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CYBER-PHYSICAL SYSTEMS

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1. Overview of the Global City Teams Challenge (GCTC) Program

Smart cities are enabled by cyber-physical systems (CPS),[1] which involve connecting smart devices and systems—such as Internet of Things (IoT) technologies—in fundamentally new ways. When applied to diverse sectors such as transportation, energy, manufacturing, and healthcare, these technologies will enable cities and communities to improve services, promote economic growth, and enhance the quality of life. With 54 percent of the world's population now living in cities,[2] the development of smart cities and smart communities is becoming a major focus around the globe.

Hundreds of cities and dozens of technology providers are working to realize civic benefits and potential profits across a broad range of services and markets. However, the critical goal of interoperability is in danger of being overwhelmed by the large wave of isolated and customized solutions, along with the accompanying proliferation of proposed standards and protocols.

The task of providing leadership and useful guidance at this key point in time falls squarely within NIST's mission. But it is a daunting challenge, and NIST has carefully considered how best to make a meaningful contribution in the midst of this rapidly expanding, constantly evolving, and highly complex ecosystem.

The NIST Global City Teams Challenge (GCTC) program offers one strategy for addressing this need:

1. Stimulate the growth and assembly of a large and diverse set of smart city projects. At the same time, build a broad and deep community of organizations and individuals working in the smart city space.
2. Using this GCTC community of projects as the "at-scale testbed environment," apply a variety of analytical approaches to distill significant commonalities and identify quantifiable measures of success and effectiveness. These will be the technical outcomes.
3. Through an iterative process of conferences, expos, and networking, work with the GCTC community to encourage the entire smart city community toward greater interoperability, scalability, measurability, and replicability, identify best practices and encourage coherence.
4. Use insights from GCTC ecosystem, with its fast growing and diverse application space for CPS at scale and in real time, to inform development of the NIST CPS testbed and research program.

The following report briefly describes the GCTC 2016 program and then provides its status. The report then describes the analytical approaches that are being developed and applied in order to enable smart city interoperability, both in the United States and across the globe.

2. The GCTC Program: Goals and Impacts

Because many of today's smart city/community development efforts are isolated and customized projects, NIST has launched the Global City Teams Challenge (GCTC) to encourage collaboration and the development with industry leadership of voluntary, consensus standards. The Global City Teams Challenge's long-term goal is "to demonstrate a scalable and replicable model for incubating and deploying interoperable, adaptable, and configurable IoT/CPS technologies in smart cities/communities."

[1] https://pages.nist.gov/cpspwg/
[2] http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html

To put it simply, this program will create a collaborative environment where communities can benefit from working with others to improve efficiency and lower costs.

Partners in the challenge include US Ignite; the National Science Foundation (NSF); the U.S. Department of Transportation (DoT) and Department of State; the International Trade Administration (ITA); the General Services Administration (GSA); the Census Bureau; the National Telecommunications and Information Administration (NTIA) and the National Coordination Office/The Networking and Information Technology Research and Development (NCO/NITRD); organizations from the private sector, including IBM, Intel, GE, and AT&T; and the central governments of the Netherlands, Italy, South Korea, and Japan (See the GCTC website.[3] for more details on the complete list of partners and team members).

A. Goals

The Global City Teams Challenge aims to achieve its goals by facilitating partnerships and interconnections among city/community planners and project managers so they can identify common issues, as well as among technology innovators/providers so that they can form teams around specific issues such as transportation, disaster response, energy, healthcare, environment, and others; or any combination of the above. Then, GCTC fosters partnerships between the cities/communities and innovators/providers termed "action clusters" that bring together cities and innovators around these specific issues to jointly identify solutions that are scalable and replicable.

NIST, along with its partners, helps the action clusters to organize and identify common issues and interests and create possible solutions. Through this incubation process, NIST provides technical knowledge and consultation with the goal of encouraging the action clusters to coalesce around standards-based, interoperable, and replicable solutions with clear metrics of success. Through this process, GCTC also gives participants an opportunity to collaborate to address common standards and measurement challenges in deploying IoT and CPS, to contribute to the creation of a smart city framework (IES-City Framework), and to play a role in the development and application of key performance indicators (KPIs) that measure the multi-dimensional impacts of large-scale IoT deployments in the city/community environment.

