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1 Accomplishments

1.1 What are the major goals of the project?

1. Adapt Argonne's "Waggle" resilient embedded systems platform for urban installation and for production in quantities of 100s.
2. Purchase and install a network of 500 platform nodes in Chicago to operate as a national science instrument, providing (a) open data on urban weather, environment, and activity, (b) opportunity to test, at scale, new sensor and embedded systems technologies, and (c) a programmable environment for in-situ deep learning and other computational and communication capabilities, such as for event or condition detection involving multiple sensors, images, sound, etc.
3. Make measurement data openly available to the science community and the general public, in forms and through mechanisms that maximize the utility of the data and the potential for evaluating its quality for scientific use.

1.2 What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?

1.2.1 Major Activities:

1. Deployed and rigorously evaluated several dozen early test systems in Chicago and Denver to validate system packaging and internal resilience in winter weather, identifying and addressing several moisture and electronics resilience issues.
2. Developed an RFI for assembly partners and evaluated multiple options, gaining insight into cost factors.
3. Worked with City of Chicago Department of Transportation to test and refine installation procedures to streamline associated costs and scheduling.
4. Developed, evaluated, and refined system assembly processes to correct reliability issues caused by improper material handling and assembly with initial contractor. Evaluated multiple assembly partners and contracted for up to 150 units from selected partner.
5. Developed detailed assembly manuals, hardware test jigs, and software testing procedures, and all associated documentation for third party assembly and system burn-in.
6. Evaluated new and/or experimental sensors for inclusion in platform.
7. Partnered with multiple City of Chicago departments, community groups, and scientific research groups to finalize site selection criteria and locations for the first 100 installations.
8. Established processes, pipeline, and facilities for characterization and evaluation of planned and future air quality sensors (particles, gasses) in partnership with scientists at Argonne, UChicago, DePaul, City of Chicago, City of Portland, and Cook County.
9. Tested and improved data APIs to enable scientists to combine measurement data with other relevant urban data such as related to infrastructure, economic activity, city operations, etc.
10. Developed an initial partnership plan with Intel for manufacture of platform internals, enabling mass-manufacture and lower cost and complexity for assembly. Moreover, the plan will promote and support ease of reuse of the open source hardware/software platform.
11. Established governance and policy bodies per documented project policy and governance.

1.2.2 Significant Results:

Significant results below are aligned with major activities in 1.1.1 above. Many results from FY16 set the foundation for the items below, and thus the FY16 annual report is useful for context. In April 2017 we also published a paper summarizing the motivation, scientific requirements, design, and early experience building AoT, as noted in section 2 (Products)

1. Platform Improvements. (a) Discovered electronic instability caused by extreme cold, in which the platform supervisor board ("WagMan") did not properly interpret heartbeat monitor from system controller (Linux device) following a power interruption, and thus preventing full system restart. This was temporarily fixed through a hardware patch (to correct a threshold error in a specific transistor) and has been corrected in the design of the next iteration of the board. (b) Discovered moisture

and related corrosion on internal system components, leading to failure of some units in the field following rapid temperature changes. Did extensive analysis and field testing, with assistance from industry partners Cisco and Intel, leading to (i) a double-layer Plexiglas dome on the top of the unit (for camera), (ii) addition of a Gore-Tex vent to allow system breathing without importing moisture, and (iii) more completely sealing the main enclosure at the power entry point and sensor cable entry point, which had originally been sealed with porous foam (to prevent insects entry but to allow breathing) but had also allowed moisture to be drawn into the enclosure.

