TESTIMONY

Raj Rajkumar
George Westinghouse Professor of Electrical and Computer Engineering, Director of the Metro21 Smart Cities Institute, and Director of the Mobility21 National University Transportation Center

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INTRODUCTION: SEIZING THE FUTURE THAT SMART CITIES CAN MAKE POSSIBLE

Good Morning Chairwoman Stevens, Ranking Member Lucas, and Members of the Committee:

Thank you for this opportunity to testify before this important hearing today.

My name is Raj Rajkumar. I am from Carnegie Mellon University in Pittsburgh, Pennsylvania where I am the George Westinghouse Professor of Electrical and Computer Engineering, director of the Metro21 Smart Cities Institute, and director of the Mobility21 National University Transportation Center.

I am pleased to be in Livonia. As with many of my colleagues, I have an intense personal and professional interest in smart cities, stemming from a career that began focused upon the transformation of the automobile—with research supported by General Motors since 2000. I therefore find it very appropriate to have this important dialogue in the heart of America's advanced transportation industry.

As my remarks will indicate, I strongly believe that the ability to advance smart city technologies and initiatives depends upon robust and sustained support for fundamental research. While research support is necessary, that in itself is not sufficient. How these technologies benefit our communities depends on how effectively we can deploy and integrate them.

Ultimately, our national well-being will rest in part on the ability to foster deployment and cross-regional collaboration. I currently have the privilege of collaborating with colleagues in Michigan on connected and automated vehicles. This hearing can serve to underscore how critical it is to foster collaboration across communities, researchers, institutions, industry, and technology components.

Let me first begin my remarks by expressing my personal gratitude to the work of this Committee. Virtually my entire academic career and my success as an entrepreneur have benefited from funding from the federal agencies whose mission has been shaped by this Committee's authorizing legislation. It is not an overstatement to express the view that you have helped make ongoing revolutions in innovation and sustained economic leadership possible.

The incredible advances in autonomous vehicle technology, reflected now in the tens of billions of dollars in private sector investments taking place in regions such as Michigan, Texas, California and my home in Pittsburgh, owe their roots to the decades of research support provided by agencies such as NSF, DOE, DOT, NASA and NIST, among others. The continuing work in these agencies is spearheading a revolution in smart city innovation. I would like to acknowledge, in particular, Mark Dowd's leadership during the previous administration in this regard.

This is a time to both imagine and seize the future. Let us assess the possibilities that smart city innovations hold:

- Imagine a community in which the lighting, heating and cooling of buildings is continuously optimized by data on traffic patterns that can predict when workers will arrive or leave.
- Imagine tens of millions of savings in infrastructure maintenance achieved by advanced condition monitoring, made possible not from costly built-in sensors but using data collected from regular fleet and auto traffic.
- Imagine being able to immediately translate data indicating very early signs of a potential flu outbreak to provide readily actionable and precise information to citizens in particular communities.
- Imagine the capacity to predict water main and other infrastructure breaks or fires before they occur to help municipalities prioritize projects and head off costly emergency repairs and damage.
- Imagine the ability for autonomous vehicle technology to also play a role in addressing the last-mile broadband challenge.
- Imagine a future where advances in materials and computational technologies allow the structural components of buildings to be programmed based on thermal sensing to optimize energy savings and enable sustainability.
- Finally, imagine that each of these initiatives helps create new pathways to STEM education in every neighborhood they touch.

Advances similar to these are already being piloted in regions across the nation. My testimony today will highlight three key strategic elements that are vital to realizing the full potential of this smart city revolution:

First, continued US commitment to advancing the basic sciences that underpin smart city innovation;