B. Impacts

Since its launch in 2014, GCTC has recruited and incubated over 160 action clusters with participation from over 150 cities and 400 companies/organizations from around the world. Many of the projects nurtured through the program have made significant contributions in advancing the frontier of the IoT and the smart city landscape. For example, one of the GCTC teams, the Smart Mobile Operation OSU Transportation Hub (SMOOTH) team from The Ohio State University, became the central component of the proposal[4] from Columbus, OH, which won the $50 million prize in the DoT's Smart City Challenge. In fact, six out of the seven finalists in DoT's Challenge were cities that participated in GCTC, and many of these teams used their GCTC outcomes as a major component of their proposals. Another example of a successful GCTC action cluster is New York City's LinkNYC, which is a collaboration between the city, Qualcomm, CIVIQ Smartscapes, and Intersection, a portfolio company of Sidewalk Labs by Google.[5] It is being considered for replication in other cities including San Francisco, CA and Columbus, OH.[6] The PA

[3] https://pages.nist.gov/GCTC/
[4] https://www.transportation.gov/sites/dot.gov/files/docs/Columbus%20OH%20Vision%20Narrative.pdf
[5] http://www.recode.net/2016/7/1/12072122/alphabet-sidewalk-labs-city-wifi-sidewalk-kiosks
[6] http://www.crainsnewyork.com/article/20160317/TECHNOLOGY/160319866/linknyc-will-soon-pop-up-in-another-city

2040 project,[7] conceived at the GCTC kickoff meeting in November 2015 and nurtured through the two rounds of GCTC, has become the flagship smart city project of Washington, DC.

The Global City Teams Challenge has also made a significant impact in the academic research community. Nearly 15 universities received research funding from NSF's smart city EAGER program to work in partnership with GCTC in 2015,[8] and it is expected that the same program will support a dozen additional GCTC action clusters led by academic institutions this year.[9] In addition, the Array of Things (AoT) project from Argonne National Laboratory (ANL) and the University of Chicago, an action cluster in the GCTC 2015 round, received a $3.1 million award from NSF to build a city-wide sensor network testbed in Chicago, IL.[10] Georgia Tech University is working with ANL in GCTC 2016 to replicate and enhance the AoT platform in Atlanta, GA. As part of the CPS Week held in Vienna, Austria, in April 2016, GCTC created an academic workshop focusing on the smart city and IoT—the First International Workshop on Science of Smart City Operations and Platforms Engineering in partnership with the Global City Teams Challenge (SCOPE-GCTC). Twelve peer-reviewed papers were presented at the conference, and seven of them were published in the IEEE Xplore Digital Library.[11]

The Global City Teams Challenge's impact on the industry has also been significant. Many companies found new partners, new business opportunities, and sometimes new funding through GCTC. Some companies have been so inspired by GCTC that they have embraced the model as a new paradigm. For example, through its experience in GCTC, AT&T created a new smart city division that focuses on the bottom-up deployment model based on the playbook of GCTC, with AT&T's GCTC team lead as the technical head of the division. The AT&T smart city division is selecting ten U.S. cities for initial partnership and is investing millions of dollars in the cities/communities, including Montgomery County, MD.[12] AT&T is working with other companies—such as IBM, GE, Qualcomm, Intel, GE, IBM, CH2M, Cisco, Ericsson, and Deloitte—to create a platform that will incorporate diverse solutions to cover different sectors such as emergency response, transportation, and water management, with the emphasis on increasing replicability, scalability, and interoperability of the solutions.[13] As another example, the technology and the concept of the Autonomous Robotics for Installation and Base Operations (ARIBO) team, which was originally funded by the U.S. Army and incubated through the SmartAmerica Challenge and GCTC, became the core platform of Olli, a commercial self-driving electric shuttle manufactured by Local Motors. Olli is being deployed in Washington, DC, in partnership with IBM Watson.[14] In Montgomery County, Maryland, the Safe Community Alert Network Project (SCALE) team deployed one of the first city-scale low-power wide area network technologies (LPWAN) in the U.S. as part of its SmartAmerica/GCTC program. A generalized concept of the LPWAN is being standardized by the LoRa Alliance.[15]

The impact of GCTC on the international smart city landscape is also noteworthy. About 40% of the action clusters participating in GCTC are based in non-US cities. Cities from 13 countries participated in GCTC 2016. Among them, the Netherlands, Italy, South Korea, and Japan have actively collaborated with GCTC as foreign government partners. After the SmartAmerica Challenge, a predecessor of GCTC,