2. <u>Request for Information on Assembly</u>. We analyzed multiple responses to an assembly RFI [included along with an associated FAQ as supplemental documents], noting that without more detail about assembly procedures the assembly charges varied from $500 per unit to over $2000 per unit. Further, more details would be required to determine the costs for managing the supply chain of inventory, obtained from 30 different sources with varying lead times. We thus reoriented the assembly approach to focus on 6-8 batches of 20 units, making the supply chain a straightforward set of bulk purchases rather than managing inventory over time—a much more complex operation.
3. <u>Streamlining City Installation Process</u>. Based on initial documentation procedures for installation, several modifications were made. First, the mounting of units and wiring of poles were separated, enabling the electricians to install wiring in locations as their schedule allowed, without needing to wait for nodes to be available. Moreover, the original installation design called for three types of node configurations, allowing for three possible angles of installation, with camera angled right, straight, or left. The rational for this approach was to minimize the interference of traffic fixtures mounted above the AoT nodes, by mounting nodes perpendicular to overhead obstructions (primarily fixture arms). However, this approach would require that installers would have units specifically designated for particular locations, not only adding complexity to the installation coordination, but also demanding tight coupling between node assembly (need n right, m left, and p center versions) and assembly locations. Consequently, we simplified installation so that all nodes have center-aimed cameras and can go in any location. [sample pages from installation guide and full assembly manual included as supplemental documents]
4. <u>Establishment of Third Party Assembly Line</u>. Working with our design partner (PDT, Inc.) we originally contracted the assembly of 75 units to be completed by September 2016. The initial 20 units had high failure rates, traced back to deficiencies in assembly procedures and associated instructions. A full review in October resulted in moving assembly to PDT's parent company, Telefonix, in November. When the Telefonix assembly line had not produced working units by early January another review was done. In this review we reviewed (a) high rates of component failures, with no pattern across units that would indicate a particular component or vendor as the source of the failures, and (b) the assembly procedures and documentation, including software loading and testing. Telefonix requested more extensive system loading and testing software and documentation. When assembly had not successfully resumed 4 weeks later our team visited the assembly line and discovered that (a) the assemblers were not using the documentation, but rather "eyeballing" assembly from an uncertified unit, resulting in incorrect and/or incomplete wiring, and (b) the assemblers were handling the electronic components in a fashion that caused physical damage (explaining the high rates of component failures reviewed in January). At this stage, reviewing the RFI responses in terms of pricing and details, we elected to extend our partnership with Surya Electronics, a partner of three years producing our custom circuit boards. We negotiated a 20-unit assembly contract with Surya, and within six weeks they had successfully worked with our team to establish the assembly line, train assemblers, and produce 20 working units. During May through July we (a) wound down the relationship with Telefonix, (b) collaborated with PDT, Cisco, and Intel to diagnose moisture issues, design modifications, and field test the solutions (see item 1.2.3.1 above), and (c) transitioned all inventory and partially assembled units from Telefonix to Surya, in context of a new contract with Surya to build at least 6 batches of 20 units at 10 per week beginning on September 11, 2017.
5. <u>Assembly, Test, and Documentation Materials</u>. As part of the debugging of assembly and restarting with a new contractor we developed much more detailed assembly manual [see supplemental documents], created hardware test jigs for critical sub-assemblies, and deepened the software testing procedures and all associated documentation for third party assembly and system burn-in. Integrating lessons learned in October through May we found that the detail required for assembly

documentation and testing is considerably greater than what is required for university students who are part of the project, for instance. To illustrate, all testing results must not only report the exception or error found, but must indicate what actions an assembler or tester must take to correct the issue, including stopping assembly to request technical support from the design team.