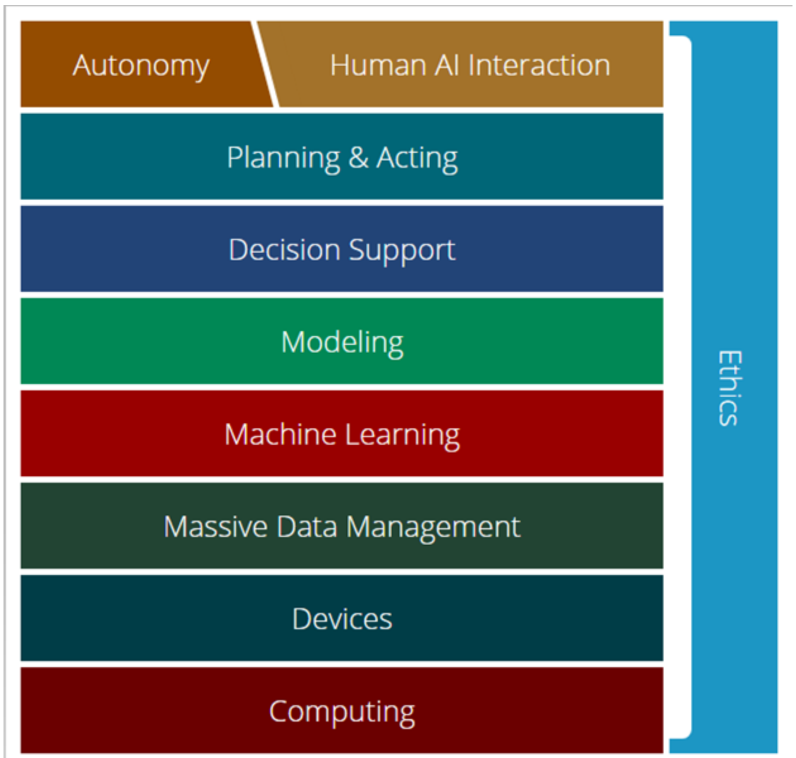
Second, a focus on integrating research and innovation with deployment at the regional level; and

Third, enhancing the capability of regional research initiatives to inform policy, incorporate information sharing across deployment communities, and launch workforce and talent pipeline development components are essential to accelerating deployment of smart city innovations, not only in cities but in communities of all sizes and characteristics.

INVESTING IN AND ADVANCING THE SCIENCE OF SMART CITY INNOVATIONS

Smart city applications are dependent upon the synergistic integration of a host of technological breakthroughs that span the entire domain of cyber-physical systems. At Carnegie Mellon, we refer to this integration challenge as the "AI Stack."

CARNEGIE MELLON AI STACK



The AI Stack captures the core enabling technologies that underpin smart city innovation. The "computing" and "devices" layers capture advances in computing power, innovations in the cost and effectiveness of networking technology, as well as sensing capabilities for perception such as LIDAR sensors ("Light Detection and Ranging," a remote sensing method that uses light in the form of a pulsed laser to measure distance).

The "machine learning" layer represents the data science elements of the Stack, including innovations in collecting and managing big data, increasingly at the hardware level and in cloud-computing operations. The "modeling," "decision support" and "planning & acting" elements of the Stack incorporate algorithmic advances for translating data analytics into recognizable patterns for prediction.

These combined capabilities then facilitate action---- either by autonomous systems, humans, or even better a combination of the two working together. Such autonomous systems range from autonomous vehicles and automated building systems to cognitive assistance tools such as advanced traffic, public health notices or data-informed strategies for optimizing infrastructure repairs.

Finally, as the AI Stack diagram highlights, the design and application of research in these domains must be informed by policy and ethics considerations across all these technology layers.

One example of the AI Stack at work can be found in one of the first major applications of Carnegie Mellon's Mobility21 National University Transportation Center: the development of AI-enabled adaptive traffic signals deployed across 150 intersections to improve traffic flow, reduce wait times and significantly reduce emissions. Uniquely, this system is entirely decentralized, with each node communicating data to the others and adapting traffic flow throughout the network without any central control module.

This breakthrough relies on advances in camera technology (a sensor) as well as advances in the ability to compute at the device level—in this case at the individual traffic signal and across a network of signals. These traffic signals perform millions of calculations per second, converting images to data and running improved algorithms on that data in order to model traffic flow and plan to optimize it throughout the system in real-time.

In addition to capturing the fundamental science and technology elements of smart city applications, the AI Stack helps us envision a path forward for smart city research and development.

First, the AI Stack highlights the imperative of continuing research in the domains that the work of this committee has supported over the last few decades. For example, smart city innovation is dependent upon continued advances in the ability to compute at the "edge," which refers to the ability to process certain functions at the device level rather than across the system or in the cloud, saving bandwidth and improving latency. This includes hardware improvements and lower-cost sensing networks, the ability to train machine-learning algorithms on less data, the ability to generalize across similar data sets, and continued advances in human/machine teaming. This research field incorporates social and behavioral science including psychology, design, law, and other disciplines outside of computer science and engineering.

Fundamental research such as what this Committee has supported in cyber-physical systems, computer networking, AI and machine learning, robotics and human/machine teaming at NSF, DOE, DOT and NIST will continue to be vital to advancing these capabilities to improve the way we move in and interact with our physical communities.