[7] http://octo.dc.gov/page/pa2040-project
[8] https://www.nsf.gov/pubs/2015/nsf15015/nsf15015.jsp
[9] http://www.nsf.gov/pubs/2016/nsf16036/nsf16036.jsp
[10] http://www.ci.anl.gov/press-releases/national-science-foundation-awards-31-million-array-things-project
[11] http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=7514735
[12] http://about.att.com/content/csr/home/blog/2016/06/the_smart_city_solut.html
[13] http://about.att.com/story/launches_smart_cities_framework.html
[14] https://www.washingtonpost.com/news/innovations/wp/2016/06/16/how-to-get-a-free-ride-in-a-self-driving-shuttle-this-summer/
[15] https://www.lora-alliance.org/

South Korea launched $100 million smart city/IoT initiative, which was dubbed "Smart Challenge" projects.[16] The Netherlands developed a national smart city initiative inspired by GCTC.[17] Nigeria developed five smart city projects using GCTC as a platform.

The Global City Teams Challenge has made an impact on the formation and execution of smart city/IoT strategies of U.S. government agencies, including the White House Smart City Initiative,[18] the DOT's $50M smart city challenge,[19] the NSF's Smart and Connected Communities initiative,[20] and other smart city programs at the Department of Energy (DOE)[21] and the Environmental Protection Agency (EPA). In the Department of Commerce, the ITA significantly increased its activities in smart cities through its partnership with GCTC, and the NTIA and the Census Bureau have both been closely working with GCTC.

The Global City Teams Challenge has inspired and influenced the formation of multiple new non-profit smart city activities, including the Metrolab Network[22] (35 pairs of U.S. universities and cities) and the Global Smart City and Community Coalition (GSC3),[23] all of which are designed to catalyze the collaboration between cities and technology providers to replicate and scale successful solutions that can improve the quality of life.

3. Brief History

The Global City Teams Challenge is an outgrowth of the successful SmartAmerica Challenge. Both programs were designed to incubate partnerships and enhance interoperability across technology deployments by showcasing participants' accomplishments towards greater integration.

Smart America: From December 2013 through June 2014, the SmartAmerica Challenge,[24] organized by two White House Presidential Innovation Fellows,[25] brought together more than 100 companies, universities, and other organizations to form teams that developed and applied IoT and CPS technologies.

GCTC 2015: Based on the success of the SmartAmerica Challenge, GCTC added another important group of stakeholders—the end users, i.e. cities and communities. GCTC Round One (September 2014 – June 2015) demonstrated that these technologies can improve the quality of life and provide socio-economic benefits.

GCTC 2016: GCTC Round Two (September 2015 – August 2017), also called GCTC 2016, extends the breadth and depth of these innovative programs and encourages deployment of replicable, scalable, and sustainable technologies that produce measurable and quantifiable benefits.

[16] http://www.businesskorea.co.kr/english/news/ict/8702-hyperconnected-society-national-local-govts-encourage-iot-big-data
[17] https://gsc3.city/wp-content/uploads/NL_Smart_City_Strategie_EN_LR.pdf
[18] https://www.whitehouse.gov/the-press-office/2015/09/14/fact-sheet-administration-announces-new-smart-cities-initiative-help
[19] https://www.transportation.gov/smartcity
[20] http://www.nsf.gov/cise/scc/
[21] http://energy.gov/eere/cities-leading-through-energy-analysis-and-planning
[22] http://metrolab.heinz.cmu.edu/
[23] https://gsc3.city/
[24] http://smartamerica.org/
[25] https://presidentialinnovationfellows.gov/

Since the SmartAmerica Challenge, the following major events have been held:

- SmartAmerica Expo (at Washington, DC, Convention Center, June 11, 2014; GCTC was announced)
- Global City Teams Challenge Kickoff (at NIST, September 29-30, 2014)
- Global City Teams Challenge Tech Jam (at NIST, February 12-13, 2015)
- Global City Teams Challenge Expo (at National Building Museum in Washington, D.C., June 1, 2015)
- GCTC 2016 announced as a key part of the Administration's Smart Cities Initiative (at White House Smart Cities Forum, September 14, 2015)
- GCTC 2016 Kickoff (at NIST, November 12-13, 2015)
- GCTC 2016 Tech Jam (at NIST, March 22-23, 2016)
- GCTC 2016 Expo (in Austin, TX, June 13-14, 2016)

4. Status of GCTC 2016 and the Expo in Austin, Texas

The second round of GCTC was launched in September 2015 as part of the White House Smart Cities Initiative.[26] This round of GCTC is made up of two phases for a total duration of 20 months. (See Figure 1.) For the last ten months, NIST and US Ignite, a major partner in GCTC, have worked together on the following activities:

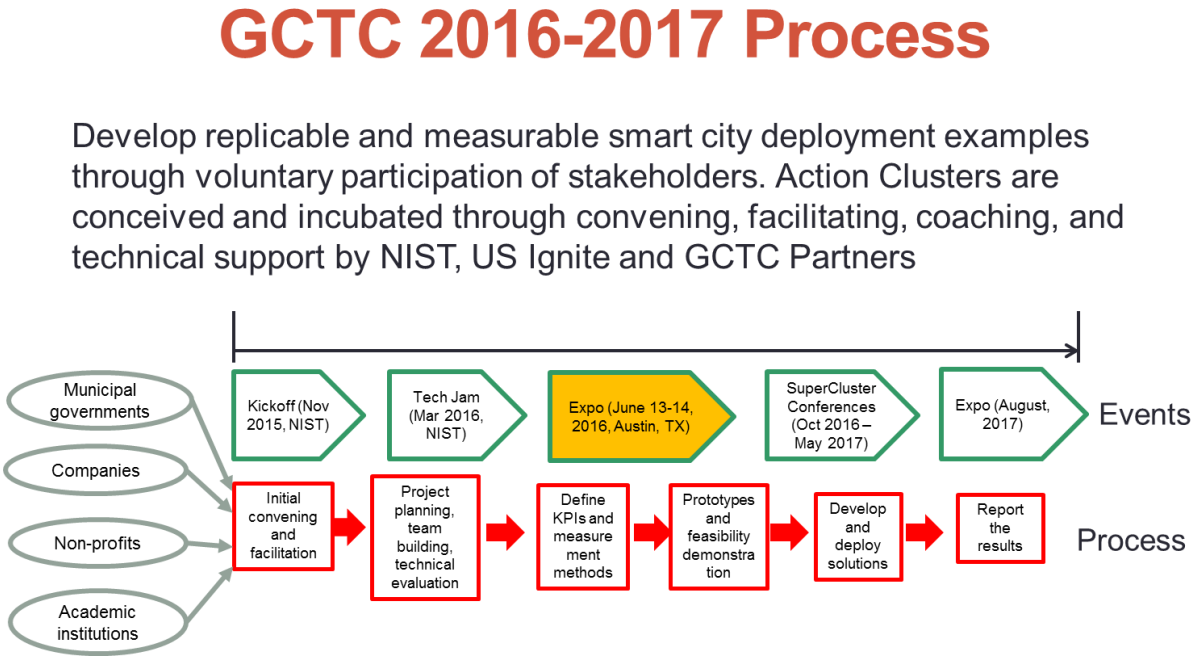

Figure 1: GCTC Timetable

[26] https://www.whitehouse.gov/the-press-office/2015/09/14/fact-sheet-administration-announces-new-smart-cities-initiative-help

- recruiting participating organizations;
- facilitating the formation of action clusters;
- helping the action clusters define their goals and key performance indicators (KPIs);
- identifying technology gaps and add partners to the teams; and
- driving the teams to focus on creating replicable and scalable solutions that can produce measurable and tangible impacts.

Over the course of Phase 1, GCTC has convened three major workshops and conferences, including the kickoff workshop in November 2015, the Tech Jam workshop in March 2016, and the GCTC Expo in June 2016. The kickoff workshop was attended by 350 participants and formed 16 initial action clusters, including teams from the U.S., Europe, Asia, and Africa. As of June 2016, over 100 action clusters were registered in GCTC, and these action clusters are working with 120 cities from 13 countries. Over 300 companies, universities, non-profits, and government agencies are participating in at least one of the action clusters.

The GCTC 2016 Expo—convened by NIST and US Ignite in Austin, Texas, on June 13-14, 2016—was the culmination of Phase 1 of GCTC 2016 and attracted over 2000 attendees to see the latest developments in the rapidly expanding smart city sector. Nearly 100 action clusters presented their projects including the goal, status, KPIs, and their plans of deployment and measurement for Phase 2, which will culminate in summer 2017. More than 110 cities from 11 countries gave on-stage presentations and hosted display booths at the Austin Convention Center.