6. Sensor Selection and Testing. The sensor configuration finalized in FY16 included (a) the Alphasense particle sensor, capable of providing measurements in 16 bins from 1-10 microns and with an experimental firmware version spreading these 16 bins from 1-40 microns, and (b) an Intel-designed gas sensor board using seven printed electrochemical sensors from SPEC. Our internal testing of Alphasense in FY16 could not reproduce the results reported by the EPA's three-season testing in Colorado, in that we tested six units and found that they were reporting significantly differently when compared to one another. Further we found that the units reported artificially high particle counts as a function of humidity—something that these more expensive particle sensors are designed to counter through heating elements to eliminate water particles. In early 2017 we thus elected not to order these sensors for all nodes (at ~$500 each) but rather to attempt to work with the company to understand the nature of the problems we found in our tests. As of August 2018 this issue has not yet been resolved, but we expect a resolution within 1-2 months, with the likely cause to be damage in shipment combined with firmware errors. Concurrently, through the NSF-funded CENTRA project's Smart University Towns (SUNTOWNS) workshop we established a collaboration with Academia Sinica and their AirBox project (http://p2.5.lass-net.org/en/), which uses a low-cost ($30) PM2.5 sensor from a Chinese manufacturer, Plantower. We subsequently added this sensor to the AoT configuration. Similarly, we have tested the SPEC gas sensors and issued purchase orders for 120 of these units, to be produced by a third party company using Intel's open source board design. The first batch of these units arrived in May and had high failure rates, which we worked with the company to diagnose as arising from excessive heat during the board manufacture process. This process has been corrected and boards will arrive at a rate of 15 units per week beginning in early October. In the meantime, several dozen units will be installed without these gas sensors, placed in locations where they can be swapped out later with minimal impact (including UChicago campus where the city electricians need not be involved). The remainder of the units assembled prior to October will be retrofitted with these boards prior to installation
7. Location Selection. During FY17 we used the rubric developed in FY16—selecting locations with intersecting interest and engagement from residents, scientists, and local government—to select an additional 60 locations [see supplemental documents for map]. The first 40 locations included groupings to evaluate measurement and node placement strategies for (a) air quality, (b) lake effect, and (c) transportation flows. An additional 60 locations have been selected to include sites to support (a) a 4,000-family cohort participating in a University of Chicago asthma triggers and treatment strategies research project, (b) high-accident intersections and corridors identified by the Chicago Vision Zero traffic safety program (eliminate fatal traffic incidents by 2022) involving ten city agencies and departments, (c) eight locations where AoT devices will be collocated with county and state air quality monitoring stations, (d) several neighborhood areas participating in a Chicago Department of Public Health air quality evaluation and public engagement project funded by Bloomberg Philanthropies, (e) frequent flood zones in collaboration with a proposed smart and connected communities project led by Northwestern University, and (f) locations along a planned bus rapid transit (Ashland Avenue) and around a planned multi-hundred acre development (North Branch Framework), in cooperation with the Chicago Department of Planning and Development to asses traffic flow and walkability as affected by the development activities in both areas over the next 2-3 years. Several additional locations were selected based on community input, for instance a major street intersection based on a request from a school crossing guard reporting heavy truck traffic (and associated emissions) during school opening/closing times despite ordinances prohibiting such traffic during those periods.
8. Sensor Measurement Characterization and Evaluation. We enlisted scientists from Argonne National Laboratory and DePaul University to develop a process for characterizing and evaluating data from air quality sensors, specifically for particles (a low-cost PM2.5 sensor and a high-cost PM1-40 sensor) and gases (seven electrochemical gas sensors as part of the Intel-designed board). Through the NSF/US-IGNITE/NIST Global Cities Team Challenge (GCTC) activities, we also enlisted in this effort Prof. David Lary (U Texas, PI of the "Geolocated Allergen Sensing Platform (GASP)" project, an NSF grant to study asthma in Chattanooga) and Dr. Christine

Kendrick, a PhD air quality scientist from the City of Portland (with a grant from NIST to evaluate air quality sensors, including AoT units). The air quality science team developed a procedure whereby samples of the air quality boards will be evaluated using both a test chamber at Argonne and a site operated by the Cook County Department of Environmental Control. Evaluation for some sample boards will be done in a sheltered chamber and for others the evaluation will be done with fully assembled AoT units in the elements. In Portland, a three-phase testing process will begin with AoT nodes in a test chamber, then the units will be moved to be collocated with state and county air quality measurement stations, and finally to locations along a major bike path. The City of Portland is also interested in working with the machine learning community to use the cameras and edge-processing of AoT units to measure (a) private versus bike-share bikes, and (b) helmet use, in order to determine whether riders are less likely to wear helmets while on bike-share bikes.

