Facilitation of Smart City and Community Technology Convergence

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***Abstract*— The National Institute of Standards and Technology (NIST) has led a series of efforts designed to propel consensus toward reusable, standards-based smart city solutions through open collaborations with worldwide participation. This paper describes the novel strategy and methods used in these activities.**

Keywords—Smart City, Architecture, Framework, Composable, Interoperable, Internet of Things, Cyber-Physical Systems

I. Introduction

Cities and communities of all sizes and types seek to use advanced technologies to make communities safer and more secure, livable, and workable. There is power and value in the propagation of emerging cyber-physical systems (CPS) and Internet of Things (IoT) applications into smart communities. The global smart cities market size is projected to grow from USD 425 Billion in 2017 to USD 1.2 Trillion by 2022 [2].

However, for these solutions to be deployed, some degree of interoperability must be achieved to convince stakeholders that they will not be locked into a single vendor or vendor ecosystem, and, to reduce the costly barriers to integration of new features and capabilities.

For cities and their residents, interoperability is needed to provide for reduced costs, evolvability and extensibility, customization through modularity, expanded range of options and choices, and access for small/rural communities. For innovators and entrepreneurs, interoperability is desirable to enable expanded markets, opportunities for startups and small and medium enterprises (SMEs) including those that produce components but not end-to-end solutions, and platforms for innovation.

Matt Turck in 2016 [1] identified over 1200 organizations directly involved in providing technology to the IoT space which includes smart cities. There are dozens of organizations pursuing IoT and smart cities standards. Additionally, the availability of low-cost kits of powerful computing platforms makes it easy to "invent" an application overnight. [20] As a result, most smart city deployments are built with ecosystems of collaborating service providers that can principally interoperate only with themselves. Convergence among these ecosystems is needed because this diversity is an obstacle to the penetration of these technologies due to lack of replicability, composability and fears of vendor lock-in.

Diversity is a naturally occurring and positive property. However, uniformity is beneficial for lowering cost and achieving economies of scale. For several years, it has been apparent that widespread penetration of specific technologies into smart cities has indeed been hampered by lack of consensus resulting in many applications not progressing beyond pilot stage [3].

IoT, and more generally CPS, pose important measurement and interoperability challenges since smart city applications are inherently cross-sector, multi-technology, and at-scale instances of IoT. Overcoming these obstacles, and achieving the corresponding properties, can be facilitated through interoperability standards. An emerging global smart city technologies market is a growth opportunity for US industry, but conflicting local or regional standards could make it difficult for US companies to compete – especially SMEs.

NIST's Smart Grid and Cyber-Physical Systems Program Office (SGCPS) works to develop and extend the foundations and measurement science for CPS. The SGCPS considers smart cities to be a key opportunity to study CPS and IoT at scale incorporating all the complexities of cross-domain and cross-ownership collaborations between devices, applications, and humans.

In support of this mission and its research interests in Smart Cities and Cyber-Physical Systems, NIST plays a facilitator role in supporting smart city stakeholders and the evolution of IoT technologies deployed in smart cities and communities. This paper describes activities to assist cities and their technology service providers in achieving replicable and scalable smart city deployments. The overall goal is to foster convergence around best practices for smart cities by encouraging the collaboration between stakeholders for the common good and economies of scale.

How can a small part of a small agency have a positive impact in a large economic sector like smart cities? Overall, NIST has employed a unique stakeholder engagement strategy. NIST's strategy was to organize teams of cities/vendors/government/academics, giving voice in particular to cities to explain their needs and have partners respond to those needs. The teams were focused enough to make tangible progress on an identified opportunity.

This NIST strategy was that of growing collaborative concentric circles of stakeholders allowing them to absorb designs and concepts from one and other. This was also consistent with our technical strategy, which involved using systems engineering principles (NIST's CPS Framework [9]) to work bottom-up from device-level performance characterization to system performance to connected systems to infrastructures (local scale) to extreme-scale complex connected infrastructures.

Specifically, the problems to be addressed were: (1) costly, constrained custom solutions and associated market fragmentation and stranded investments [4]; (2) lack of interoperability; and (3) disjointed standards efforts.

The SGCPS approach to addressing each of these three problems are:

(1) Create forces for convergence:

  a. Connect cities/communities to one another to work together,
  b. Promote public-private partnerships that join industry and academia with city partners, and
  c. Nurture, identify, and replicate success.