Each presentation and/or booth featured the ongoing work of a GCTC action cluster—a team comprising leaders and experts from municipal, technology, and academic organizations. Many of the action clusters include at least two cities, an aspect of the challenge designed to move the smart city community toward scalability and replicability. Some action clusters are also looking to integrate smart city technologies across several sectors (e.g., energy, transportation, environment, emergency response, lighting, etc.). Brief summaries of each of the action clusters are available online.[27]

Four action clusters were highlighted at the plenary session:

- Connected Intelligent Transport (Portland, OR)[28]
- SCALE: Safe Community Awareness and Alerting Network (Montgomery County, MD)
- IoT-Based IDP Tracking and Monitoring System (Taraba, Nigeria)[29]
- Hyperlocal Testbeds for Citizen Science (Boston, MA)

As of June 2016, over 100 action clusters registered, including teams that were not able to participate in the Expo. The following is a breakdown of the action clusters by sector:

Category of sector served by action cluster:
General / Platform / Other – 18 projects
Transportation – 25 projects
Public Safety / Disaster / Resilience – 27 projects
Agriculture – 1 project
Healthcare – 3 projects

[27] www.globalcitychallenge.org
[28] https://www.portlandoregon.gov/bps/article/582392?archive=yes
[29] http://www.biztechafrica.com/article/nitdas-taraba-smart-city-project-receives-global-r/11578/#.V5ffLvkrIQ8

Energy & Utilities – 14 projects
Education & Workforce – 2 projects
Environment – 11 projects

Photo Credit: TechConnect

Phase 2 of GCTC 2016 (i.e. GCTC 2017) was kicked off at the Expo in Austin. In Phase 2, the action clusters are focusing on the real-world deployment and measurement of the impact of their solutions based on the suggested KPIs. All action clusters aim to present their results at the Phase 2 GCTC Expo in summer 2017. Phase 2 of GCTC 2016 adds special emphasis on the formation of "SuperClusters" – a collection of multiple action clusters and municipal governments that agree to collaborate around similar issues their cities are facing today. GCTC is hosting additional sector-specific workshops with the purpose of creating such SuperClusters between fall of 2016 and spring of 2017. Successful SuperClusters that achieve the goals of replication, scalability, and measurability will be highlighted at the Phase 2 GCTC Expo.

5. Technical Outcome of the GCTC Program: Framework, Key Performance Indicators, Cooperative Agreement Awards, and Technical Analysis

As described above in the introduction, a key element of the GCTC program involves treating this GCTC community of projects as the at-scale testbed environment or a community of practice that can be used to produce a variety of technical outcomes. The cadre of organizations participating in the current round of GCTC—over 300 organizations, including 120+ cities in 13 countries—provides NIST with a rich and

deep source of data, information, and knowledge about the rapidly growing smart city sector. This community of practice consists of the following components:

- a diversity of projects (involving topics from energy and emergency response to healthcare and transportation);
- a broad spectrum of organizations (including civic, federal, technical, academic, corporate, and non-profit);
- a range of architectures, platforms, and business models (including those being developed by ISO/IEC JTC1, IEC, IEEE, ITU, and various consortia); and
- many individual stakeholders (including both the developers and the intended users of these projects).

Now that the community of practice has been assembled, the next challenges for NIST are to leverage the community to identify the right questions and analyze the practices that will yield useful technical results related to standards and interoperability.

So far, the following four complementary programs are being pursued to probe different aspects of the smart city standards and interoperability issue:

A. IES-City Framework

The IoT-Enabled Smart City Framework (IES-City Framework) project is an outgrowth of the GCTC activity. While GCTC focuses on existing deployments by individual teams in a powerful bottom-up activity, IES-City Framework tries to distill from these efforts a set of consensus Pivotal Points of Interoperability (PPI) through a technical analytic activity. This activity is expected to lead to the discovery of common choices made by independent technologists providing goods and services to the smart city and IoT marketplace.

(i) The IES-City Framework Project

In order to organize this activity and motivate participation, a team of "partners" were recruited to lend their auspices to the effort. The partners for IES-City Framework include:

- ANSI – American National Standards Institute
- ENEA – Italian National Agency for New Technologies, Energy and Sustainable Economic Development
- ETSI – European Telecommunications Standards Institute
- FIWARE – An effort funded by the EU to develop smart city software components
- MSIP – Ministry of Science, ICT and Future Planning (South Korea)
- USGBC – U.S. Green Buildings Council
- TIA – Telecommunications Industry Association

These collaborators have formed a working oversight committee to help establish and guide the project. The output of the working group will be a white paper providing a consensus foundational analysis of smart city technologies that will support more interoperable and portable smart applications through the identification of PPI that can inform design for interoperability. Thus, the working group effort will facilitate the work being done by various standards organizations, consortia, and others.