9. Data Access and APIs. Following work in FY16 and the October 2016 release of APIs and documentation for the Plenario geospatial database and associated portals, the data team streamlined the data pipeline using Amazon Web Services capabilities to add a streaming service. The team also worked with scientists at Argonne, UChicago, Northwestern, and elsewhere to develop a scheme for map-based search of AoT measurements. In keeping with the concept of map-based searching for general urban data such as inspections, crimes, or infrastructure information the AoT data will be organized in two ways. First, a map-based search will find the data set of AoT node locations, each with individual configuration information (increasing in importance as future deployments will be heterogeneous with newer nodes having upgraded processing and sensor equipment). Second, the data from AoT nodes will be organized by measurements, with spatial time series data sets such as “temperature,” “vibration,” or “ozone.” Finally, the data portal team improved the APIs so that they could provide comparison capabilities, such as graphs or maps showing, e.g., crime and air quality over space and time. Underlying all of this work has also been a commitment to working with data users on the APIs, thus the team has worked with Schneider Electric, Microsoft, the City of Chicago, CityZenith, CartoDB, and others who are working on applications or portals to present AoT data to specific communities and constituencies.
10. Streamlining Open Source Platform and At-Scale Production. Building on our partnership with Intel—their design of the gas sensor boards and their assistance with moisture challenges and protective enclosure designs—we have established a memo of agreement that outlines a plan for a next generation of the core Waggle platform used by AoT. The partnership is designed with several objectives, including the need for an open source hardware and software platform that can be used by researchers wanting to place sensors, edge computing, and other devices “in the field” (urban or remote). Lessons learned in assembly, as detailed earlier, reveal several key inherent difficulties with at-scale production of a research platform such as today’s version. Chief among these is that the cost and complexity of assembly are largely driven by the number of components and connections required to assembly a device. Today’s units require some 30 individual connections within the processing and management electronics, not including the connections associated with building the sensor board harness that is placed in the external Stevenson Shield. These connections include boot select pins, heartbeat monitors, power (WagMan provides power to all other devices), and thermistors to monitor CPU temperature on the system controller and edge computing Linux devices. The partnership with Intel will involve a single board with both the WagMan supervisor functions and an Intel Linux system to run the system controller stack, with standard interfaces for sensors and (through GbE) guest processors, the first of which is the edge-computing system. The schedule of the partnership is to complete this refactoring of the platform by Spring 2018, at which time we can elect either to adopt this platform or to continue with an incrementally improved version of the current platform. Ultimately the memo of agreement outlines a plan for Intel to produce a reference platform in quantity, as an open source system, for use by any research or commercial effort including the AoT project. The ongoing partnership between Argonne, UChicago, and Intel will involve continued innovation on this platform and experimentation with new sensors and guest processing systems, in support of AoT and other similar projects. Argonne and UChicago will retain responsibility in developing the open source platform software stacks and data pipelines, working with the research community to evolve these for AoT and other projects.

11. Policy and Governance. The policy and governance documents define three governance bodies: Executive Oversight Committee (EOC), Technical Security and Privacy Group (TSPG), and Scientific Review Group(SRG). The EOC, co-chaired by the project PI (Catlett) and the City of Chicago Chief Information Officer (Danielle Dumerer) provides high-level oversight to the project, with the goal of balancing public interest with scientific objectives. In FY17 we recruited Don DeLoach, president of the Illinois Technology Alliance and co-chair of the Chicago Internet of Things Council, to identify and vet EOC candidates from diverse constituencies including government, law, industry, academia, and communities (residents). An initial membership was established in March 2017 including those named above and: Lynn Osmond (President, Chicago Architecture Foundation), Elissa Tenny (President, School of the Art Institute of Chicago), Aaron Koch (City of Chicago Chief Sustainability Officer), Glenn Eden (Weber Shandwick Public Relations and Communications), Stephen Philpott (Community Organizer), Ari Scharg (Privacy lawyer, Edelson), Brenna Berman (UILabs, formerly City of Chicago CIO), and Karen Weigert (Chicago Council on Global Affairs, formerly Chicago Chief Sustainability Officer). We are working with Von Welch (Director, Indiana University Center for Applied Cybersecurity Research) to identify security and privacy experts to participate in the TSPG, with a plan to organize a workshop with leading candidates in late 2017. Similarly, we are working with SRG co-chairs Dan Reed (University of Iowa) and Pete Beckman (Co-I, Argonne National Laboratory and Northwestern) to invite members to participate in the SRG, having identified potential candidates with experience in large-scale science projects and design and operation of scientific instruments. We will be extending invitations to these individuals in fall 2017.

1.2.3 Key outcomes or other achievements:

Despite delays in at-scale implementation, AoT continues to capture the imagination of the science and policy communities, with over 90 requests to test units in other cities around the world, coming from either cities or from research teams interested in using the platform for their research.

The Intel partnership represents a significant opportunity to capture all of the lessons learned and insights from the AoT project and produce an open source platform for similar projects—urban or wilderness. The high demand for such instrumentation, as illustrated by the requests for pilot projects, suggests that having the analog of an open "Arduino" platform that groups can customize with sensors and other devices (e.g. software defined radio for wireless network and spectrum measurement), along with open hardware designs for enclosures and Stevenson Shields, will be valuable to the research community. In addition to having a commercial source and an active open source software stack, such an approach will also drive the cost of the platform down significantly.