(2) Identify emerging points of convergence, or Pivotal Points of Interoperability (PPI), in existing deployments and architectures.

(3) Use the CPS Framework [9] as a 'Rosetta Stone' to map the various standards efforts to one another, identify standards gaps, and facilitate prioritization of standards efforts.

Success can drive stakeholder convergence around best practices, interoperability, composability for smart city applications. This in turn speeds the penetration of these IoT and CPS applications so that the social and economic benefits can be realized.

The balance of this paper describes efforts by NIST's SGCPS to help facilitate voluntary convergence of applications of smart features in cities and municipalities.

II. Create Forces for Convergence

In order to encourage cooperation and coordination among stakeholders – communities, businesses, academic institutions, and non-profit organizations, SGCPS has undertaken a sequence of collaboration projects. These projects address the concerns of smart city propagation from two directions:

(1) A market-driven component that provides a place for smart cities and their vendors to collaborate and exchange lessons learned and best practices from their experiences; and

(2) A technology-driven component through analysis of deployment architectures and requirements analysis of smart city features.

Over the course of several years, these efforts have been successful at increasing the ability of smart city applications to be deployed and replicated, without picking winners or losers or making value judgements about the participants.

NISTs smart city convergence efforts began with the Smart America Challenge Workshop, held with the support of the Office of Science and Technology Policy (OSTP) Presidential Innovation Fellows program at the end of 2013. [5][6] This effort broadened in subsequent years to become the NIST Global City Teams Challenge (GCTC) [11] and the Internet of Things Enabled Smart City Framework (IES-City Framework). [19]

What follows is a description of the components of these activities that were brought to bear on the smart cities challenge.

A. *Partnering with Stakeholders*

A key element of NIST's approach has been strategic engagement with multiple classes of stakeholders:

Partner with agencies – Several agencies in the US federal government have smart city activities including OSTP, Department of Transportation (DOT), Department of Homeland Security (DHS), National Science Foundation (NSF), Department of Energy (DOE), National Telecommunications and Information Administration (NTIA), and International Trade Administration (ITA).

Partner with cities and communities – Through Global City Teams Challenge activities, smart city proponents and pioneers are provided a forum in which to discuss and compare their efforts to mutual benefit and leverage each other's investments and knowledge. GCTC teams with multiple cities also enable development of common sets of requirements to support development of more comprehensive and scalable solutions applicable to a broad set of cities and communities, thus increasing potential market size.

Partner with technology providers – Through the challenge activities, technology providers gain an opportunity to showcase their solutions and learn from each other.

Incubation of projects – Projects that begin as small pilots and even academic research can progress through stages of iteration, maturing, and gaining acceptance.

Kickoff / match making – A forum is created for potential ecosystem collaborators to meet and join to address potential applications together.

Expos – Expositions provide all collaborators the opportunity to showcase and learn from each other's achievements.

B. *Nurturing of participants*

Through the course of engagements in the various collaborative activities, active engagement with the participants and teams is achieved through teleconferences, email, in-person presentations and small workshops. Cities and communities in search of best practices with the goal to address common issues are encouraged to collaborate to deploy shared solutions. Technology providers and researchers establish project teams through partnership with cities and communities to demonstrate the value of their capabilities. Once successful examples are identified, technology providers are encouraged to work with additional cities and communities to replicate their success.

Additionally, several grant award opportunities from NIST and NSF were made available for the teams to jumpstart building partnerships and accelerate research and development.

C. Timeline

Over the course of three years, the market-driven component sequentially progressed with broader and broader degrees of convergence and interoperation of smart city applications. Figure 1: Successive Convergence in GCTC illustrates these achievements.

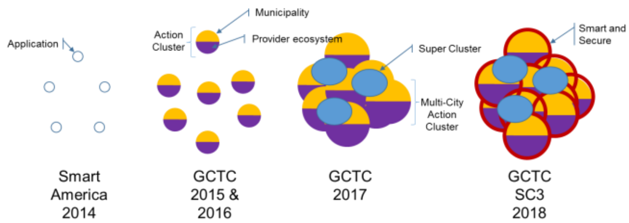

Figure 1: Successive Convergence in GCTC

1) *Smart America*

The Smart America Challenge (SmartAmerica) attempted to address the issue of fragmentation in IoT and CPS technologies and applications. Specifically, SmartAmerica sought to bring together organizations with IoT and CPS technologies, programs, and testbeds with the goal of demonstrating the potential of multi-domain collaboration of IoT and CPS to create tangible economic benefits, create jobs, save lives, and improve the overall quality of life.