The project has been organized according to the following schedule:

- March/April 2016 Kickoff Workshops at NIST and ENEA – mutual awareness and establish working groups
- June 15-16, 2016 Workshop in Austin, TX -- presentations of parallel interim results
- Fall 2016 -- composite draft framework
- August 2017 -- final draft framework

NIST provides overall project leadership, meeting resources, and collaboration sites.

(ii) Scale of the Problem

Two barriers currently exist to effective and powerful smart city solutions. First, many current smart city ICT deployments are based on custom systems that are not interoperable, portable across cities, extensible, or cost-effective. Second, a number of smart city architectural design efforts are currently under way (e.g. ISO/IEC JTC1, IEC, IEEE, ITU, and consortia) but have not yet converged, creating uncertainty among stakeholders. There is a lack of consensus on both a common language/taxonomy and on smart city architectural principles that could lead to divergent or conflicting standards outputs.

(iii) Pivotal Points of Interoperability (PPI)

If too many details are standardized, innovation is overly constrained. If nothing is standardized, the result is non-interoperable clusters of function that are not easily integrated. The concept of "Pivotal Points of Interoperability" (PPI) is that a limited set of consensus standardized interfaces exists in practice. These interfaces address the composition of cyber-physical systems without constraining innovation and in the absence of any formal agreement. The IES-City Framework seeks to elucidate the landscape of technologies being applied to smart cities and to highlight potential PPI.

(iv) The Working Groups

Three working groups were established—Application Framework, Consensus PPI, and Deployed PPI. These working groups are capturing technical details including:

- breadth of applications for smart cities;
- readiness of smart cities to absorb applications;
- technical choices by various technology suites that may be PPI; and
- case studies of multiple "SuperCluster" GCTC projects that may illustrate the PPI required to integrate multiple domains and technologies.

The working groups are analyzing technologies and deployments according to the architecture-agnostic CPS Framework produced by NIST in collaboration with a public working group in 2014-2016.

(v) The Path Forward

This endeavor began in March and April 2016 with twin kickoff workshops at NIST and ENEA. At those workshops, leadership and goals were established for the three working groups. The progress of the activities is captured and may be observed on a collaboration web site.[30]

Since the kickoff events, the working groups have been meeting and working on their concepts and implementing their charters. The goal for the "midpoint" workshop in June 2016 was to have the work

[30] https://pages.nist.gov/smartcitiesarchitecture/

begun and far enough along that the plans of each working group could be shared with the others. From this scaffold, the "shape" of the results was considered, and a shared vision was developed for the white paper to be completed by fall 2017.

These goals were quantitatively met. The key highlights from the June 2016 workshop include the following:

- The Application Framework working group further refined their plans and identified some writing targets to help form their deliverable.
- The Consensus Framework working group worked with oneM2M to refine their detailed analysis through application of the CPS Framework's "Aspects" and "Concerns."
- The Deployed PPI working group refined their plan to interact with a selected set of cities that represent SuperClusters, which will be used to obtain initial information and then more detailed information to help the group populate its case studies.

B. Hybrid KPIs for Smart City Applications

NIST's mission of advancing measurement science becomes more complex in areas such as the smart city sector, in which there is a strong interaction between technology, economics, and human factors. It is a research challenge in complex systems, such as smart cities, to determine the best properties to measure and the ways to measure these properties.

Cities are complex systems[31] and provide many services, each of which must be evaluated in its own way. But the provision of these services often impacts the provision of other services. Many existing smart city solutions, such as those implemented in GCTC action clusters, are designed to have a measurable impact on KPIs. For example, the success of a smart parking application may be measured by increased revenues from parking meters and decreased numbers of parking tickets. However, the parking solution, in optimizing the usage of parking spaces (for example, by identifying available parking spaces), may thereby decrease traffic congestion from drivers looking for parking spaces. Decreased traffic congestion may then have a measurable impact on public health. Similarly, a separate air pollution reduction project by intentionally diverting traffic may negatively impact the performance of the city's transportation system.

Most existing works on KPIs for smart city applications—such as ISO/TS 37151:2015,[32] ISO 37120:2014,[33] ITU-T FG-SSC,[34] and CITIKeys[35]—present their findings in the form of ontologies. Correlations and tradeoffs between KPIs are not well considered. Many suggested KPIs measure only a single aspect and do not represent the "system of systems" nature of smart cities. In addition, many KPIs are still based on the Likert scale,[36] which is qualitative and anecdotal. Lastly, the relevance and sensitivity of each KPI to specific projects is not well defined.

