy bills and City O&M cost.

1436 E-learning: iSocial Virtual learning environment for social skills development in adolescents with
1437 High Functioning Autism (HFA), thus teachers, students, parents and therapists benefits from
1438 access to quality evidence-based learning platform.

1439 **Smart Central Operation Center:** Unlike traditional information involved many disconnected
1440 and conflicting data source and the prediction for trends and direction is in a long-range,

nowadays, data is integrated with sensors, video and voice. With the smart central operation center, detailed action is given in real time; various departments can coordinate in an interconnected way across city stakeholders. For examples, IBM's Intelligent Operations Center: e.g. relative to attending an entertainment event at a stadium. IOC can improve overall navigation to the stadium, ease of parking, and waiting in line, and prove 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 has installed display (IHD) unit, a portable device that provides real-time information on their household electricity consumption, as a part of their Nationwide Intelligent Energy System initiative.

Wireless water meter: New York City's Automated Meter Reading (AMR) system consists of 817000 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, saved over \$3 million per year by avoiding manual meter readings.

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 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 promote the efficient use of existing parking facilities

On-demand & shared transport: it is new trend to car business to attract new use cases for the car as a driver or passenger, and realizing societal benefits from reduced car ownership and resulting congestion/pollution. Ohio State University launched on-demand automated shuttles for solving the first-mile/last-mile problem in the Ohio State University Campus They will have a demonstration using 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 will result in a great reduction in CO2 emissions and radical transformation of the global transportation system. And it is replicable in elsewhere.

Public traffic information web portal: Singapore ONE.MOTORING web portal serves citizens with online accessible traffic information collected by surveillance cameras installed on roads

and GPS enabled taxi vehicle, and additionally provide information such as current ERP rates (electrical road pricing), sections of road under construction, traffic news, travel time calculator, and parking information, etc.

Traffic signal priority system: improving the traffic movement: New York City's DOT and MTA introduced Transit Signal Priority (TSP) system to improve the efficiency and dependability of bus mass transit. PS and location-based traffic control software are built into the buses and traffic controllers, thus allow them to communicate with each other via DOT's Traffic Management Center. A bus equipped with TSP system can request priority service when it approaches to an intersection and can change the normal signal operation to improve the traffic flow.

Smart signage system: New York City 24/7 Smart Screens are interactive platform that integrates information from open government programs, local businesses, and citizens to deliver real-time hyper-local information on events, merchants, services for people, and 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: Emergency Medical Service (EMS) is operated by Singapore Civil Defense Force (SCDF) can be reached through mobile application, "myResponders", which has been designed to increase survival rate from incidents such as increase survival rate from incidents such as out-of-hospital cardiac arrest, guiding them to respond before the SCDF arrives.

Tele-medicine: provides real-time health data of the customers before doctoral examination. Serves as health tracker. Tele-medicine is another major aspect of Smart Nation initiative, which aim to promote the widespread use of wearable technologies such as fitness trackers, smart watches and even smart clothing which is 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.

Web app: PlowNYC is a public-facing web app developed by DSNY to provide citizens real-time snow removal progress monitoring. The snow removal equipped GPS-enabled flip-phones can sends GPS signals to 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 solutions.

Governance Improvement

Data platform: The 5D Smart San Francisco 2030 District Project is a data visualization platform project mapping building energy consumption and GHG emissions data to a 3D visualized model of downtown San Francisco that empower building owners with information and application 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, international institute, to 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, aiming to accelerate the smart city wave. The smart city platform could bring in a dashboard with information and insights that is supporting and stimulating the development of smart

solutions for public safety in the Stratumseind in Eindhoven: less incidents, a safer place, attracting more people.

City Data Platform:

- [Barcelona](#) is developing an open distributed and public infrastructure of city data and providing strategies that involved citizens, businesses, communities and the academic world with a clear policy promoting democracy. This project includes CityOS, Sentilo, Ecosystem of open city data, DECODE. More detailed available at:
- [London](#) Data store provides over 600 datasets to citizen, business owner, researcher or developer helping them understand the city and develop solutions to London's problems.
- [Chicago](#) data portal hosts over 200 datasets about City department, services, facilities and performance.

Smart Infrastructure: The CLOUD project of London, a giant viewing structure, composed of ETFE bubbles, and thousands of LED lights, which is a new form of observation deck, immersing visitors in euphoric gusts of 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: 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, CityPost interactive digital kiosks and mobile citizen engagement, etc.

Equitability

IoT education & workforce development: Millions of connected sensors generate data that is used to improve quality of life and operational efficiency. This initiative is creating IoT recipes (hardware, software, data, use cases) modeled after smart city applications and deploying them to students through semester projects, workshop, 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, 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 bring a tight connection between government, academia, industry and citizens. The data will be used for pollution emission sourcing, adaptation policy making, 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 LOHAS living.

Foolproof receipt booklet: A lot of government Internally Generated Revenue is usually lost to fraud. Miscreants, touts and fake agents pocket Government Revenue to the detriment of Government and citizens who have paid Taxes/ Levies and are expecting Services from Government. Anambra State of Nigeria proposed to deploy a software solution to eradicate

fake receipts used to illegally siphoned Government internally generated revenue. The solutions will generate coded receipts, thus ensure that IGR is substantially received by government. Employment opportunities will be created for agents who are required to collect IGR with the new system
The quality of life of the citizenry will be uplifted 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 time shifting consumption from daytime to night-time and 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 (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 zone to prevent crimes, car accidents and improve sense of security, Busan Korea has created a safe school zone by scanning vehicles and pedestrian using video cameras which are embedded in street lights and vehicle detecting sensors, setting alarm sign using digital signage and ground LED light devices. Thus, also contribute in saving energy bills and City O&M cost.

Emergency warning system: A resilient warning systems for Tornados and flash floods were developed in North Central Texas. This network is for delivering hyper-local, user driven, context aware severe weather warnings. Mobile phones and hyper-local data enable customization to improve response and outcomes. **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 app. This system will provide essential information to mobile users in severe weather events based on context. - See more at:

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

Business Emergency Operation Center: Lafayette, LA will prototype a municipal Business Emergency Operations Center based on a multiagency, 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, 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 street 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 in t

Underground smart infrastructure: Beijing 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 benefit 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: City of Chattanooga 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. Involve city, police, public safety officials, application developers, electrical power board, enterprise center, company lab, and citizens.

Vision Zero fatality: The Seattle Department of Transportation is collaborating with Microsoft, the nonprofit DataKind, and data scientist from 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 result in saving lives, reducing congestion, lowering the monetary and reducing burdens on first responders.

Smart platform for data management: City of 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. meteor-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 providing mid-long-term forecasting to address the Climate Change risks related.

StormSense: City of Newport News uses new 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, aid in rerouting emergency routes for public safety, thus saving lives and reducing property damages.

3.3.2.3.4 Citizenry – Economic Benefits

Empowerment

AI: Watson Health's cognitive systems understand, reason, and learn, 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: London: The Love Clean Streets Network consists 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 & shared transport: it is new trend to car business to attract new use cases for the car as a driver or passenger, and 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 enabling 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 is developing an IoT-based Healthcare Services, to improve the quality of life of people and support 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 which improve Quality of Life (QoL) metrics for individuals, cohorts and the community at large. Hometown Dashboard 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: PA2040 Environmental Sensing (Washington DC) project is creating a network of environmental sensors distributed on campuses throughout DC, which 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 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.

Electric Vehicle (EV) - ready Transit Hubs: Baltimore residents has huge challenge in transit services since many parts of the city's public transit are limited, and bus routes are confusing and rail development is cost-prohibitive. Thus, the B' Smart project is focused on planning and piloting electric vehicle (EV) - ready transit hubs in Maryland, starting in Baltimore. It will

combine the infrastructure elements of high speed Internet and Wi-Fi, clean energy and clean, active transportation connections (bus, rail, electrical vehicle charging, car and bike share). This hub will also serve as community centers for citizens as an open public smart space.

Smart leisure strategy: The cities of Valencia, Spain and Lindale, TX, US 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: The city of Guadalajara, Spain started a pilot project to create a visualization dashboard for generation, visualization and tracking of KPIs for urban waste management and thoroughfare cleaning services. The relevant data are gathered through open APIs from various sources such as sensors, surveys, external systems) to generate a set of KPIs which can be used to assess fulfilment in municipal services. Such project brought change in the economic relationship of municipality with utilities and service providers, from the fixed assignment of resources to dynamic adaption to the needs of the city. 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 Market

Urban farming (vertical vegetables): The roofs of buildings and even walls can use soil-less hydroponic systems to grow vegetation more efficient than grow food in remote farmland and transport to city center Companies such Freight Farm up cycle shipping containers delivering a plug and play working urban farm all controlled from your smart phone, which can have placed in redundant space such as garages, rooftops. Aquaporin 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, rephrasing 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, a giant viewing structure, composed of ETFE bubbles, and thousands of LED lights, which is a new form of observation deck, immersing visitors in euphoric gusts of 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 particular 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: City of Perugia, Italy, is developing 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 responsive during emergencies.

(Digitally) Re-programmable space: Transformation of the urban space for adaption to technological development, thus minimizing the overall urban footprint: City centers are more easily adapt to the new clean, knowledge-based and lightweight industry, rather than the heavy, invasive technologies of 20th century. Vancouver has reduced its allowable urban footprint; Glasgow has moved from a policy of expansion to concentration, and Melbourne 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 was considered one of the most dangerous cities in the world, in 1992. But today, under the mayoral administration of Sergio Fajardo (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 as the key symbols of city's spatial, social, economic and cultural transformation by connecting city's low-income residents with wealthier commercial center. This dramatically changes Medellin in the past 10 years, both in its spatial dynamics and mentality and perception of its inhabitants.

Underground smart infrastructure: Burlington City use 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, also reduce environmental impacts such as energy use, and 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 created an ideal of having a "Intelligent Agent for Quality of Life" to improve the quality of service to citizens, and ultimately improve 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 a number of aspects, social/ public safety, health, socio-economic, knowledge and education, and also generate replicable methodology that can be applied to other city or communities.

3.3.3 Conclusions

In the IES-City Framework, the benefits metrics provide SDO/Cities/Vendors/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 world demonstrate 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 that 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, the 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 the 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.

4 Discovering Pivotal Points of Interoperability (PPI)

4.1 Project goals

4.1.1 What was the goal?

The purpose for discovering PPI (see section 4.2) analysis 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....
- Determine 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 interoperability**.

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 through 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 inter-operability. The method reduces the observed degrees of freedom of the implementation space so that systems developers can simplify systems design and lower barriers to inter-operability.

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 Aspects and Concerns are used. Referring to Figure 16: PPI Analysis Model, the technologies are reduced to rows of a spreadsheet by considering first, the relevancy of a concern to the technology and then to what technical solutions are used to address the concern (see section 4.2.2).