Smart America was able to assemble over 100 commercial and academic organizations and government agencies in this collaboration. The program lasted a year culminating in a showcase event in 2014 with 24 cross-disciplinary teams, each of which was composed of multiple organizations. Participating teams were asked to develop cross-domain applications such as a "Crash-to-Care" scenario, where the victims of massive traffic accidents could be efficiently triaged and transported to appropriate medical facilities in a seamless manner. Through the process, SmartAmerica tried to identify cross-cutting themes shared by multiple IoT/CPS applications in different domains. SmartAmerica was also able to demonstrate a number of cross-domain applications with the potential for IoT and CPS to create tangible economic benefits or to save lives. For example, the Smart Emergency Response Team (SERS) [7] demonstrated that a combination of robots, sensor-equipped dogs, drones, and a command center could effectively collaborate to deal with several emergency response scenarios. The Closed-loop Healthcare team [8] demonstrated the importance of interoperability between in-hospital and in-home health monitoring systems, in providing better healthcare experiences while saving costs. Through such examples identified and incubated in its process, SmartAmerica demonstrated that it was not only possible, but also necessary, for different applications to collaborate to unleash the true potential of IoT and CPS technologies.

2) *Global City Teams Challenge*

Based on the success of Smart America, and recognizing that IoT and CPS applications were being deployed throughout the cities and communities around the world, the Global City Team's Challenge (GCTC) was created. [11]

GCTC was devised to provide a forum for demonstrations of smart city applications with tangible benefits to community residents. The collaborators in these demonstrations were provided with facilitation resources, encouragement, and a means to demonstrate their results in an annual conference.

A couple of important use cases are instructive. Imagine a new entrant into the smart city application space. Any prospective customer might ask a technology provider – "where is your technology deployed?" This sets up a "catch 22 [1]" situation. However, through GCTC this technology provider can be part of a team deploying a pilot application exposed at a GCTC exposition. And thus, the catch is resolved. Another case is of a team with a great idea and a willing municipality to try the idea. However, the absence of a critical component or skill prevents moving forward. At a GCTC "match making" event, the gap can be filled and all can pursue the opportunity together. Finally, even mature and well-funded participating enterprises can benefit from the availability of recognition in a forum where such achievements can be viewed by both existing and prospective customers.

Through the GCTC process, cities and communities can help each other find and replicate proven solutions which might have already produced successful results in other municipalities, at a lower cost than developing a similar solution from scratch. Technology providers can replicate successful solutions to a larger number of cities and communities and benefit from the economies of scale.

The design of GCTC includes the facilitated formation of "action clusters" which are teams of collaborators working voluntarily on one or more smart city deployments. Each action cluster consists of a host city or cities and the team of technology providers and researchers that together will realize the deployment.

Initial action clusters meet at an annual kick-off workshop where discussion and matchmaking occurs. During the course of the challenge, these groups make progress, are enhanced by interactions and addition of new team members, and new action clusters join by associating their efforts with GCTC.

At the end of the challenge year, the participants share in a showcase expo where their achievements can be viewed and otherwise celebrated.

These features enabled GCTC to attract hundreds of projects and a willingness to converge within this venue. The 2015 instance of GCTC featured 64 action clusters including over 50 cities from around the world at its expo. The 2016 version had 100 action clusters and 110 cities.

Based on the success of this GCTC model in its first year, NIST sought to increase the degree to which these deployments could be made more replicable. The experience with the action cluster teams of previous challenges revealed several recurring themes and classes of applications. NIST recognized the opportunity for further convergence by creating the notion of a "SuperCluster."

SuperClusters represent groups of action clusters around a common theme. For example, a transportation supercluster was formed to align the efforts of several smart city transportation related projects. To date super clusters have been formed as follows: Transportation, Public Safety, Utility (Energy, Water, Waste Management,) Data Platform/Dashboard, Public WiFi/Wireless, Data Governance/Exchange, Agriculture/Rural, and Education.