[31] https://books.google.com/books?id=yX-YAQAAQBAJ&lpg=PR7&ots=2jOm2_I8lA&dq=science%20of%20cities&lr&pg=PR7#v=onepage&q=science%20of%20cities&f=false
[32] http://www.iso.org/iso/catalogue_detail?csnumber=61057
[33] https://www.iso.org/obp/ui/#iso:std:iso:37120:ed-1:v1:en
[34] http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx
[35] http://www.citykeys-project.eu/
[36] https://en.wikipedia.org/wiki/Likert_scale

In this project, a system of "hybrid KPIs" will be designed to help city officials and smart city project directors measure the systemic impact of their smart city deployments. This system will be piloted in a few action clusters, including the Local Sense Lab in Boston, with a future goal to extend it to other action clusters in the GCTC program.

This project strives to answer the following questions:

- For a given project or application, what are the right KPIs? Or how can the right KPIs be selected?
- What are the (prior) relationships and interdependencies between multiple KPIs for a particular project?
- How do we predict the impacts (positive or negative) on multiple KPIs after the deployment of solution(s)?
- What measurement methods are needed for KPIs?

Possible outcomes and impacts for this project include the following:

- Publication or technical report on hybrid KPIs in smart cities.
- A model that relates variation of KPIs to other KPIs.
- A methodology for connecting this model to deployed applications and updating this model with respect to new data.
- A pilot, web-based dashboard displaying KPIs related to deployed applications in Boston's GCTC Action Cluster, the Local Sense Lab, and in other participating action clusters.
- A basis for exporting the methodology and tools developed by the research team, including the Boston-led action cluster and others, to other action clusters and other participating teams.
- A basis for improving Boston's CityScore[37] and smart city measurement methods from other SDOs and working groups.

C. Replicable Smart City Technologies Cooperative Agreement Program

The main purpose of the NIST Replicable Smart City Technologies (RSCT) Cooperative Agreement Program is to support cities and communities to take a lead role in the team-based GCTC effort. The active participation of communities in Challenge teams is critical if the innovations that emerge are to be viable and feasible in the real world. However, many community budgets do not provide for the travel, staff time, and other costs associated with participating in a research, development, and deployment effort that is being undertaken in concert with commercial and academic sector innovators. Therefore, the RSCT program provides funding to enable awardee City/Community Partners to play a lead role in the team-based GCTC effort to advance the measurement science of replicable, standards-based smart city technologies that provide measurable performance metrics, meet the needs of cities and communities of all types and sizes, and provide platforms for entrepreneurship and innovation.

The applications received in response to this program covered a wide range of technological topics and were geographically diverse. They were reviewed in accordance with the federal funding opportunity (FFO) announcement.[38] Applications from the City of Portland (OR), Montgomery County (MD), the City of Bellevue (WA), and the City of Newport News (VA) were selected for funding.

[37] https://www.boston.gov/cityscore
[38] https://www.nist.gov/document-360

The City of Portland is conducting lab and field test deployments of low-cost air quality sensors and provide guidelines for how to use such sensors to measure urban air pollution. Standardized procedures for using low-cost air quality sensors are needed, because the state of "off-the-shelf" sensor technology is not useable, due to sensitivity limitations and interference issues. The major performance goals for this project are to produce and share a framework for use of low-cost air quality sensors for urban air quality applications. These guidelines are intended to provide design and implementation plans for other cities to implement similar sensor monitoring networks. Such guidelines and procedures enable other cities to benefit from the City of Portland's lessons learned, helping keep costs down and accelerating replication.

Montgomery County is working to stabilize, document, and enhance the underlying platform developed during the Safe Community Alert (SCALE) project in preparation for its replication elsewhere. The County will take the prototype platform into a new stage of development that will allow it to be replicated locally and in other communities. This will take the form of an easy-to-launch cloud platform using a redundant message-broker approach to maximize uptime and scalability of an Internet of Things (IoT) backend, as well as a bidirectional Low-Power Wireless Personal Area Network (LoWPAN) implementation of edge sensors in varied test environments. The team will also extend the platform to Pittsburgh, PA, through a partnership with Carnegie Mellon University and the Metro21 initiative.