Although the installation schedule has been delayed, the overall project has moved forward in all aspects, and the delays have had several advantages. First, we were able to find enclosure design issues with the winter deployment that were not triggered during previous testing in Spring, Summer, and Fall tests. As a result, only a dozen units were affected rather than many dozens, and thus we did not impose on the City electricians to replace large numbers of units. Second, the process of selecting locations is an intensive one involving not only scientific collaboration but public engagement and briefings of multiple levels of multiple agencies and departments, including each of over two dozen local wards, where the elected official (alderman) must be briefed. Third, we found many opportunities during FY17 to drive the siting of the first 100, where we could immediately respond to the science and policy interests (see 1.2.3 item 7) involving a 4,000-family NIH-funded asthma study, a Chicago Department of Public Health air quality project, several major transportation-related development projects, and an NSF-proposed smart and connected communities proposal that involves an already ongoing set of flooding studies by the City and county. Finally, through the new discussions in FY17 with the Chicago Department of Public Health, we were able to identify eight sites where AoT nodes will be collocated with the more expensive state and county air quality stations, providing eight reference points for interpretation of overall AoT data.

1.3 What opportunities for training and professional development has the project provided?

As in years past the project has involved summer student teams working at Argonne and University of Chicago on systems, software, and data access projects. In both 2016 and 2017 our summer students included undergraduates, graduate students, and high school students. This year the program included three undergraduate students working on data systems, nine undergraduate students, and one high school student (who had participated in the Lane of Things high school program two years in a row, see below). The students were all from technical areas (electrical engineering, computer science, mathematics) and we had six women and six men.

For a second year, funding from cost-share partner Motorola Solutions enabled our collaboration with the School of the Art Institute of Chicago and Lane Tech High School, the largest public High School in Chicago (4200 students), where we conducted an 8-week Data/Sensor-driven science curriculum with 150 students in Spring 2016 and again in Spring 2017. This program was highlighted in the media as well as on the project website [see supplemental documents “Lane of Things”]. Motorola Solutions has already granted an additional $50,000 for FY18 to repeat the curriculum and package it for use by other schools. To this end, a new requirement was included in the Spring 2017 session where each of the 50 teams of students were required to document their projects online (at http://hackster.io - search for “Lane of Things”). An example of a project write-up is included as a supplemental document. Their documentation included an overall description of the project and its science objectives, a difficulty and time required rating, a bill of materials, wiring diagrams, and software source code.

1.4 How have the results been disseminated to communities of interest?

As with FY16, results are disseminated through talks at conferences, the project website, publications, and the media. The project website includes access to reports on community engagement and transparent policy development, project policies, project technical details, presentations, and science and education goals. The project website, http://arrayofthings.org, keeps links to all videos and major news publications about the project, and is continually deepened with detail on policy, status, and technology.

1.5 What do you plan to do during the next reporting period to accomplish the goals?

Goal 1: Adapt Argonne's "Waggle" resilient embedded systems platform for urban installation and for production in quantities of 100s. We are working with our assembly partner (Surya Electronics) to deliver 100 nodes by November 2017.

Goal 2. Purchase and install a network of 500 platform nodes in Chicago to operate as a national science instrument. We will finalize the installation schedule with the Chicago Department of Transportation at a planning meeting scheduled for late September, with the goal of having 100 installed by the end of the calendar year.

Goal 3. Make measurement data openly available to the science community and the general public. We are nearly finished with an upgrade of our central data systems (accessed via the Plenario portal) and associated application programming interfaces. In FY18 we will be engaging the science community to assist in evaluating data from the first 100 nodes, as outlined earlier in 1.2.3.8 (Major Activities).

2 Products

2.1 Journals or Juried Conference Papers

Catlett, C. E., Beckman, P. H., Sankaran, R., & Galvin, K. K. (2017). Array of things: a scientific research instrument in the public way: platform design and early lessons learned. Paper presented at the Proceedings of the 2nd International Workshop on Science of Smart City Operations and Platforms Engineering.

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

2.2 Audio or Video Products.

Several videos were produced by third parties including an in depth profile of the project by BBC Click and a highlight video for Supercomputing 2017.

2.3 Websites

2.3.1 City of Chicago Public Engagement Report

http://arrayofthings.github.io/engagement-report.html

Report detailing public engagement efforts, goals, and results. Public engagement objectives were to inform residents about the instrument goals and capabilities, discuss privacy concerns, and provide details on policies. An overarching objective was to position the instrument as a community "asset" as distinct from a sterile device or a surveillance program.