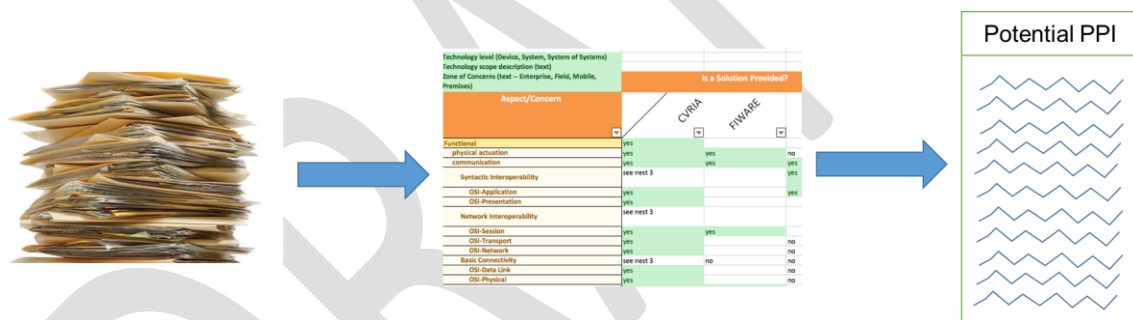


Figure 16: PPI Analysis Model

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 process, and appropriately so. This, however, makes these technologies exceeding 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:

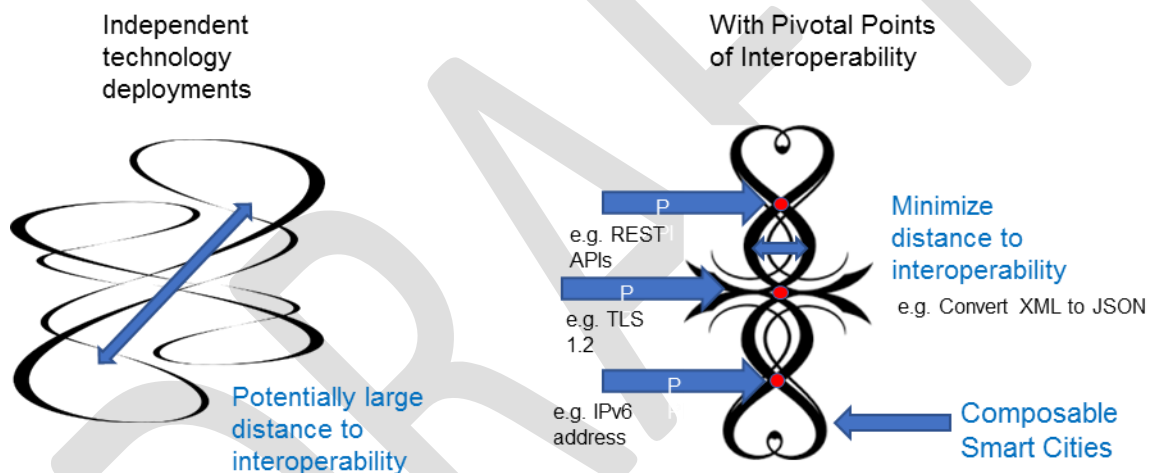


Figure 17: PPI Reduces Distance to Interoperability

Look at an 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 17 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 team “B”’s offering work with team “A”’s. 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 [110].

1902 It is a challenge, in the scope of smart city applications, to seek a comprehensive single
 1903 standard. In fact, it is not desirable – because if you standardize everything, you limit the
 1904 opportunity for discovery and innovation. Of course, if you standardize nothing, you get little or
 1905 no interoperability.

1906 The concept of discovering the PPI through analysis of prominent technologies in use in smart
 1907 city applications, promises to reveal common choices by technology providers acting
 1908 independently. Note that this framework does not seek to declare PPI but simply reveal
 1909 potential PPI through dispassionate analysis.

1910 The following section describes how the NIST CPS Framework Aspects and Concerns can be
 1911 used to study PPI.

1912 4.2.2 CPS Framework

1913 As stated previously the NIST CPS Framework provides for a holistic concern driven analytical
 1914 concept for conceptualizing, realizing and assuring cyber-physical systems. This framework uses
 1915 the methodology described in the CPS Framework for decomposing complex architectures to
 1916 *CPS Framework Normal Form* to expose potential Pivotal Points of Interoperability (PPI).

1917 The reason this work is helpful for IES-City Framework is that it provides a means to condense
 1918 the many pages of documentation of smart city and IoT technologies to a manageable and
 1919 understandable summary.

1920 The following figure illustrates the structure of the framework:

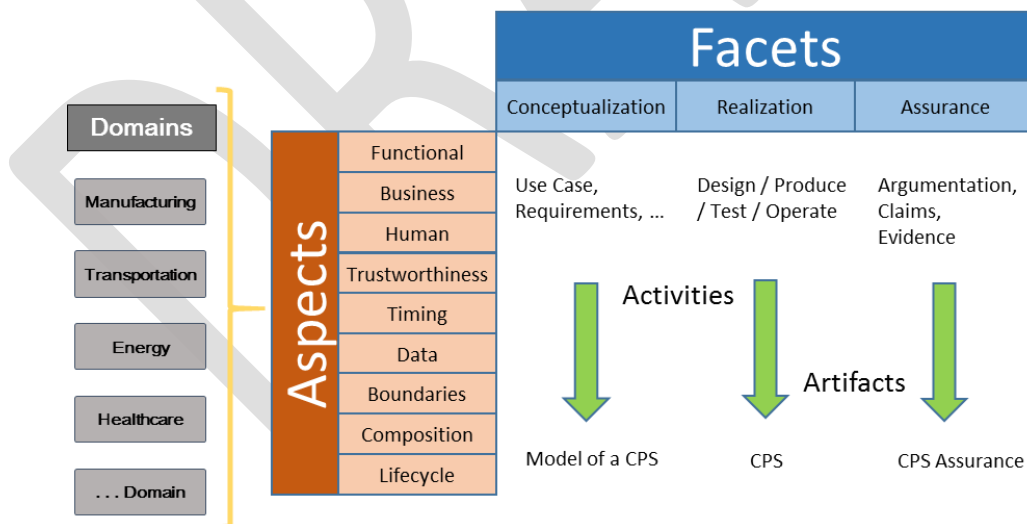


Figure 18: CPS Framework

1923 The framework has two principle concepts – Aspects/Concerns, and Facets. Facets are modes of
 1924 thinking during a systems engineering process for a cyber-physical system. Note that a CPS can
 1925 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. ISO/IEC/IEEE FDIS 15288 [110] 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 the comprise a complete data set describing the CPS.

The Aspects group common concerns that must be addressed in any given CPS and 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.
Timing	Concerns about time and frequency in CPS, including the generation and transport of

Aspect	Description
	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.

1951 Each aspect is further detailed in the CPS Framework to identify a hierarchy of concerns. For
 1952 example, a critical topic for smart cities is the Trustworthiness aspect. Trustworthiness further
 1953 describes concerns that deal primarily with the avoidance of harm and include security, privacy,
 1954 safety, reliability, and resilience.

1955 The complete set of concerns identified in the framework are summarized in a spreadsheet
 1956 with 115 rows. Each technology can be analyzed:

- 1957 1) As to whether the technology addresses a given concern, and,
- 1958 2) What technology or standard was identified to address the concern

1959 By this means, each suite of technology descriptions can be distilled down to the 115 rows of
 1960 the spreadsheet. By placing the choices of multiple technology sets side by side, otherwise hard
 1961 to compare technologies can indeed be compared and PPI revealed.

1962 4.2.3 Zones of Concern

1963 Smart city applications are often provided by an “ecosystem” collaboration of vendors. And, for
 1964 many smart city applications, it seems necessary to deploy everything – i.e. the entire layered
 1965 architecture from devices through to applications – before providing anything of value to the
 1966 acquirers.

1967 When deploying the individual components of smart city infrastructure and IoT devices, their
 1968 network points of attachment typically impose a common set of requirements and protocols for
 1969 “citizens” of the network. This framework calls this term these zones of concern (ZofC).

Clearly layered architectures make for sound designs. The ecosystem teams, however, typically have members that participate at specific interfaces of any given architecture. Other layers may be defined but are internal to the ecosystem member responsible for their collective function. These are internal interfaces. Commonly in smart city and IoT architectures, three important layers and two interfaces can be identified that require interoperable sets of services so that vendors do not have to collaborate at the design and every other stage of deployment.

In the smart city and IoT space, the providers typically fall into three distinct categories:

- 1) Infrastructure providers,
- 2) Device manufacturers, and,
- 3) Applications developers

Because these categories are often fulfilled by distinct and often different enterprises, they naturally connect a layered architecture at distinct points. These are termed the “northbound” interface for applications, and, the “southbound” interface where devices attach and the layer in between is termed the “trustworthy infrastructure” (see Figure 19: Zones of Concern) [111].

Many of the architectures reviewed have this 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.

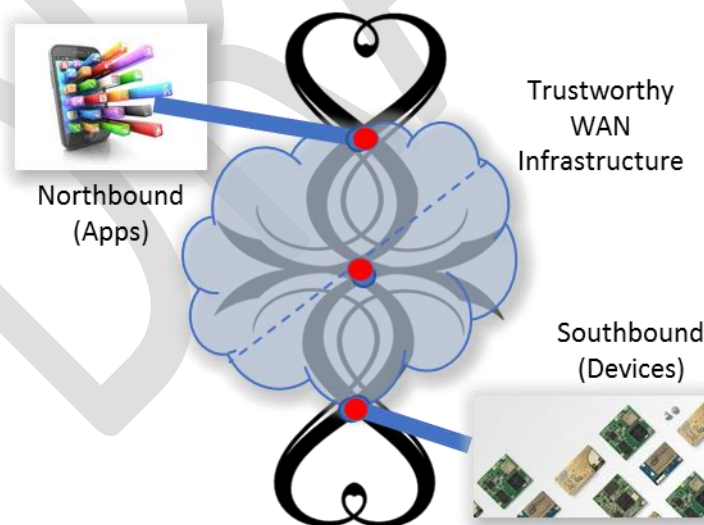


Figure 19: Zones of Concern

While this picture may appear as an oversimplification, interoperability will result if the services available at northbound and southbound have been condensed and 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

1995 smart city environment where it is not necessary to only sell end to end solutions but piece
 1996 parts.

1997 The northbound and southbound conceptual ZofC do not imply that these are the only
 1998 potential ones of note. For example, a service provider might bundle a series of trustworthiness
 1999 services that satisfy needs at either northbound or southbound interfaces shown above or even
 2000 some other point of interface. Another might provide device commissioning and management
 2001 services.

2002 IES-City Framework uses this taxonomy for analyzing technology suites. From these analyses,
 2003 stakeholders can study the ZoC represented at the northbound and southbound interfaces of
 2004 an architecture.

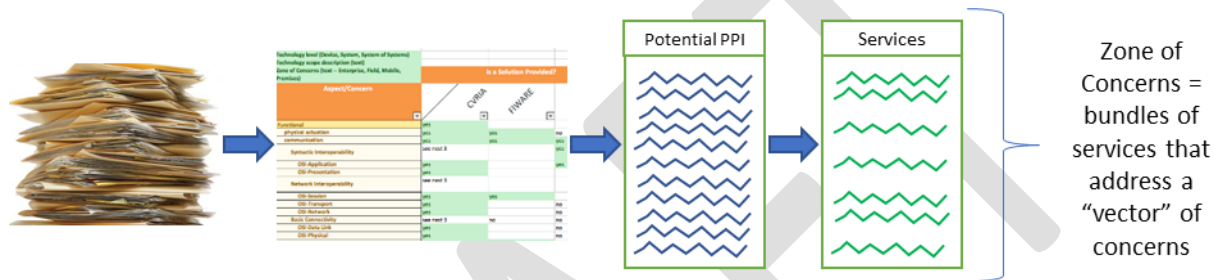


Figure 20: How to derive Zones of Concern

2005 As technology suite providers analyze their suites against this list of concerns and identifying
 2006 the technology choices that were identified to address the concerns, these common services
 2007 can be identified.

2008 There are some typical use cases for applications with ZofC. These examples do not intend to
 2009 prescribe a design to any ZofC but illustrate how they might evolve depending on the individual
 2010 choices of service providers. Here are just a few:

2011 **Application provider to consumer:** This use case has an application provider providing a
 2012 mashup of several application programming interfaces (API)s exposed at the northbound
 2013 interface by one or more providers. The developer needs to know what the end points of the
 2014 data provider are and the description of data and the access rules of that ZofC.