The City of Bellevue is building dashboard interfaces for sharing data among city departments, and in the future, with the public. The proposal utilizes a layered, open, standards-based architecture. The CityPortal will seek to normalize the data/formats of different sources and provide interoperability. Because the architecture is agnostic to communication protocol and can integrate with any software architecture or sensor technology, it can be more flexible, scalable, and modular. The City will work to develop data analytics and improve city-wide interconnectivity of department systems, including Police and Fire, Civic Services, Transportation, Utilities, Environmental, and IT. The ultimate goal is to enable all city staff to leverage real-time data in their daily activities to improve efficiency and effectiveness.

The City of Newport News is developing urban hydrodynamic models to predict flood events. The models will be validated using a suite of 12 proposed water-level sensors. The predictive modeling tool with a focus on visualization will be useful in planning for emergency responses. The proposed system is composed of three main elements—deployment of 12 water-level sensors, development of urban hydrodynamic models to predict inundation, and crowd-source data collection through an app. This project is a collaboration between Virginia Institute of Marine Science (VIMS) and eight partner cities in the Hampton Road region of Virginia. Some of the partner cities, such as the City of Norfolk, are already working on a broader resilience strategy, so this project will help Norfolk reach these goals and increase situational awareness of storm events for the entire region.

NIST staff are working closely with the awardees to gain insights and lessons learned from their projects, such as their approaches on technology integration and architecture. Kickoff meetings have been held with the awardees and monthly coordination calls are held. NIST staff are encouraging awardees to document their progress and lessons learned in technical publications to broaden the knowledge base for the field and further enhance replicability of the solutions.

6. Next Steps for GCTC

Since its launch in 2014, GCTC has accomplished:

- Recruited and incubated over 160 action clusters with participation from over 150 cities and 400 companies/organizations from around the world.

- Created a unique public-pricate partnership platform for smart city stakeholders to test and deploy advanced technologies in a collaborative manner.
- Enabled dozens of universities to receive research funding from NSF's smart city EAGER program to work in partnership with GCTC.
- Inspired the industry to invest in the deployment of the CPS/IoT solutions in collaboration with cities and communities.
- Inspired foreign counties to adopt similar approaches in their smart city and IoT national strategy and funding programs.
- Inspired and enabled other US government agencies to launch federal programs on smart cities and communities.
- Influenced the formation of multiple new non-profit smart city activities.
- Spun-out other CPS programs on smart cities and communities at NIST

The June 2016 GCTC Expo served as the mid-point of the GCTC 2016-2017 initiative. In the following months, the 100+ action clusters have continued to refine and deploy their projects, and measure progress toward goals and key performance indicators. The Challenge will culminate in 2017 with a major Expo event, planned for August 2017 in Washington, D.C.

The outcome of the hybrid KPI research will be made available to all GCTC action clusters, which will then be able to use the model to predict, measure, and verify the impact of their solutions. GCTC will encourage the action clusters to present their results at the GCTC Expo in 2017.

During Phase 2 of this round of GCTC (July 2016 – August 2017), GCTC is encouraging the existing and future action clusters to form multi-city, multi-team "SuperClusters" organized around the common project objectives and shared solutions in the sectors including transportation, public safety/emergency preparedness/disaster recovery/resilience, energy/water/waste management, city data platform/dashboard, public Wi-Fi and healthcare. NIST provides convening opportunity, partnership development, and technical support for action clusters that commit to participate in a SuperCluster. Technical support offered to SuperCluster participants includes guidance from NIST, US Ignite, and GCTC partner organizations. NIST has worked with several cities and communities to host and lead sector-specific SuperCluster workshops from October 2016 to May 2017. The project teams under the RSCT Cooperative Agreement program have been major participants in SuperClusters. Multiple sub-SuperClusters are expected to emerge from each sector, depending on the specific topics of interest. For example, the transportation group may produce sub-SuperClusters on traffic management, smart parking, and autonomous vehicles. Public safety/disaster workshop may produce sub-SuperClusters on flood prediction, data resilience, and crime reduction. GCTC expects to feature the results of SuperClusters throughout the year, and to recognize the most successful ones at the GCTC Expo in 2017.

The SuperClusters are jointly developing and deploying standards-based, replicable, scalable solutions to address the critical needs of the participating cities. Every SuperCluster is developing a sector-specific smart city blueprint/playbook that will help the cities and communities to 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. The blueprint/playbook will be the foundation for the next rounds of GCTC. This direction, which represents the next step for the rapidly growing and evolving smart city sector, promises to provide a rich ground for future NIST research and technical contributions.

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