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[1] Catch 22 refers to the notion expressed in a satirical novel by Joseph Heller that considers the enigma of a goal that can't be achieved because it requires the prior achievement of said goal.

Each SuperCluster was encouraged to bring together multiple cities and applications which could be designed and replicated across multiple locales. These designs have been captured in "blueprints" which are published documents describing the common requirements and concepts behind the projects. Although every city and community is different to an extent, there are a number of common issues shared by groups of municipalities. SuperCluster blueprints document the technologies that can address common issues and help the cities and communities jumpstart planning and deployment of replicable and successful best practices without going through the painful and complicated process that other cities may have already gone through. During the 2017 round, GCTC SuperClusters have published 5 blueprints [12]. The action clusters nurtured in GCTC are actively replicating their solutions in multiple cities. Examples include Array of Things [13] being deployed in Chicago, Illinois and Portland, Oregon. The kiosk technology initially deployed in New York City is now also adopted by Bexar County, Texas [14]. The concept of the SuperCluster and its blueprints are referenced and modeled by the Virginia Smart Communities Working Group [15].

GCTC was able to attract several government and non-profit grant making organizations that helped fund several of the cluster activities. Included were NSF Early-concept Grants for Exploratory Research (EAGER), and NIST funded Replicable Smart City Technology (RSCT) grants. The goal of NIST's RSCT grant program was to identify and nurture the technologies with the best potential of replication in multiple cities and communities. RSCT grantees were encouraged to work with more than one municipality to share their solution. One of the NIST grantees was the StormSense team composed of seven cities and counties in Southern Virginia. The team has developed an inundation forecasting technology that can estimate water level rise during flooding events. Since flooding typically affects multiple municipalities, it made sense for the cities to jointly develop and deploy an interoperable solution that can be shared together. Although a variety of wireless technologies were adopted by different jurisdictions (WiFi, LoRa, cellular), collected sensor data were commonly brought into a shared cloud platform and injected into the same analytics model, which produced a comprehensive forecast covering a broader region than a single municipality [16]. Another NIST grantee working with Montgomery County, Maryland, has developed a data sharing and exchange platform that could easily connect multiple applications covering different domains such as transportation, agriculture and healthcare [17]. Multiple cities and communities including Washington DC are considering adoption of the platform. One of the action clusters in the 2015 and 2016 rounds, the Smart Mobile Operation OSU Transportation Hub (SMOOTH) project from the Ohio State University that tested a network of on-demand automated vehicles, became a core component of the proposal from the City of Columbus, Ohio, winning the $40 Million DOT Smart City Challenge in 2016 [18].

3) GCTC-SC3

SmartAmerica and GCTC have successfully nurtured and documented replicable smart city deployments over four years. The growing number of innovations, however, cannot be practically adopted at scale without serious considerations of security and privacy. Cities and communities are aware of the importance of planning for cybersecurity, privacy, and trustworthiness risks in their IoT and CPS deployments, but many of them lack a clear vision and the expertise to address risks in a systematic manner. Industry stakeholders are eager to address the issues in their products and solutions as well, but many of them struggle to find a clear business and engagement model with city and community customers.

In the 2018 round of GCTC, NIST has partnered with the US Department of Homeland Security (DHS) Science and Technology Directorate (S&T) to tackle these issues as a first order concern. DHS S&T has a strong track record of working with cybersecurity and privacy professionals and possesses abundant internal and external expertise on the relevant issues. Building on GCTC, NIST SGCPS and DHS S&T Cybersecurity Division decided to jointly run a 12-14-month program for teams of cities and innovators to demonstrate value and return on investment for designed-in trustworthiness for smart city deployments. This new program has been named the Smart and Secure Cities and Communities Challenge (SC3). In GCTC-SC3, action clusters are required to describe and demonstrate their considerations of security and privacy as well as the replicability and practical impacts of their solutions. It is the goal of the program to facilitate introduction of best practices for good security and privacy measures into the domain-specific SuperCluster activities and update their blueprints to include strong flavors of security and privacy. These blueprints can be used by cities and communities in adopting replicable, secure, trustworthy, and privacy-enhancing IoT and CPS solutions.