2015 **Application analytics to application:** This use case has one application interacting with another
 2016 application through the northbound interface. Like the application to consumer, each
 2017 application needs to know the APIs exposed and the rules of the ZofC.

2018 **Sensor data stream to Application:** This is the common IoT smart sensor application. This use
 2019 case has two parts – the sensor and the application. The sensor provides a data stream through
 2020 the southbound interface which has rules about network admittance, persistence, and
 2021 authentication. The application knows that the sensor data is present at the northbound
 2022 interface due to the semantic exposition of data available at that interface. It is not necessary
 2023 per se for the application to know it came from a specific sensor, only that it can access the
 2024
 2025

desired data – for example local temperature – and its metadata – for example its location, units of measure and precision.

Field device to field device application: Especially in the case of critical infrastructure applications such as smart grid, field devices need to communicate with each other and not necessarily up to a cloud, for example. 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 composition of, and, the services and constraints available at each ZofC are entirely left to the market participants. However, by providing the analysis in the IES-City Framework in this manner, a basis for discussion and interchange of ideas is provided so that formal offerings of ZofC can evolve and be described in the smart city space.

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 21: 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 format of messages encoding		

Figure 21: PPI Analysis Spreadsheet

For each row of the spreadsheet, a concern from the CPS Framework is listed. The technology under review would indicate 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

2052	• Is a Solution Provided (y/n)?	Is there a solution addressing the concern specified for the technology?
2053		
2054	• Solution	Description of the solution.
2055	• Solution Reference(s)	References to the solution.
2056	• External References	Additional external references if needed.
2057	• Additional Notes	Additional notes if needed.

2058 For each technology, two tabs are filled out representing the concerns that dominate at the
 2059 northbound and southbound Zones of Concern.

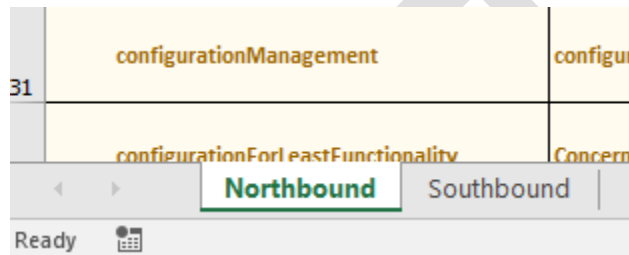


Figure 22: Northbound and Southbound Analysis Tabs

2062 4.3 Comparison of the Individual Analyses

2063 The artifacts produced in these analyses can be found in the links on the collaboration site
 2064 (see Library [115]).

2065 During the development phase of the framework, six analyses were completed from:

2066	CVRIA	Connected Vehicle Reference Implementation Architecture, developed
2067		by the US Department of Transportation to identify interfaces, use
2068		cases, and technical requirements. CVRIA covers interfaces between
2069		cars, clouds, infrastructure, and more [113][114].
2070	AWS	Amazon, as one of the world's largest cloud infrastructure providers
2071		offers a comprehensive set of service definitions and supporting
2072		implementation for IoT and smart cities.
2073	oneM2M	oneM2M is a technology aimed at providing a universal IoT and smart
2074		city infrastructure prevalent in Europe and Asia and sponsored by
2075		eight regional SDOs. It defines many details of a layered architecture
2076		with a simplified viewpoint.
2077	FIWARE	The FIWARE Foundation is responsible for the development of a
2078		series of open-source "Generic Enablers" that are focused on the
2079		Northbound interface but also support accessories to satisfy the
2080		Southbound.
2081	E015	E015 provides an interface documentation standard and is supported
2082		by an application catalog that simplifies the creation of supporting

2083 services and the acquisition of applications by potential
2084 municipalities.

2085 OpenIoT presents a minimal and therefore efficient model of the Northbound
2086 interface and provides a primarily gateway specification to enable the
2087 implementations to support the Southbound.

2088 Together, these exemplars offer broad coverage of the kinds of technology suites being
2089 offered for implementing IoT and smart city systems of systems.

2090 In addition to the six initial analyses, a comparison spreadsheet was constructed to allow
2091 for side by side comparison. In this initial effort, in order to compare the specific decisions
2092 made by each analyst, the reference links in the spreadsheets must be used to understand
2093 how the concerns were specifically addressed.

2094 There was generally good correlation among the concerns addressed, however noting that
2095 the individual technology suites were targeted at different perspectives on the deployment
2096 of smart city technologies.

2097 The authors believe that based on these analyses additional reviews can be performed to
2098 produce an even greater set of detail to be compared. As these technologies are compared,
2099 it should be possible for their authors, and other stakeholders, to migrate their works to
2100 have greater and greater overlap further reducing the barriers to integration of unlike
2101 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 the exciting enhancements to city life offered by this revolution of technology injections into municipal 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 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 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 possible 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 the most relevant features and 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.

6 References

6.1 Introduction and Overview

- [1] NIST (2017) Griffor, E., Greer, C., Wollman, D., and Burns, M., *Framework for Cyber-Physical Systems: Volume 1, Overview* (NIST Special Publication 1500-201).
<https://dx.doi.org/10.6028/NIST.SP.1500-201>
- [2] NIST (2017) Griffor, E., Greer, C., Wollman, D., Burns, M., *Framework for Cyber-Physical Systems: Volume 2, Working Group Reports* (NIST Special Publication 1500-202).
<https://dx.doi.org/10.6028/NIST.SP.1500-202>
- [3] NIST (2017) Wollman, D., Weiss, M., Li-Baboud, Y., Griffor, E., and Burns, M., *Framework for Cyber-Physical Systems: Volume 3, Timing Annex* (NIST Special Publication 1500-203).
<https://dx.doi.org/10.6028/NIST.SP.1500-203>
- [4] Retrieved from: <https://www.whitehouse.gov/blog/2015/09/16/launching-smart-cities-initiative-tackle-city-challenges-innovative-approaches>
- [5] Pierce, P., Andersson, B (2017), *Challenges with smart cities initiatives – A municipal decision makers' perspective*, Proceedings of the 50th Hawaii Conference on System Sciences, <http://hdl.handle.net/10125/41495>
- [6] Pollak, B (Ed.), Feiler, P., Gabriel, R., Goodenough, J., Linger, R., Longstaff, T., Kazman, R., Northrop, L., Schmidt, D., Sullivan, K., Wallnau, K. (2006). *Ultra-Large-Scale Systems: The Software Challenge of the Future*. Software Engineering Institute. Retrieved from: http://resources.sei.cmu.edu/asset_files/Book/2006_014_001_30542.pdf
- [7] Schon, D. (1984). *The Reflective Practitioner: How Professionals Think in Action*. New York, New York: Basic Books.
- [8] National Aeronautics and Space Administration. (2007). NASA/SP-2007-6105: *NASA Systems Engineering Handbook*. Retrieved from: <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080008301.pdf>
- [9] INCOSE. (2006). *INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities Version 3.0*, C. Haskins, Ed., San Diego, CA: INCOSE.
- [10] Buede, D. (2009). *The Engineering Design of Systems: Models and Methods*, Hoboken, NJ: John Wiley & Sons, Inc.
- [11] Lee, E. (2008). "Cyber-physical systems: Design challenges," International Symposium on Object/Service-Oriented- Real-Time Distributed Computing (ISORC). May 6, 2008, Orlando, FL, USA. Retrieved from: http://chess.eecs.berkeley.edu/pubs/427/Lee_CyberPhysical_ISORC.pdf

- 2163 [12] Xie, F. (2006). "Component-based cyber-physical systems," in NSF Workshop on Cyber-
2164 Physical Systems, Austin, TX, 2006. Retrieved
2165 from: <http://varma.ece.cmu.edu/CPS/Position-Papers/Fei-Xie.pdf>
- 2166 [13] Fischer, G., Hermann, T. (2011). "Socio-technical systems: A meta-design perspective,"
2167 International Journal for Socio-technology and Knowledge Development, vol. 3, no. 1,
2168 pp. 1-33, 2011.
- 2169 [14] Dodder, R., Sussman, J., McConnell, J. (2004). The concept of the "CLIOS
2170 process": Integrating the study of physical and policy systems using Mexico City as an
2171 example, Cambridge, MA: MIT ESD, 2004. Retrieved
2172 from: [http://web.mit.edu/mtransgroup/presentations/pdf/CLIOS%20Process%20Conce](http://web.mit.edu/mtransgroup/presentations/pdf/CLIOS%20Process%20Concept.pdf)
2173 [pt.pdf](http://web.mit.edu/mtransgroup/presentations/pdf/CLIOS%20Process%20Concept.pdf)
- 2174 [15] Kevrekidis, I., Gear, C., Hummer, G. (2004). "Equation-free: The computer-aided analysis
2175 of complex multiscale systems," *AIChE Journal*, vol. 50, no. 7, pp. 1346-1355.
- 2176 [16] Manganelli, J. (2013). Designing complex, interactive, architectural systems with CIAS-
2177 DM: A model-based, human-centered, design & analysis methodology. Pp. 64-89.
2178 (dissertation (Order No. 3609779, Clemson University)). Retrieved from:
2179 [http://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=2250&context=all_dissertati](http://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=2250&context=all_dissertations)
2180 [ons](http://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=2250&context=all_dissertations)
- 2181 [17] Xie, F. (2006). "Component-based cyber-physical systems," in *NSF Workshop on Cyber-*
2182 *Physical Systems*, Austin, TX, p.1. Retrieved
2183 from: <http://varma.ece.cmu.edu/CPS/Position-Papers/Fei-Xie.pdf>
- 2184 [18] Manganelli, J. (2013). Designing complex, interactive, architectural systems with CIAS-
2185 DM: A model-based, human-centered, design & analysis methodology. P. 61.
2186 (dissertation (Order No. 3609779, Clemson University)). ProQuest Dissertations and
2187 Theses, 690. Retrieved
2188 from <http://search.proquest.com/docview/1499237325?accountid=6167>.
2189 (1499237325)
- 2190 [19] Retrieved from:
2191 [http://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=2250&context=all_dissertati](http://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=2250&context=all_dissertations)
2192 [ons](http://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=2250&context=all_dissertations).
- 2193 [20] LEED Rating System, <http://www.starcommunities.org/rating-system/>
- 2194 [21] Retrieved from: [http://www.paladinoandco.com/law-requires-disclosing-energy-and-](http://www.paladinoandco.com/law-requires-disclosing-energy-and-water-consumption-to-reduce-usage/#.WBxJ6deV4UE)
2195 [water-consumption-to-reduce-usage/#.WBxJ6deV4UE](http://www.paladinoandco.com/law-requires-disclosing-energy-and-water-consumption-to-reduce-usage/#.WBxJ6deV4UE)
- 2196 [22] Retrieved from: <https://www.leedon.io/>
- 2197 [23] Retrieved from: <https://www.wellcertified.com/>
- 2198 [24] Retrieved from: <https://ecodistricts.org/>