2.3.2 FAQ on Privacy and Policy and Feedback

http://arrayofthings.github.io/policy-responses.html

Exhaustive (regularly updated) FAQ that addresses all of the public comments and suggestions, initially taken from public meetings, email, web forms, and multiple online options for commenting on draft policies (including the OpenGov Foundation's Madison site).

2.3.3 Node Location Request

https://docs.google.com/forms/d/e/1FAIpQLScIG6YevqzWW4d1U0eH1D2tNSQuHnlng6AMrIDE4V8Gf136qQ/viewform

Form for use by residents or others requesting that AoT place one or more nodes in a specific location or neighborhood. Allows a non-scientist to articulate a science question in terms of goals, type of measurement, and locations.

Note this form is linked from the friendlier URL of the main project site, http://arrayofthings.us

2.3.4 Plenario System Overview

https://github.com/UrbanCCD-UChicago/plenario-stream/wiki/System-Overview

Extensive system documentation for the Plenario system that will serve as a key portal for all AoT instrument data. The site is necessary to support developers wishing to create portals, analytics tools, or applications that use instrument data.

2.3.5 Project Information Portal

http://arrayofthings.github.io

Main project website with links to all policies, technical documentation, press, etc.

2.3.6 VIDEO: BBC Report on Chicago Array of Things]

http://www.bbc.com/news/av/technology-39229221/air-quality-tracker-for-chicago-to-roll-out-city-wide

An update on air quality and Array of Things, published March 2017 and following a previous BBC profile on the project:

http://www.bbc.com/news/av/technology-32511363/key-to-chicago-s-quality-of-life-the-array-of-things

2.3.7 VIDEO: AoT Technology and Privacy

https://www.youtube.com/watch?v=pFL5QNwgs6A

Short video focusing on the manufacture, technology, and privacy of the AoT instrument. The video was developed specifically to help residents understand the privacy protections built into the device and into policy.

2.3.8 Waggle Platform Software Site

https://github.com/waggle-sensor/

Developed site to document the open source software stack, and eventually the hardware specifications, for the instrument. This site is also essential to engaging the research and development community in evaluating and hardening the software stack.

3 Impacts

3.1 What is the impact on the development of the principal discipline(s) of the project?

We have continued to see a growing level of demand for a general purpose, reliable sensor and embedded systems platform in the science community. As noted we have assisted the NSF-funded "GASP: Geolocated Allergen Sensing Platform" (NSF Award CISE/CNS 1541227) program, and this collaboration has improved our platform and air quality through interactions with these “early adopter” users (PI David Lary, UT-Dallas).

This year we had more engagement with the machine learning community, investigating methods for detecting standing water, classifiers for counting (e.g.) pedestrians or vehicles, and object tracking methods to measure (e.g.) traffic flow. This engagement has included machine learning experts from Argonne, University of Illinois-Chicago, UChicago, Northwestern, Northern Illinois University, New York University (sound), and elsewhere. With NYU, for instance, our team is collaborating with Prof. Juan Bello and the NSF-funded SONYC project to explore (a) locating SONYC sensors along side some AoT nodes, (b) adopting SONYC sound classifiers for use in AoT nodes, and (c) adopting SONYC’s sound annotation platform and potentially adapting for use with image annotation.

With the publications about the platform design and early lessons this year and the Waggle platform itself last year we also contribute to areas ranging from reliable embedded systems to computer vision (in that the platform runs standard libraries, ultimately offering computer vision experts an urban-scale computer vision instrument with 1,000 cameras).

3.2 What is the impact on other disciplines?

Outside of computer science, Co-I Kathleen Cagney (UChicago) has engaged social scientists from Ohio State University, UChicago, and NYU to explore collaboration with computer scientists on “observations” whereby social scientists would describe types of objects (person walking baby) or events (groups lingering in frame) that might be detected through computer vision techniques. Senior personnel Rob Jacob (Argonne) has expanded our air quality and atmospheric sciences team to include collaborators working on air quality sensor evaluation as well as environmental scientists exploring the use of image processing to detect flooding, or extending the AoT platform through low-power, low-bitrate networks such as LoRaWAN to connect moisture and flow sensors. Co-I Daniel Work (UIUC) led a transportation workshop, in collaboration with Chicago Deputy Commissioner of Transportation Abraham Emanuel, in February 2017. The workshop invited transportation scientists from UIUC, UIC, UMichigan, Argonne, Northwestern, and elsewhere to interact with Chicago transportation and data analytics staff to understand where there is constructive overlap between the questions the city must answer about transportation and the research being done in the academic community. As a result of this workshop, the City is finalizing legal agreements to share detailed transportation data through the AoT team.