Throughout the 4 rounds of SmartAmerica and GCTC, NIST has built a strong community of smart city and IoT stakeholders who are willing to collaborate and deploy solutions in partnerships. In fact, over 180 action clusters composed of more than 400 technology providers and 160 municipal governments have participated in SmartAmerica and GCTC. At the time of this writing GCTC-SC3 is underway.

III. IDENTIFY EMERGING POINTS OF CONVERGENCE

While GCTC can be considered a market-driven effort at driving smart city convergence, a new activity was begun in 2016 called the Internet of Things Enabled Smart City Framework (IES-City Framework). The goal of this effort was to provide an impetus towards technical convergence. The IES-City Framework was released at the beginning of 2018 as a draft for review and anticipates a formal release around summer of that year.

A collaboration sponsored by eight national and international partners, IES-City Framework convened technology providers and researchers to define a taxonomy and methodology for comparing smart city applications and technical components.

IES-City established two key principles to help in this analysis: Pivotal Points of Interoperability (PPI) and Zones of Concern (ZofC). Additionally, a tool was created to enable the rapid review of smart city applications for their breadth and functional requirements, the readiness of a city or municipality infrastructure to mount or absorb applications, and the benefits to the city or municipality from these applications.

Discovering PPI

Pivotal Points of Interoperability is a powerful concept that recognizes that when you standardize everything, innovation can be frozen out; if you standardize nothing, interoperability will not be achievable. There is a range of optimal convergence in between these two extremes. There are many architectures and technology components in application of smart cities as previously established. Yet, on careful inspection, it can be seen that many such technology components were built with common building blocks: not through coordination but through similar independent technical choices in the absence of coordination. An easy example is the adoption of Internet Protocol [21] for the identification of endpoints in a communications network and a means to routing messages to them. Virtually all smart city and IoT applications rely on this PPI.

IES-City conceived that there are numerous such common decisions that were made independently by smart city decision makers in the design of smart city applications.

In order to expose these "consensus in place" choices, an analytical approach was devised using the *aspects* and *concerns* from the NIST CPS Framework [9]. The concept is that for any given part of a system or system of systems there is a set of concerns that are being addressed: privacy of data is a good example. The CPS Framework derived nine groupings of concerns termed *aspects* including functional, business, human, trustworthiness, timing, data, boundaries, composition, and lifecycle *aspects*. Within those *aspects* are over 100 individual subsidiary concerns. For example, the trustworthiness *aspect* consists of several concerns at the next hierarchical level: security, privacy, safety, reliability, and resilience. Note how this cluster of concerns encapsulates the family of concerns about the avoidance of harm in the design and deployment of CPS.

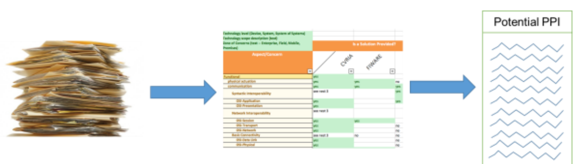

Figure 2: Revealing PPI

Using this concept, proponents of architectures and technology suites prominent in smart cities were invited to analyze their designs via a table where the rows were CPS Framework concerns (see Figure 2 Revealing PPI). While this approach does not intend to collate all the detail of their designs, it does serve the purpose of exposing the substantial choices made in technologies to address the concerns. By offering the ability to present these analyses side by side, it is anticipated that PPI can be revealed, i.e., common choices made in addressing a common concern.

Zones of Concern (ZofC)

As one reviews the concerns from the CPS Framework and the analyses provided by the proponents of technology suites, sets of services that address related sets of concerns emerges. These so-called zones of concern (ZofC) can result in service offerings that can simplify the distribution of responsibilities among teams working to deploy smart city applications – this is a form of convergence itself. For example, there are typically three kinds of collaborators in the deployment of smart city applications – the device vendor that makes IoT sensors and actuators and such, the application designer that composes information and provides the visible benefit to the citizens, and the infrastructure provider that maintains the glue that allows applications to be device agnostic and the device vendors to be application agnostic.

When a reviewer surveys the many architectures being proposed and deployed for IoT and smart cities, these distinct boundaries of responsibility can be seen in the architectural diagrams. Typical is the illustration of a "northbound interface" where applications including human presentation and analytics connect, and, a "southbound interface" where devices connect. Finally, the "glue" is an infrastructure where assembled sets of services addressing concerns can be made available at the appropriate northbound and southbound interfaces.