- 2199 [25] Retrieved from: <https://www.link.nyc/>
- 2200 [26] Retrieved from: <http://money.cnn.com/2016/07/20/technology/google-deepmind-data-center/>
- 2201
- 2202 [27] Retrieved from: <http://www.buildingsmart-tech.org/future/linked-data/linked-data>
- 2203 [28] Retrieved from: <http://inlinepolicy.com/2014/the-global-race-for-drone-regulation/>
- 2204 [29] Retrieved from: http://www.nytimes.com/2016/09/20/technology/self-driving-cars-guidelines.html?_r=0
- 2205
- 2206 [30] Retrieved from: <https://www.wellcertified.com>
- 2207 [31] Global City Teams Challenge. Retrieved from: <https://pages.nist.gov/GCTC>
- 2208 [32] IES-City Framework, retrieved from: <https://pages.nist.gov/smartcitiesarchitecture/>
- 2209 [33] Retrieved from: [IDC FutureScape: Worldwide Smart Cities](#)
- 2210 [34] A. A. Cárdenas, et al., "Attacks against process control systems: risk assessment, detection, and response," in Proceedings of the 6th ACM symposium on information, computer and communications security, 2011, pp. 355-366.
- 2211
- 2212
- 2213 [35] Manganelli, J. (2014). *Reframing AECOO Project Delivery*. Journal of the National Institute of Building Science, 2(6), 12-15.
- 2214
- 2215 [36] Retrieved from <https://cyber.stanford.edu/research-and-publications/introduction-concept-cyber-social-systems>
- 2216
- 2217 [37] RobertasJucevicius, Irena Patašien, MartynasPatašius «Digital Dimension of Smart City: Critical Analysis» doi: 10.1016/j.sbspro.2014.11.137
- 2218
- 2219 [38] Public services provided with ICT in the smart city environment: The case of Spanish cities <http://bit.ly/1U3lwMA>
- 2220
- 2221 [39] "Tending the Artifact Ecology: Cultivating Architectural Ecosystems", Joe Manganelli, <https://datastructureformdesign.com/2015/10/04/tending-the-artifact-ecology-cultivating-architectural-ecosystems/>
- 2222
- 2223
- 2224 [40] Turck, M (March 28, 2016), Blog, *Internet of Things: Are We There Yet? (The 2016 IoT Landscape)*, retrieved on 11/17/2017 from <http://mattturck.com/2016-iot-landscape/>
- 2225
- 2226 [41] NIST Framework for Cyber-Physical Systems was published as three separation NIST Special Publications:
- 2227
- 2228 SP 1500-201 (<https://www.nist.gov/publications/framework-cyber-physical-systems-volume-1-overview>) and
- 2229
- 2230 SP 1500-202 (<https://www.nist.gov/publications/framework-cyber-physical-systems-volume-2-working-group-reports>)
- 2231

- 2232 SP 1500-203 ([https://www.nist.gov/publications/framework-cyber-physical-systems-](https://www.nist.gov/publications/framework-cyber-physical-systems-volume-3-timing-annex)
2233 [volume-3-timing-annex](https://www.nist.gov/publications/framework-cyber-physical-systems-volume-3-timing-annex))
- 2234 [42] Retrieved from [https://www.cisco.com/c/en/us/about/security-center/secure-iot-](https://www.cisco.com/c/en/us/about/security-center/secure-iot-proposed-framework.html)
2235 [proposed-framework.html](https://www.cisco.com/c/en/us/about/security-center/secure-iot-proposed-framework.html)
- 2236 [43] Retrieved from [http://www.zdnet.com/article/huawei-announces-smart-city-control-](http://www.zdnet.com/article/huawei-announces-smart-city-control-centre/)
2237 [centre/](http://www.zdnet.com/article/huawei-announces-smart-city-control-centre/)
- 2238 [44] Retrieved from [http://www.eunetair.it/cost/workshops/Brindisi/01-](http://www.eunetair.it/cost/workshops/Brindisi/01-PRESENTATIONS/01_Day1_TALKS/T14_BRINDISI_TD1105_Carli.pdf)
2239 [PRESENTATIONS/01_Day1_TALKS/T14_BRINDISI_TD1105_Carli.pdf](http://www.eunetair.it/cost/workshops/Brindisi/01-PRESENTATIONS/01_Day1_TALKS/T14_BRINDISI_TD1105_Carli.pdf)
- 2240 [45] Retrieved from <https://www.gsma.com/iot/iot-big-data/>
- 2241 [46] Retrieved from [https://www.tmforum.org/press-and-news/driving-towards-open-](https://www.tmforum.org/press-and-news/driving-towards-open-future-data/)
2242 [future-data/](https://www.tmforum.org/press-and-news/driving-towards-open-future-data/)
- 2243 [47] Retrieved from [http://www.oascities.org/wp-content/uploads/2016/04/Open-and-](http://www.oascities.org/wp-content/uploads/2016/04/Open-and-Agile-Cities-Lol-30-May-2016.docx)
2244 [Agile-Cities-Lol-30-May-2016.docx](http://www.oascities.org/wp-content/uploads/2016/04/Open-and-Agile-Cities-Lol-30-May-2016.docx)
- 2245 [48] Retrieved from [http://www.etsi.org/news-events/news/1152-2017-01-news-etsi-](http://www.etsi.org/news-events/news/1152-2017-01-news-etsi-launches-new-group-on-context-information-management-for-smart-city-interoperability)
2246 [launches-new-group-on-context-information-management-for-smart-city-](http://www.etsi.org/news-events/news/1152-2017-01-news-etsi-launches-new-group-on-context-information-management-for-smart-city-interoperability)
2247 [interoperability](http://www.etsi.org/news-events/news/1152-2017-01-news-etsi-launches-new-group-on-context-information-management-for-smart-city-interoperability)
- 2248 [49] Atkins, K., C. L. Barrett, et al. (2008). "An interaction based composable architecture for
2249 building scalable models of large social, biological, information and technical systems."
2250 CTWatch quarterly: cyberinfrastructure technology watch **4**(1): 46.
- 2251 [50] Barbato, A., A. Capone, et al. (2011). Forecasting the usage of household appliances
2252 through power meter sensors for demand management in the smart grid. Smart Grid
2253 Communications (SmartGridComm), 2011 IEEE International Conference on, IEEE.
- 2254 [51] Castro, M., A. J. Jara, et al. (2012). An analysis of M2M platforms: challenges and
2255 opportunities for the Internet of Things. Innovative Mobile and Internet Services in
2256 Ubiquitous Computing (IMIS), 2012 Sixth International Conference on, IEEE.
- 2257 [52] Chourabi, H., T. Nam, et al. (2012). Understanding smart cities: An integrative
2258 framework. System Science (HICSS), 2012 45th Hawaii International Conference on,
2259 IEEE.
- 2260 [53] Da Xu, L., W. He, et al. (2014). "Internet of things in industries: A survey." IEEE
2261 Transactions on industrial informatics **10**(4): 2233-2243.
- 2262 [54] Guillemin, P., F. Berens, et al. (2013). "Internet of Things Standardisation—Status,
2263 Requirements, Initiatives and Organisations." RIVER PUBLISHERS SERIES IN
2264 COMMUNICATIONS: 259.
- 2265 [55] Jazdi, N. (2014). Cyber physical systems in the context of Industry 4.0. Automation,
2266 Quality and Testing, Robotics, 2014 IEEE International Conference on, IEEE.

- 2267 [56] Jin, J., J. Gubbi, et al. (2014). "An information framework for creating a smart city
2268 through internet of things." IEEE Internet of Things journal **1**(2): 112-121.
- 2269 [57] Lee, J.-H. and M. Hancock (2012). "Toward a framework for smart cities: A comparison
2270 of Seoul, San Francisco and Amsterdam." INNOVATIONS FOR SMART GREEN CITIES:
2271 WHAT'S WORKING, WHAT'S NOT, WHAT'S NEXT. Oberndorf Event Center: 26-27.
- 2272 [58] Lee, J. H., M. G. Hancock, et al. (2014). "Towards an effective framework for building
2273 smart cities: Lessons from Seoul and San Francisco." Technological Forecasting and
2274 Social Change **89**: 80-99.
- 2275 [59] Nam, T. and T. A. Pardo (2011). Conceptualizing smart city with dimensions of
2276 technology, people, and institutions. Proceedings of the 12th annual international digital
2277 government research conference: digital government innovation in challenging times,
2278 ACM.
- 2279 [60] Paskaleva, K. A. (2009). "Enabling the smart city: The progress of city e-governance in
2280 Europe." International Journal of Innovation and Regional Development **1**(4): 405-422.
- 2281 [61] Samad, T. (2016). "Control Systems and the Internet of Things [Technical Activities]."
2282 IEEE Control Systems **36**(1): 13-16.
- 2283 [62] Schaffers, H., N. Komninos, et al. (2011). "Smart cities and the future internet: Towards
2284 cooperation frameworks for open innovation." The future internet: 431-446.
- 2285 [63] Sehgal, V. K., A. Patrick, et al. (2014). A comparative study of cyber physical cloud, cloud
2286 of sensors and internet of things: Their ideology, similarities and differences. Advance
2287 Computing Conference (IACC), 2014 IEEE International, IEEE.
- 2288 [64] Theodoridis, E., G. Mylonas, et al. (2013). Developing an iot smart city framework.
2289 Information, intelligence, systems and applications (iisa), 2013 fourth international
2290 conference on, IEEE.
- 2291 [65] Washburn, D., U. Sindhu, et al. (2009). "Helping CIOs understand "smart city"
2292 initiatives." Growth **17**(2): 1-17.
- 2293 [66] Winters, J. V. (2011). "Why are smart cities growing? Who moves and who stays."
2294 Journal of regional science **51**(2): 253-270.
- 2295 [67] Zanella, A., N. Bui, et al. (2014). "Internet of things for smart cities." IEEE Internet of
2296 Things journal **1**(1): 22-32.

2297 6.2 Smart City Application Framework

- 2298 [68] ITU-T (2014) *Common requirements of the Internet of things* (ITU-T Y.2066). Retrieved
2299 from [https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-Y.2066-201406-I!!PDF-
2300 E&type=items](https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-Y.2066-201406-I!!PDF-E&type=items)

6.2.1 Application Framework References: Breadth Assessment References

Built environment

[69] Web Page: Lisa Montgomery “10 Key Features in a Home Automation System”, 2015 (<https://www.electronichouse.com/smart-home/10-features-to-look-for-in-a-home-automation-system/>)

[70] White Paper: Accenture “Energy-Smart Building”, 2011, <http://czgbc.org/energy-smart-buildings-whitepaper.pdf>

[71] International Symposium: Hubert N. van Lier, Daniele De Wrachien “Land Use Planning: A Key to Sustainable Development”, XXX INTERNATIONAL SYMPOSIUM ACTUAL TASKS ON AGRICULTURAL ENGINEERING 2002, <https://air.unimi.it/retrieve/handle/2434/29169/70337/RelVanLierDeWrachien1.doc>

Water and wastewater

[72] Web Page: ITU News, “CT for smart water management”, 2011, <http://itunews.itu.int/en/570-ICT-for-smart-water-management.note.aspx>

[73] Schneider publication: Manuel Parra, “Smart Water Networks”, 2013, https://www.schneider-electric.com/solutions/il/en/med/84737322/application/pdf/1734_998-1198693_gma-gb_hr.pdf

[74] Technical report: ITU-T, “ITU-T Focus Group on Smart Sustainable Cities - Smart water management in cities” 2014, https://www.itu.int/en/ITU-T/focusgroups/ssc/Documents/Approved_Deliverables/TR-SWM-cities.docx

[75] Oracle White Paper: Oracle, “Smart Metering for Water Utilities”, 2009 <http://www.oracle.com/us/industries/utilities/046596.pdf>

[76] Web article: Hannah Rosenstein, “The need for Smart Wastewater Networks”, 2016, <https://www.swan-forum.com/wp-content/uploads/sites/218/2016/08/WIPAC-The-Need-for-Smart-Wastewater-Networks.pdf?x12236>

Waste

[77] Paper: Jose M.Gutierrez, Michael Jensen, Morten Heniusa, Tahir Riaz, “Smart Waste Collection System Based on Location Intelligence”, Procedia Computer Science Volume 61, 2015, Pages 120-127