The privacy policies continue to be of interest to other projects as examples of community engagement and balancing science and privacy needs.

3.3 What is the impact on the development of human resources?

We view the Lane of Things high school program, outlined earlier, and a key component to developing human resources. The program is a collaboration between Kate Kusiak Galvin (UChicago), Douglas Pancoast, Satya Mark David and Robb Drinkwater (School of the Art Institute of Chicago), and Dan Law and Jeff Solin (Lane Tech High School). With over 300 high school students to date we have seen countless students emerge from the program with not only an interest in science but a sense of accomplishment and confidence about being able to define a question and use the scientific method to begin to answer that question. To be able to envision a sensor platform and then create it is also an empowering experience for these students.

The summer program is also key to developing human resources, including students from high school to graduate school. The students are supervised by our own team (Pete Beckman, Charlie Catlett, Rajesh Sankaran) but also visiting scientists (Dr. Eugenio Cesario, University of Calabria) and collaborators including Chicago Chief Data Officer Tom Schenk and former Chicago CIO Brett Goldstein. Our students are able to interact with scientists in the university and at Argonne, but also with city officials through Tom Schenk and with the Chicago startup community through Brett Goldstein, who now directs a venture fund and oversees several startup companies in the civic data analytics space.

Test deployments have allowed partners to engage their own students at Northern Illinois University (Co-I Mike Papka) and University of Washington (Bill Howe working with Seattle CTO Michael Mattmiller).

3.4 What is the impact on physical resources that form infrastructure?

We have documented and published many lessons learned through our work with the city and in particular with the Chicago Department of Transportation on physical design and installation procedures. As the project builds out to at least 100 sites in early FY18 we are also working with the City to identify locations involving buildings, and have begun to define an agreement with a major building management company regarding the installation of nodes at different heights on tall buildings, including rooftops and building set-backs. These new installations will be important to providing data about the vertical layers of urban atmosphere including air quality.

3.5 What is the impact on institutional resources that form infrastructure?

The AoT project has been the impetus behind relationships between Argonne and UChicago with eight layers of management in the Department of Transportation, five layers of management in the Department of Innovation and Technology, and new relationships with deputy commissioners and department heads in the Departments of Public Health, Planning and Development, Buildings, and Water-related agencies.

3.6 What is the impact on information resources that form infrastructure?

By piggybacking on the NSF-funded Plenario system (http://plenar.io) we are able to integrate sensor data with other urban data, such as 311 calls, crimes, permits, or inspection data. Further, the City of Chicago selected Plenario as their "back end" for a new portal designed for residents, called OpenGrid.io. The city has also provided funding to the University of Chicago to package Plenario with OpenGrid as open source tools that can be installed with a "single click" within Amazon Web Services (or readily ported to other cloud providers or local servers).

3.7 What is the impact on technology transfer?

We have established a mechanism whereby we can support pilot projects in a sustainable fashion, with a "turnkey system" approach with centrally managed nodes irrespective of geographic location. We are experimenting with this approach in a limited fashion with several partners (University of Washington, City of Portland, Panasonic and the City of Denver) to determine the best approach to satisfying the high demand for pilot projects without impacting the Chicago AoT instrument. To date these limited pilot interactions have been useful in providing valuable feedback on the reliability of nodes in different locations and the level of interaction necessary to support “users.”

The partnership with Intel is extremely valuable from a technology transfer standpoint in that it is designed to enable the commercial provision of our open source hardware and software platform, in partnership with the Argonne and UChicago team to continue to drive the platform for scientific use (principally, AoT). Such an arrangement will allow other research teams to use the platform, collaborating with the AoT team but with professional platform support through Intel and a separately funded support structure.

3.8 What is the impact on society beyond science and technology?

The near weekly contacts from cities and universities interested in building AoT-like infrastructure reveals an increasing need for a platform that can be rapidly deployed in cities, focused on specific questions in particular neighborhoods, to provide insight into challenges, to provide ongoing measurement of conditions, and/or to evaluate the impact of major urban development projects. Today these projects are extremely costly and tend to involve bespoke systems that are either academic-generated (not reproducible) or proprietary (not producing open data; not available to support innovation from the science community.