Application Framework Tool

Finally, to simplify initial research into smart city applications by less-technical stakeholders, an application framework tool was constructed around a set of categories and subcategories of smart city applications observed in deployments in GCTC and elsewhere around the globe. The categories and subcategories represent the breadth of known smart city applications.

These categories were analyzed in each of three dimensions:

Breadth, and functional and ICT requirements: For this dimension, each subcategory was analyzed against the CPS Framework *aspects* and concerns for high level requirements for their realization.

Readiness required by city infrastructures and citizenry to enable the mounting of these applications: rather than a complete set of metrics or maturity characteristics, this subset of key indicators was reviewed against each subcategory to determine general support for the potential deployment.

Benefits to the citizenry and city from the deployment of these applications: each subcategory was analyzed for the public sector, private sector, and citizenry benefits afforded. And within each benefit grouping economic, environmental, and social benefits were assessed.

Together, this analysis tool facilitates early evaluation of smart city technologies by smart city stakeholders allowing for optimized planning and specification of the evolution of their locales.

IV. The NIST CPS Framework as a Rosetta Stone

In communicating about an application, a terminology is helpful. If the terminology is specific to the application, the interpreter must first master the terminology before understanding what the terminology is used to describe. Unless this terminology is more widely used, the learning curve for understanding in each instance is a barrier to understanding. NIST recognized this need and addressed the design of such a Rosetta Stone of terminology for describing CPS and IoT. The NIST CPS Framework provides this common set of terminology.

CPS is an inherently complex topic because it is cross-cutting over enterprises, function, and technologies. For this reason, NIST convened a CPS public working group which produced the material allowing a NIST Special Publication of the CPS Framework in 2017 [9].

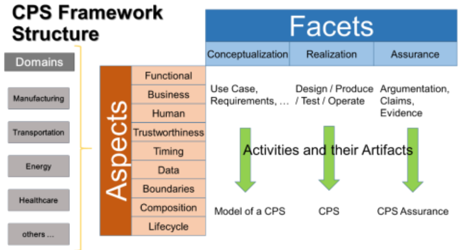

Figure 3: CPS Framework

As shown in Figure 3: CPS Framework, the CPS Framework identifies two axes of definition: *aspects* and *facets*.

Aspects allow for the categorization of concerns for which a CPS/IoT/Smart City application needs to address. It is asserted that all possible concerns that drive services are potentially in mutual support or conflict and therefore need to be treated uniformly. The *aspects* are further decomposed into concerns and sub-concerns producing a "concern tree." For example, the Trustworthiness *aspect* is comprised of concerns about security, privacy, safety, reliability and resilience. Security is broken down further into physical and cyber. And this pattern then repeats. *Facets* represent modes of thinking about CPS. They categorize activities performed over the lifecycle of the CPS. For example, the conceptualization *facet* includes activities such as business and use case development and requirements analysis. The result is a model of a CPS. The realization *facet* deals with activities that make up the design, implementation and deployment of the CPS. As such its result is the CPS itself. Finally, the assurance *facet* is about activities that result in an assurance case that the CPS performs as desired. The result of these activities is an assured CPS.

By using these simple concepts, the pertinent characteristics of any CPS and therefore smart community application can be discussed in a way that it is comparable with any other such description.

The result is that the many disjoint efforts to describe diverse smart city, IoT, and CPS applications can use this Rosetta Stone to reduce the barrier to understanding of what is described. The IES-City Framework made substantive use of this concept in its technical analyses.

V. Conclusion

Taken together, the activities facilitated by NIST and described in this paper provide a direction toward convergence in smart cities technologies. These results lower the cost and complexity of deploying smart city applications and importantly provide a means of growing them beyond their initial scope to add additional features as they become feasible and available.

NIST's approach of convening stakeholder groups allows this convergence to occur naturally and in open non-discriminatory forums to the benefit of all participants.

The use of the CPS Framework and common application documentation from IES-City Framework and GCTC Superclusters further inspire and inform NIST research into CPS and IoT.

For additional information on GCTC activities see https://pages.nist.gov/GCTC.

For additional information on IES-City Framework activities see https://pages.nist.gov/smartcitiesarchitecture/.

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