[78] Project description: ANCI, “Smartness in Waste Management - Smart Waste”, 2013, http://www.ea.ancitel.it/resources/cms/documents/Scheda_di_Sintesi_progetto_Smart_Waste.pdf

Energy

- 2335 [79] Report: Jane Fae, Merlin Stone, "The Future of the Smart Grid: the ICT and data
2336 management perspective" 2012,
2337 [https://www.engerati.com/sites/default/files/StrategicReview-](https://www.engerati.com/sites/default/files/StrategicReview-TheFutureofTheSmartGrid_0.pdf)
2338 [TheFutureofTheSmartGrid_0.pdf](https://www.engerati.com/sites/default/files/StrategicReview-TheFutureofTheSmartGrid_0.pdf)
- 2339 Transportation
- 2340 [80] Report: ForeScout, "Smart Transportation", 2017, [https://www.forescout.com/wp-](https://www.forescout.com/wp-content/uploads/2017/04/Smart-Transportation-ForeScout-Solution-Brief.pdf)
2341 [content/uploads/2017/04/Smart-Transportation-ForeScout-Solution-Brief.pdf](https://www.forescout.com/wp-content/uploads/2017/04/Smart-Transportation-ForeScout-Solution-Brief.pdf)
- 2342 [81] Paper: Remigiusz Baran, Tomasz Rusc, Paweł Fornalski, "A smart camera for the
2343 surveillance of vehicles in intelligent transportation systems", Multimedia Tools and
2344 Applications, September 2016, Volume 75, Issue 17, pp 10471–10493
- 2345 [82] Report: Milestone, "Public Transport surveillance solutions", 2015,
2346 [https://www.milestonesys.com/Sharepoint/Verticals/public%20transportation/PublicTr](https://www.milestonesys.com/Sharepoint/Verticals/public%20transportation/PublicTransport%20vertical%20flyer_ENG_web.pdf)
2347 [ansport%20vertical%20flyer_ENG_web.pdf](https://www.milestonesys.com/Sharepoint/Verticals/public%20transportation/PublicTransport%20vertical%20flyer_ENG_web.pdf)
- 2348 Education
- 2349 [83] Wikipedia: "Learning analytics", 2017 https://en.wikipedia.org/wiki/Learning_analytics
- 2350 [84] Web Page: Nikos Andriotis, "8 LMS Requirements For Corporate Training", 2015,
2351 [https://www.efrontlearning.com/blog/2016/02/8-lms-requirements-for-corporate-](https://www.efrontlearning.com/blog/2016/02/8-lms-requirements-for-corporate-training.html)
2352 [training.html](https://www.efrontlearning.com/blog/2016/02/8-lms-requirements-for-corporate-training.html)
- 2353 [85] Government document: New Zeland Ministry of Education, "The role and potential of
2354 ICT in
- 2355 [86] early childhood education", 2004,
2356 <http://www.nzcer.org.nz/system/files/ictinecefinal.pdf>
- 2357 Health
- 2358 [87] Web Page: Orange, "Smarter healthcare in smart cities", 2016, [https://www.orange-](https://www.orange-business.com/en/magazine/smarter-healthcare-in-smart-cities)
2359 [business.com/en/magazine/smarter-healthcare-in-smart-cities](https://www.orange-business.com/en/magazine/smarter-healthcare-in-smart-cities)
- 2360 [88] Web Page: Kenny Walter, "Hospitals Get 'Smart' With IoT Technology", 2017,
2361 <https://www.rdmag.com/article/2017/09/hospitals-get-smart-iot-technology>
- 2362 Socio economic development
- 2363 [89] Policy paper: European Parliament, "eGovernment - In-Depth Analysis", 2015,
2364 [http://www.europarl.europa.eu/RegData/etudes/IDAN/2015/565890/EPRS_IDA\(2015\)5](http://www.europarl.europa.eu/RegData/etudes/IDAN/2015/565890/EPRS_IDA(2015)565890_EN.pdf)
2365 [65890_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/IDAN/2015/565890/EPRS_IDA(2015)565890_EN.pdf)
- 2366 [90] Paper: Massimiliano Bencardino, Ilaria Greco, "Smart Communities. Social Innovation at
2367 the Service of the Smart Cities", May 2014TeMA - Journal of Land Use, Mobility and
2368 Environment DOI10.6092/1970-9870/2533

- [91] Report ENEA: G. B. Sgritta et al. "Smart Cities Vs Societing", 2013, http://www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/risparmio-energia-settore-civile/2013/rds-par2013-154.pdf
- Public Safety
- [92] Web Page: Stefan Alfredsson "Smart City crime prevention: How the City of Detroit reduced violent crime by up to 50%", 2017, <https://www.axis.com/blog/secure-insights/smart-city-security/>
- [93] Wikipedia: "Surveillance issues in smart cities", 2017, https://en.wikipedia.org/wiki/Surveillance_issues_in_smart_cities
- [94] Paper: Tae-HeonMoon, Sun-YoungHeo, Sang-HoLee, "Ubiquitous Crime Prevention System (UCPS) for a Safer City", Procedia Environmental Sciences Volume 22, 2014, Pages 288-301
- [95] Paper: Maroš Lacinák, Jozef Ristvej "Smart City, Safety and Security", Procedia Engineering Volume 192, 2017, Pages 522-527
- [96] Paper: Jon Derek Loftis et al. "Emerging Flood Model Validation Framework for Street-Level Inundation Modeling with StormSense", SCOPE 2017

6.2.2 Readiness

- [97] ITU (June 2016). *Key performance indicators related to the use of information and communication technology in smart sustainable cities* (Recommendation ITU-T Y.4901/L.1601). <http://handle.itu.int/11.1002/1000/12661>
- [98] ISO (May 2014). *Sustainable development of communities – Indicators for city services and quality of life* (ISO 37120:2014). <https://www.iso.org/obp/ui/#iso:std:62436:en>
- [99] ISO/IEC (under development). *Information Technology – Smart city ICT indicators* (ISO/IEC AWI 30146). Draft Contribution retrieved from <http://isotc.iso.org/livelink/livelink?func=ll&objId=18555379&objAction=Open>
- [100] Scottish Cities Alliance (October 2014). *Smart Cities Readiness: Smart Cities Maturity Model and Self-Assessment Tool*. Retrieved from https://www.scottishcities.org.uk/site/assets/files/1103/smart_cities_readiness_assessment_-_guidance_note.pdf

6.2.3 Benefits

- [101] Shapiro, J. M. (2006). "Smart cities: quality of life, productivity, and the growth effects of human capital." *The review of economics and statistics* **88**(2): 324-335.
- [102] Schuurman, D., B. Baccarne, et al. (2012). "Smart ideas for smart cities: Investigating crowdsourcing for generating and selecting ideas for ICT innovation in a city context." *Journal of theoretical and applied electronic commerce research* **7**(3): 49-62.

- 2404 [103] Atkinson, R. D. and M. J. Mayo (2010). "Refueling the US innovation economy: Fresh
2405 approaches to science, technology, engineering and mathematics (STEM) education."
- 2406 [104] Nam, T. and T. A. Pardo (2011). Smart city as urban innovation: Focusing on
2407 management, policy, and context. Proceedings of the 5th international conference on
2408 theory and practice of electronic governance, ACM.
- 2409 [105] Zygiaris, S. (2013). "Smart city reference model: Assisting planners to conceptualize the
2410 building of smart city innovation ecosystems." Journal of the Knowledge Economy **4**(2):
2411 217-231.
- 2412 [106] Hardoy, J. E., D. Mitlin, et al. (2013). Environmental problems in an urbanizing world:
2413 finding solutions in cities in Africa, Asia and Latin America, Routledge.
- 2414 [107] Kramers, A., M. Höjer, et al. (2014). "Smart sustainable cities—Exploring ICT solutions for
2415 reduced energy use in cities." Environmental modelling & software **56**: 52-62.
- 2416 [108] Lombardi, P., S. Giordano, et al. (2012). "Modelling the smart city performance."
2417 Innovation: The European Journal of Social Science Research **25**(2): 137-149.
- 2418 [109] Rogerson, R. J. (1999). "Quality of life and city competitiveness." Urban studies **36**(5-6):
2419 969-985.
- 2420 Additionally, see linked reference text in the body of section 3.3.
- 2421 **6.3 Discovering Pivotal Points of Interoperability (PPI)**
- 2422 [110] ISO/IEC/IEEE FDIS 15288:2014(E), "Systems and software engineering - System life cycle
2423 processes,"
2424 <http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=6994196>
- 2425 [111] Condoluci, M, Sardis, F., and Mahmoodi, T (2014). "Softwarization and Virtualization in
2426 5G Networks for Smart Cities", Internet of Things. IoT Infrastructures: Second
2427 International Summit, IoT 360° 2015, Rome, Italy, October 27-29, 2015. Revised Selected
2428 Papers, Part 1: 179-186
- 2429 [112] Goessner, S. (May 2006). *Converting Between XML and JSON*. Retrieved from
2430 <https://www.xml.com/pub/a/2006/05/31/converting-between-xml-and-json.html>
- 2431 [113] Retrieved from: <https://local.iteris.com/cvria/>
- 2432 [114] Retrieved from: <https://local.iteris.com/arc-it/>
- 2433 [115] Retrieved from: <https://pages.nist.gov/smartcitiesarchitecture/library/>

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	<i>need to standardize an architecture reference model</i>
Scalability	<i>Handling: large number of device (and so of data), of applications and users (and so large amount of processing and storage => Cloud computing)</i>
Reliability	<i>reliability in communication, service and data management capabilities of IoT</i>
High availability	<i>required in service provisioning, data management, communication, sensing and actuating things of IoT</i>
Adaptability	<i>Adaptability to the new technologies emerging in the future</i>
Manageability	
2) Application support requirements	
	<i>The functional requirements from the development of IoT applications in different application domains</i>
Programmable interfaces	
Group management	
Time synchronization	
Collaboration	<i>among services or among devices</i>
User management	<i>creation, authentication, authorization and accounting of users</i>
Resource usage accounting	
3) Service requirements	
	<i>"service" as a set of functions and facilities offered to a user by a provider</i>
Service prioritization	<i>to satisfy the different service requirements of different groups of IoT users</i>
Semantic based services	<i>Semantic based services</i>
Service composition	
Mobility service	
Reliable and secure human body connectivity services	
Autonomic services	<i>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</i>
Service management	
Discovery services	
Service subscription support	
Naming and addressing	
Virtual storage and processing	
4) Communication requirements	
Communication modes	<i>Support to unicasts, multicast, broadcast, ...</i>
Communication control	<i>Support to Error control for communications and Time-critical communications</i>
Intelligent communication	<i>autonomic networking, content-aware communication and location based communication.</i>

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

2438 The previous requirement can be mapped within the CPS Framework, to complement the list of
 2439 requirements from case study analysis.

2440 *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 (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 thing
	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 thing

A.2 Application Categories and Subcategories with Sample Application Examples

Table 9: List of Smart City applications category/sub-categories

Category/Sub-category		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, reduce energy consumption and environmental impact, 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, 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 storm) 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	ghost pipe detection and

		- 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	- 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 the 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 business	
	Energy supply	to improve supply by integrating	demand/response management

	- decentralized renewable energy sources - to provide advanced energy supply service management: load management, demand-response, real time monitoring and control - to create large customer profiling	- systems - energy simulation systems - 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, transport mode selection and allowing 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 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 and roads	- video analytics-based surveillance 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 citizen 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 administration, and citizens and businesses	- e-government applications - open data platforms
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 of 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 citizen to provide information about criticalities	- mobile emergency services - cyber security 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 Sub-Category

Table 10: Requirements associated to the Category "Built Environment" sub-category "Smart Home"

	Sub-category	Aspect	Concerns	abstract requirements	Specific implementation requirements	ICT Architecture level	Geo-domain
	Smart Home	Functional	Actuation	capacity to analyze and elaborate received data	actuation capabilities	sensor; data; application; user-interface	Home

			and make decisions	
				smart appliances turning off electronics devices automatically security device management lights and thermostats management motorized shades audio/video equipment Internet connection
		Functionality	remote access	
		Controllability	to remotely control/access to the systems	remote control software fast and reliable network
		Performance	to provide feedback in time to act	real-time systems placement sensors
		Physical context	to exactly identify location of people	motion sensors placement 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	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 to define privacy policy	fast and reliable network real-time systems privacy protection mechanisms firewall
		Privacy		
		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	antispysware antivirus
	Timing	Logical time	to take into account the sequence of the events	
		Managing timing and latency Synchronization	to send data in a timely manner 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	

2447 Some other requirements are associated the other two “coordinates” of the breadth, which are
 2448 the “ICT levels” and the “Geo-domains”. These relationships are showed respectively in Table
 2449 11 and Table 12

2450 *Table 11: ICT levels and related requirements*

Aspects/Concerns	ICT Architecture level implementation requirements
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		Sensor/Actuator	Data	Application	User Interface
Functional	communication	sensors communication protocols (standard-based) sensor network communication protocols (based on standard)			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 (based on standard)	public interfaces	

	relationship between data		public, shared and standard data models	public interfaces	
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Table 12: Geodomains 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 system	sensor network local area network
	Boundaries	behavioral capacity to interact with system from other domains	software interfaces
District	Functional	communication capacity to exchange information internal to the system and between system	sensor network local area network 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 system	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

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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
FFTH Council Mana - 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 – Rapporto Smart 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

B.1.1 Smart Solutions for a greener Copenhagen

Copenhagen is one of the most livable cities across the world. The city planning is in favour of cyclist 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 world leading smart city solutions laboratory.

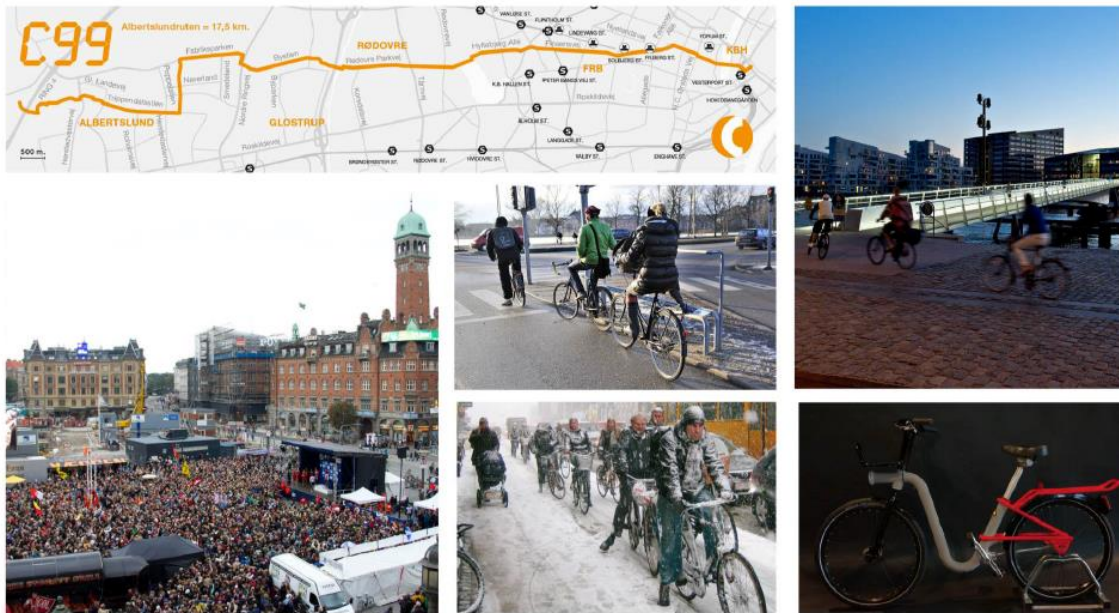


Figure 1: Copenhagen is considered the world's best city for cyclists. (At least 50% of people will go to work place by bike resulting re reduction of city's CO2 emission by over 20%, and at least 80% of cyclist feel safe and secure in Copenhagen in traffic)

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

Major achievement/key measures: Describe major projects/services that are on their planning stage, launched, or have been completed, and 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 & 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: data.kk.dk and opendata.dk)
- City Data Exchange enables purchase, sell and share 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 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.
- EnergyLabNordhavn – New urban Energy Infrastructure 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 and heating, energy-efficiency buildings and electric transport can be integrated into a systematic, flexible and optimized energy system.

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
- 180000 ton CO2 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 envisions becoming a world-renowned smart city with proactive developments of ICT. In 1998, the Hong Kong Special Administrative Region Government has 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 to be more sustainable and smarter, through intelligent and interconnected infrastructure, network and management system.
- The community to be more prosperous and equal, through and open and efficient collaborative digital ecosystem.
- Citizens and visitors to be more engaged with, and understood by businesses and government agencies via smart and interconnected touch points such as mobile application and website portal.
- Business to 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 on their planning stage, launched, or have been completed, or 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 fostering a vibrant ICT industry supported by program such 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 the 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 undertake web-based learning courses at home; and eElderly portal which encouraged the older to make better use of ICT.

- Ignite business innovation through exploitation of technology through establishing innovation and collaboration platforms, and 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 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; encourage data sharing across the 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.

B.1.3 Smart Singapore

The Smart Nation Program of Singapore was developed in 2014 in 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, create more opportunities, and to support stronger communities, in response to growing urban challenges of increasing population, aging infrastructure, and resource sustainability.

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

Major achievement: Describe major projects/services that are on their planning stage, launched, or have been completed 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, well-functioning public transport system and congestion charge, a vehicle quota system, to enhance 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 current ERP rates (electrical road pricing), sections of road under construction, traffic news, travel time calculator, and 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 promote the efficient use of existing parking facilities; and 4) Bus information system is 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

Emergency Medical Service (EMS) is operated by Singapore Civil Defense Force (SCDF) can be reached through mobile application, myResponders, which has been designed to increase survival rate from incidents such as increase survival rate from incidents such as out-of-hospital cardiac arrest, guiding them to respond before the SCDF arrives. Tele-medicine is another major aspect of Smart Nation initiative, which aim to promote the widespread use of wearable technologies such as fitness trackers, smart watches and even smart clothing which is 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.

3. Environment

Water shortages are continuous challenges for Singapore as 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. The Singapore Power provides mobile application for allowing citizens to view their utility bills, make payments, and understand their utility usage and submit meter readings, thus leads 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 to collect information on contents and location, can 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 detector can automatically turned off or adjust the luminance of the light in the building. 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, which focused on developing the enabling infrastructure and the testing of smart meters that equipped with communication capabilities. In 2012, as a part of IES project under phase 2, smart meters were installed at some residential household 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 mechanism

Singapore has emphasized the significance of connectivity between the government, industries and citizens. It has 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.

B.1.4 Smart London

London 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 cost estimated 2 billion pounds per year due to the congestion on London's roads, with Londoners spending 70 hours on average in traffic jams. Aging population also brought a huge pressure on the city's health care, social welfare system.

Major achievement/key measures: Describe major projects/services that are on their planning stage, launched, or have been completed 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 public accessible. This Datastore receives over 30,000 visits a month and more than 450 transport app has been created using open data. This encourages the development of products new business model, and creation of better, more cost effective, services for all Londoners.



Figure 1: a web page of London Datastore

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- **2. Leveraging London's research, technology & creation talent:** London is aiming to become a talent and world-class research base to solve its future challenges, to create new market opportunities, businesses and jobs, through launching programs such as Smart London innovation challenge, London Green Fund, and Smart London Export program to help emerge solutions to 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 the energy consumption.
- **4. Offering a "smarter" London experience for all:** Establish a Smart London Platform; invest in wireless networks in public spaces; Help visitors and Londoners to navigate the city easily.

B.1.5 Smart and Equitable New York City

NYC 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 dynamic, thriving economy, equally opportunities for all citizens to reach their potential and to succeed, and strong resiliency against shocks both natural and manmade.

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 to meet 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, or policy oriented strategies to be implemented along with cross-cutting efforts of the Smart Cities development.

Energy & Environment:

- Smart indoor lighting: as part of Accelerated Conservation and Efficiency (ACE) program of New York City, smart lighting solutions including LED upgrades and advanced lighting controls has been installed in many agencies building. LED lighting offers many benefits including low maintenance costs, high longevity as well as better quality lighting.
- Wireless water meters: New York City's Automated Meter Reading (AMR) system consists of 817000 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, saved over \$3 million per year by avoiding manual meter readings.
- Water quality monitoring: NYCDEP 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, traffic video cameras to collect traffic flow information.
- DOT and MTA introduced **Transit Signal Priority (TSP) system** to improve the efficiency and dependability of bus mass transit. 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 TSP system can request priority service when it approaches to 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 platform that integrates information from open government programs, local businesses, and citizens to deliver real-time hyper-local information on events, merchants, services for people, and provide security alerts in surrounding area to keep people safe. The Smart Screens can be accessed via WiFi on nearby smartphones, tablets, and computers.
- PlowNYC is a public-facing web app developed by DSNY to provide citizens real-time snow removal progress monitoring. The snow removal equipped GPS-enabled flip-phones can send GPS signals to data center every 12 seconds, where information can be processed and released on the PlowNYC website and DSNY's management tool --it is a low tech but high impact solutions.
<http://www1.nyc.gov/site/forward/innovations/smartnyc.page>

B.1.6 Smart Orlando

City of Orlando in Florida, U.S. is well known for attracting businesses of all types, and its significant inflow and outflow of population as being a world-famous tourist attraction. Orlando has applied information communication technology (ICT) and many smart city approaches to provide citizens and visitors with efficient services and perform city operation in an integrated and smart manner. The vision is to keep pursuing economic prosperity, through further encouraging tourism, 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 a tremendous burden for the energy & water demand, and civic infrastructures. Traffic control, business expansion, safety ensure are examples of demands that followed city growth.

Major achievement/key measures: Describe major projects/services that are on their planning stage, 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 provide massive public services connecting Orange County with surrounding city, towns and counties. The LYNX provides web-based services to customers for accessing information on ticket price, transit service areas, crashes, construction sites, roadblocks, tracking bus schedule & location in a real-time, and providing interactive map to allow users to find closest routes and bus stops.
- Parking information service: City of 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

- OCAAlert.net: it is an alert system that allows Orange County Government to contact citizens through emails, calls and messages during the emergency with real-time updates 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 resulting lower electricity and water consumption. Users can view their utility usage through online dashboard “MyUsage”.
- Smart waste information: “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 general public better understand and converse water by providing general information, improvement projects, regulation, and detailed data on water quality, water levels, and flows, habitats and ecology of local lakes, ponds, rivers, and watersheds, etc.

4. Citizen interaction and communication mechanisms

- Online education programs are offered by City of Orlando in collaboration with University of Florida, 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.

B.1.7 Smart Vienna

Vienna is aiming to become a vibrant metropolis and one of Europe’s most attractive cities based on conductive, long-term and structural measures of the city in all fields of

life: quality of living, sustainability, 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, CO2 emissions, and mobility patterns and hence quality of life of their citizen 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 in this context comprise the further restructuring of energy systems, the organization and financing of building rehabilitation including thermal rehabilitation as well as 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 achievement: Describe major projects/services that are on their planning stage, launched, or have been completed 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 the 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 correspond to a "living wage" standard; 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 to Vienna as a smart city.
- **Education:** Vienna is transforming many elementary school into whole-day school, enlarging the range crèches and kindergartens, and pursuing 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.

B.2 Business cases for implementing IoT enabling technologies

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

However, cities around the world need great amount of investment in infrastructures upgrade, mass transportation expansion, and energy transition, etc., and 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 megaprojects 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 facilitate economic growth of the UK, thus promote the sustainable development.

The capital cost of the project will be primarily financed in three ways : 1) through future tickets revenues generated by Crossrail services; 2) by business in London, developer contributions, and a Business Rate Supplement (BRS); 3) by national taxpayers through DFT's grant.

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

Table: Crossrail benefits and costs summary

Not only Crossrail will bring direct benefits to London, but also the impact of this project on the wider economy is 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 returns 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 term including increased tax receipts, which will exceed the initial project cost.

<http://webarchive.nationalarchives.gov.uk/20111005174015/http://assets.dft.gov.uk/publications/crossrail-business-case-update/crossrail-business-case-update-summary-report-july-2011.pdf>

<https://www.gov.uk/government/publications/2010-to-2015-government-policy-rail-network/2010-to-2015-government-policy-rail-network#appendix-2-developing-crossrail>

B.2.2 Building Energy Efficiency Business Case

An estimated number of 40% of the energy used and 1/3 of carbon emissions worldwide came from building sector, thus improving energy efficiency of buildings is of great significance. Cities can optimize buildings energy requirement 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 building 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 cost when combine the engineering and financing solutions together. 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 instalments of the advanced technologies without making any upfront investment.

<http://www.enpc-intrans.eu/wp-content/uploads/2015/07/EnPC-INTRANS-Deliverable-2.1-submitted-to-EASME.pdf>

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 to 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 formal 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 KPIs for the project? How were they established? How were they evaluated?
- What are the key city systems involved in the project (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 did 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 / initiative would have made the Smart city deployment experience simple / faster / more cost-effective?
- Are there any lessons learned that could be made 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 fund 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 accident 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 disadvantages
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 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 / measured to indicate the success of the project? Do these KPIs include maintenance and depreciation (life cycle costs)?	n/a
What one recommendation / documentation / initiative would have made the Smart city deployment experience simple / faster / more cost-effective?	n/a

Are there any lessons learned that could be made to 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.
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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're 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 5 years project that does not end with just a trial/pilot but the Goyang city will run services brought by this project. To run them, city needs the other fund/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, gather data and feed to policy making and let 3rd party providers bring new services. Those techs 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're 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'll measure it with cost-benefit analysis

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. and this also includes maintenance and depreciation aspects
What are the ongoing KPIs / measured to indicate the success of the project? Do these KPIs include maintenance and depreciation (life cycle costs)?	n/a
What one recommendation / documentation / initiative would have made the Smart city deployment experience simple / faster / more cost-effective?	although there are a lot of sensors in the market, but due to regulations/laws there are limited number of sensors. some of them are even really expensive. to enable globally interoperable smart cities, standard based sensors with proved performances.
Are there any lessons learned that could be made to 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
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 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 includes energy, health, housing, swmcol or waste management services and Public Transportation Services, Water Management and Tourism Alignment was facilitated through a steering committee involving all PPP consortium membership and 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 and 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 address all water management and sewage treatment issues in an integrated platform that allows the management of water to be itself an attraction and efficient 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, 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 _ risk management and insurance bookerage ASTI - all fiber network training, labor supply to fiber deployment companies Environmental management authority - environment cec approvals, monitoring impacts, third party validation

	Ministry of Planning MINISTRY OF Housing - place provided 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. Its deployed where the clients interface. At point of waste collection, birth, death. The solution included free WiFi in public spaces, buses and so on
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. 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 as a basis to bring more interactive electronic services to customers un community

	They also expanded the deployment of TT connect centers to community
If so, what were they? How have they been solved?	This is one of our greatest challenges. The whole issue if cyber security is a challenge. Currently laws are being reviewed addressing open data and cyber security 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 cyber security in pragmatic was.... i.e. 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 kpi 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 or 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 / measured 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 background to get on same page and explain project in terms understood by all on one page. A second would be get professional help to design, and align initiative early
What one recommendation / documentation / initiative would have made the Smart city deployment experience simple / faster / more cost-effective?	Smart cities go beyond using ict to effectively using resources to created 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 made to any relevant standards organizations?	Yes, both requirements and ppi 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 our project 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 our work along.
What are the KPIs for the project? How were they established? How were they evaluated?	Yes, they are based on our 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 infrastructure.
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 / measured 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 / initiative would have made the Smart city deployment experience simple / faster / more cost-effective?	No
Are there any lessons learned that could be made to any relevant standards organizations?	No

B.3.2 Property Set Two

Several smart cities 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, connectivity?
- What are the benefits to use that technical standard?
- What are the shortcomings of that technical standard in terms of smart city?
- What are the biggest portion of total deployment costs?
- What regulations/laws/etc. needs 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 3rd 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

What were the technical standards for service platform, data model, connectivity?

-> communications between devices and platform adopted oneM2M Release 1 standards

What are the benefits to use 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 portion 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 3rd 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 of Germany, Santander of Spain, Amsterdam of Netherland, Barcelona of Spain, etc.

B.3.2.2 Goyang, South Korea

What were the technical standards for service platform, data model, connectivity?

-> oneM2M global IoT standard

What are the benefits to use that technical standard?

-> convenience and rapidity for IoT service development

What are the shortcomings of that technical standard in terms of smart city?

-> time to education for developers and protocol dependency

What are the biggest portion of total deployment costs?

-> cost of personnel and materials

What regulations/laws/etc. needs to be changed/supported by government/municipality?

-> (not answered)

How long does the project take? (assuming commercialization after the project)

-> 2 years (2016 to 2017)

Is this a pilot project or already partially/fully commercialized? if commercialized, who runs the system/services?

-> (not answered)

Does the city provide open data API to be used by 3rd party applications? if yes, provide some examples.

-> open data API is provided (<https://data.smartcitygoyang.kr>) for example, quality of public water supply, parking, public bicycles, kinder gardens, etc.

What were difficulties during deployment?

-> complying with relevant laws and regulations

Was there any reference smart city?

-> Barcelona, New York

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 means 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 are those provided by their specifying organizations. This was done to ensure that the 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 as the global partnership project involving 8 regional SDO (Standard Development Organization) for common IoT service layer platform has been demonstrated as smart cities like 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 benefits of adopting oneM2M as smart cities base technology. By nature, smart cities consist of different services/systems/technologies and there comes the real strength of oneM2M as horizontal IoT middleware system.

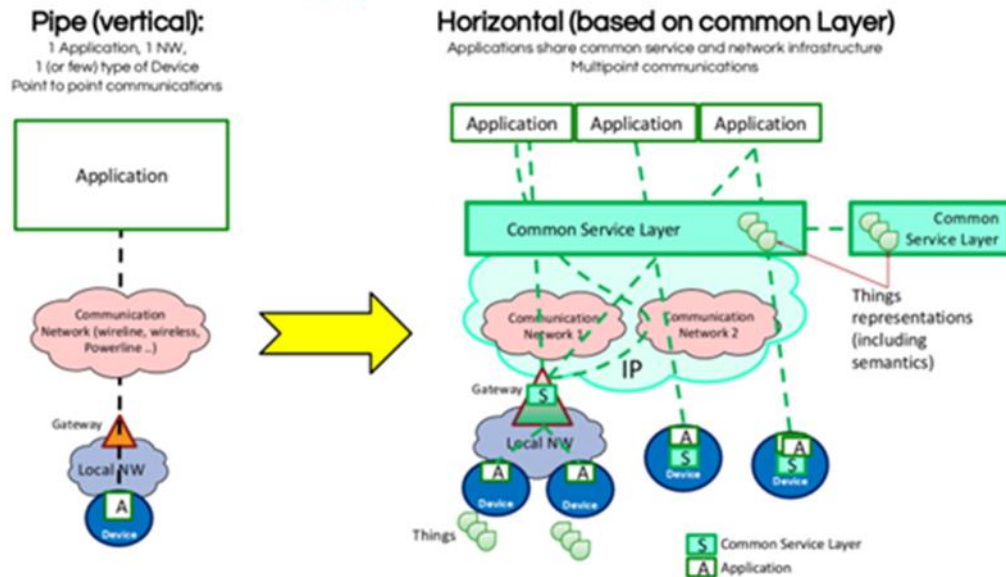


Figure 23: oneM2M High-Level View

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

For both, as the fundamental features of smart city platform, oneM2M provides security and data exchange. The security features cover basically authentication, authorization, etc. Especially oneM2M provides reach authorization schemes which 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 administrative applications still use oneM2M APIs to manage LwM2M devices already deployed in the field. This shows how existing devices can be integrated with oneM2M system in smart cities. oneM2M interworking also covers OCF, OMA DM, BBF TR-069. Several researches show that there will be much more IoT devices using cellular communications. To enable this, oneM2M provides 3GPP network interworking technologies as well.

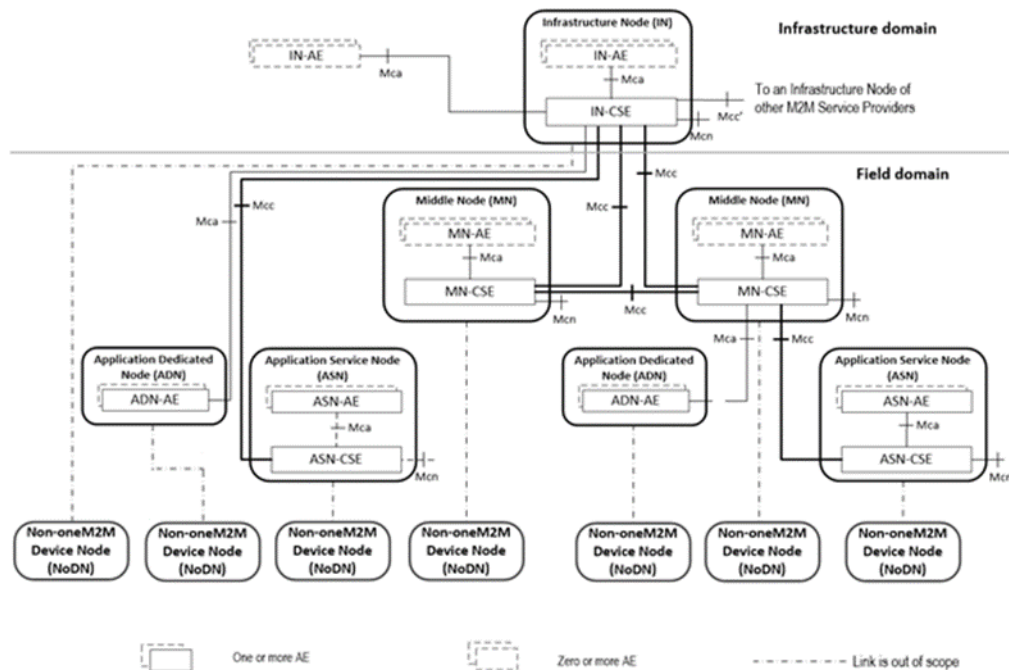


Figure 24: oneM2M Domain Interaction Model

Regarding the northbound APIs, semantics could be the prominent feature for smart city services. Reversing semantic discovery, query, 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. oneM2M server can log platform usages of applications and record them in standard format for accounting. This can be used to enable oneM2M system as part of data market place.

There are reach set of northbound specific APIs of oneM2M. For instance. subscription/notification and group management are the basic features since the first release. Recently in release 3 specifications, others like transaction management are also supported.

Finally, oneM2M provides official certification program which ensures conformance as well as interoperability among oneM2M-based products. This will provide benefits to consider oneM2M as candidate technology.

C.2 FIWARE

Figure 1: IES-City Framework Structure below depicts the Smart City Reference Architecture proposed by the FIWARE Foundation.

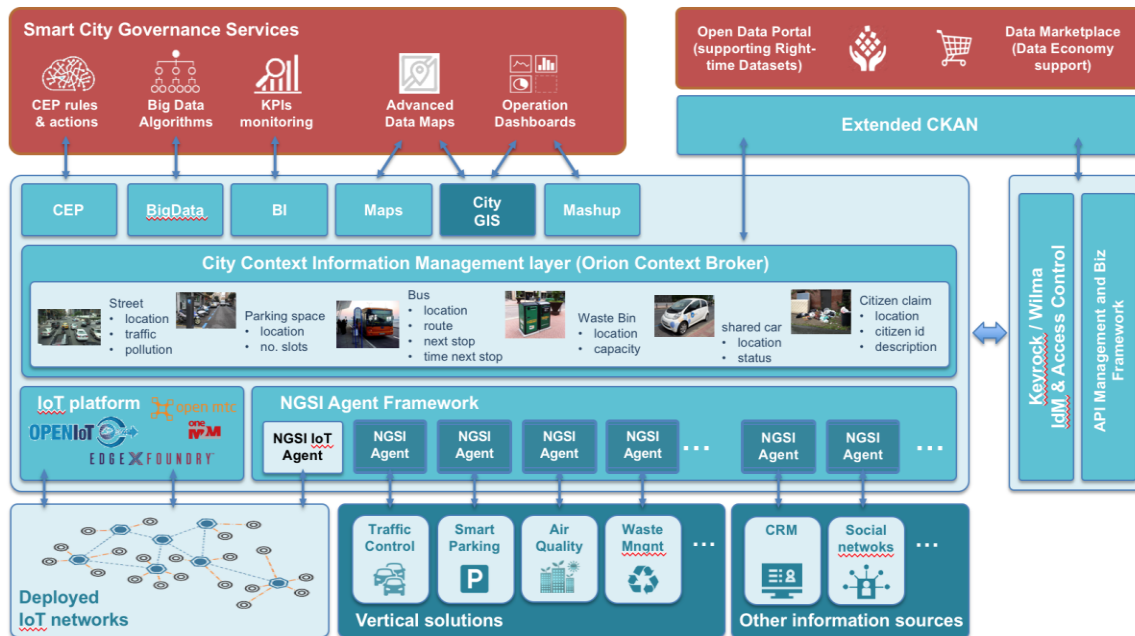


Figure 25: Smart Cities Reference Architecture Powered by FIWARE

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 like the City CRM (Citizen Relationship Management) systems or Social Networks (Twitter, Facebook, ...), 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 to gather updates on, or get access to, context information in right-time. This API is experiencing a growing adoption, as explained in section 1.2.3.

Multiple implementations of the Context Broker component can exist as far as they provide an API that is 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 (BigData analysis, Complex Event Processing, BI Analytics, etc.) which 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 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 right-time context information resources and related access control policies, thus enabling the transition from Open Data to Right-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. 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 26:

- **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 [Aberer07] 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 [Reference], 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 selects/enables the resources involved in service provision.
- **The Service Delivery & Utility Manager** performs a dual role. On the one hand, it combines the data streams as indicated by service workflows within the OpenIoT system in order 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 which 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, which 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.
- **The Configuration and Monitoring** component, which 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.

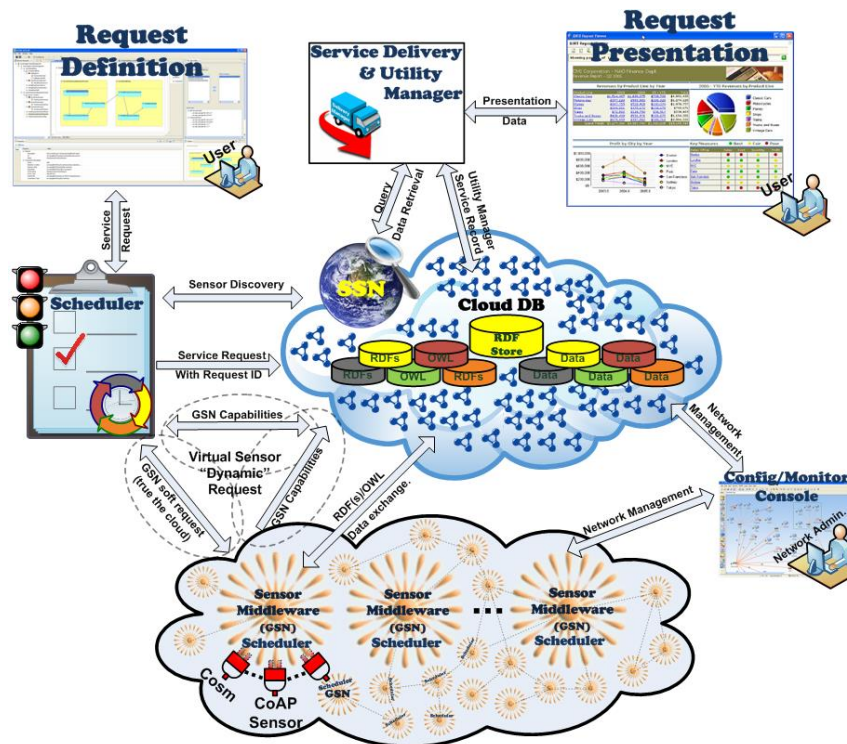


Figure 26: Overview of OpenIoT Architecture and Main Components

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 analyses 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 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 catalogue, 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 catalogue. 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/>.

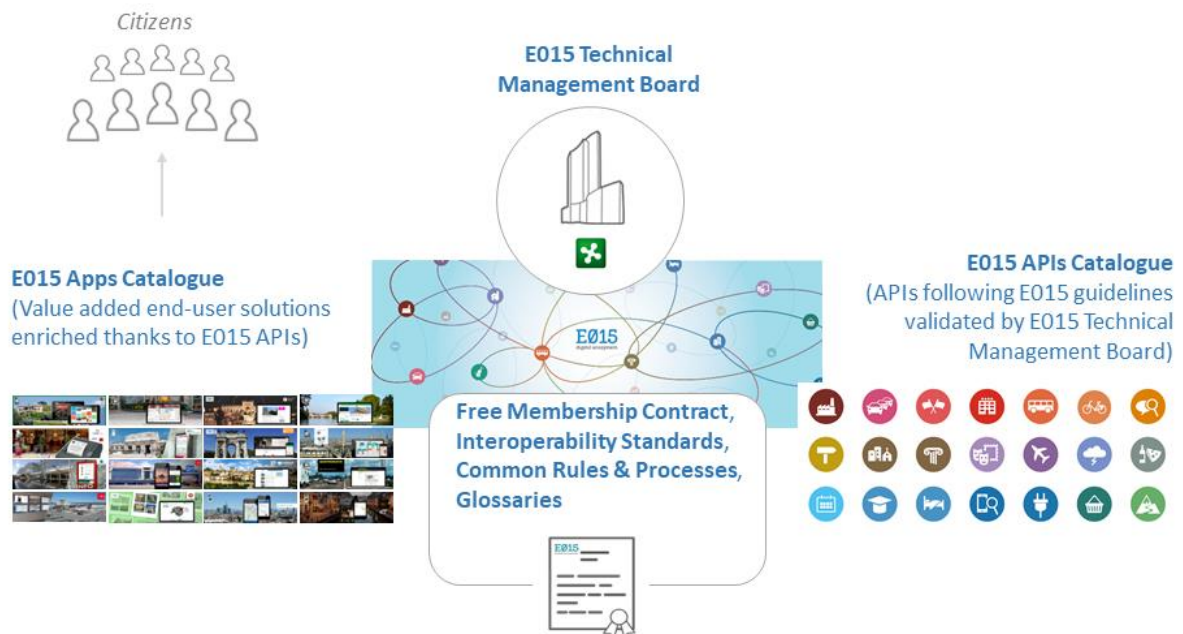


Figure 27: E015 Structure

C.6 Amazon

As a global, hyperscale cloud service provider (CSP), 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 of 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 of our services.

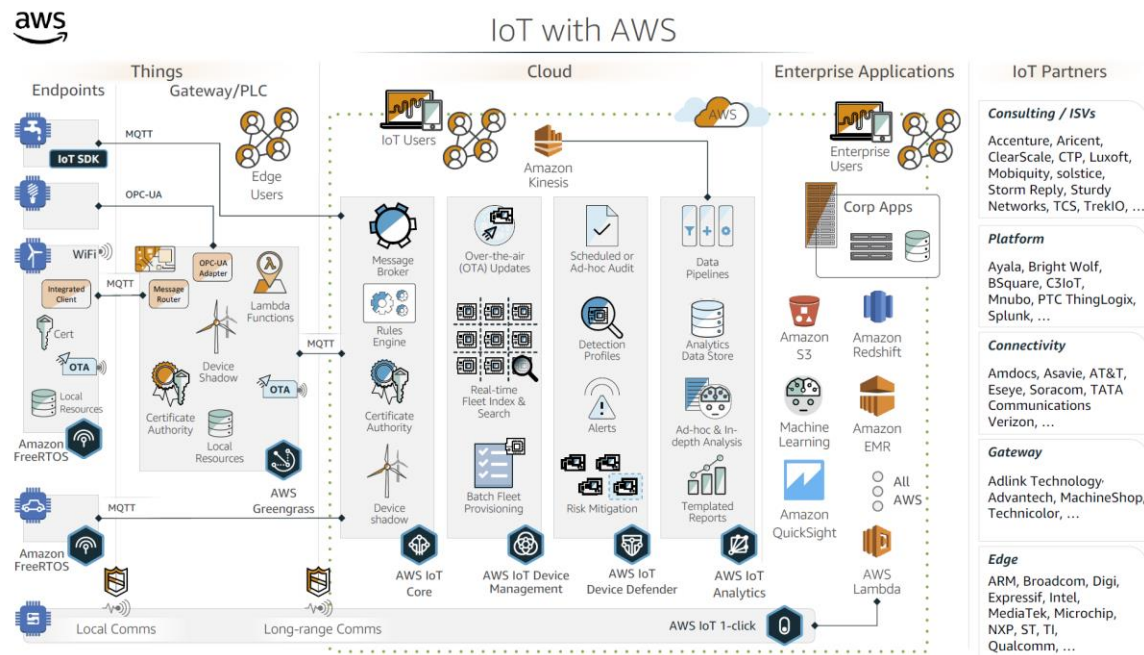


Figure 28: IoT with AWS

C.6.1 End-to-end security as a facilitator of IoT adoption.

The interconnectivity and interdependencies of “things” means 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. Since 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 Core¹ 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 Management² 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 lifecycle 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.³ 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.

¹ <https://aws.amazon.com/iot-core/>

² https://aws.amazon.com/iot-device-management/?nc2=h_l3_ap

³ <https://aws.amazon.com/iot-device-defender/>

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 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 its citizens and communities.

C.6.4 Global applicability as a catalyst for broad use.

Establishing globally applicable best practices carries a number of 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, Kansas City⁵ to increase operational efficiencies, reduce traffic fatalities, and improve natural disaster preparedness and recovery, among other benefits attained.

DRAFT