This continued support of basic research in discrete fields should also be aligned with programmatic opportunities that foster cross-disciplinary collaboration. One of the key imperatives illuminated by the AI Stack model is the need to foster intense cooperation among researchers across these disciplines. Smart city innovations, like all elements of cyber-physical systems, involve the science of systems integration. A smart city research initiative across the federal government could include the development of a roadmap highlighting specific technical areas where foundational breakthroughs in integration are needed.

Through inter-agency coordination, funding could then be targeted both to these technical challenges and specific application areas. For example, coordination of sensing or edge computing research in NSF and DOE could both advance core technologies and combine them with a distinct focus on applications in areas such as urban environments or energy infrastructure. Similarly, advances in sensors, mapping and AI will make autonomous vehicles safe, secure, reliable and fuel-efficient. This roadmap-grounded approach to interdisciplinary and cross-agency coordination could also enhance the ability to integrate social science, privacy and ethical considerations into both research and education as unique questions around application and deployment arise.

COMBINING RESEARCH AND DEVELOPMENT WITH DEPLOYMENT

In addition to highlighting the need for a framework for interdisciplinary research within its layers, the AI Stack also illustrates the imperative for fostering collaboration among technical researchers in those layered fields with domain experts in application areas. An example of this is having computer modeling and simulation researchers collaborate with experts in emergency and disaster response planning.

We refer to this collaborative model as Research, Development and Deployment (RD&D). As embedded in CMU's USDOT Mobility21 National University Transportation Center, this RD&D model focuses on creating formal mechanisms for engaging with local governments to identify research targets, and developing projects and pilot solutions that can often be scaled once proven successful.

The strength of the RD&D model is that it identifies problems needing to be addressed, usually along with data or new potential datasets from government agencies, and brings them to inter-disciplinary teams of researchers.

Through formal agreements with the City of Pittsburgh, the County of Allegheny and the Pittsburgh International Airport Authority, our Mobility21 National University Transportation Center and the Metro21 Smart Cities Institute have been able to pilot a variety of advances that have focused on specific city challenges. Each of these projects was initiated through a formal process in which the governmental entity identifies specific problems and the university manages a process of engaging faculty to propose solutions. Very often, faculty from multiple disciplines form a unique team to respond to these problems. These teams often map to disciplines across the AI Stack, and in turn engage with those in the community having domain expertise.

Returning to the example of the research. development and deployment of AI-enabled traffic signals, this initiative required the domain expertise of traffic engineers as well as community leaders who brought important values to the program, such as how the signals should accommodate the needs of pedestrians, bicyclists and public transit vehicles. The project began with nine intersections but continues to scale and is now projected to connect 200 intersections by 2020.

Additionally, one of the most powerful follow-on projects that this deployment-focused engagement produced was the development of smartphone capabilities that empower persons with disabilities to communicate with the traffic signals. By enabling the systems to recognize the presence and location of these users, the system can adapt the signal change cycles to accommodate their movements and location within the intersection, giving them greater confidence that they will have enough time to cross the intersections safely.

Because the CMU Mobility21 team also includes The Ohio State University, the University of Pennsylvania and the Community College of Allegheny County, it has the ability to leverage capabilities and build experiences across different geographic and demographic environments. Our RD&D model is focused on advancing specific technologies as well as on building the systems of systems that are so vital to scaling smart city applications.

The RD&D model also accelerates the technology transfer process. Carnegie Mellon has been able to launch several start-up companies emerging from its UTC projects. These start-ups are now disseminating these innovations to cities across the nation and internationally.

Examples of other RD&D pilots include the following projects:

- Improve and automate infrastructure monitoring through the use of machine learning, perception and smartphone technologies that convert images to data.
- Reduce automotive emissions using latency-aware cloud-based route planning.
- Predict and reduce structure risk for commercial buildings by leveraging historical fire incident and inspection data.
- Better plan spatial use for pedestrian traffic in busy thoroughfares in order to enhance traffic flow and safety by using advanced computer vision and machine learning.
- Detect signs of impending landslides by utilizing deep learning combined with computer vision.

Yet another advantage of the RD&D model is the ability to scale these innovations and best practices by networking experiences across communities. To enhance this dynamic, Carnegie Mellon helped establish the Metro Lab Network, a 501(c)3 organization. The MetroLab Network links together a virtual community of government/university partnerships across the US, engaging more than 40 cities, 50 universities and over 100 projects, ranging from transportation applications to the application of data-driven systems to create real-time interactions between physicians and emergency service providers.

Another model of collaboration in which Carnegie Mellon is involved can be found right here in Michigan. The Smart Belt Coalition is a broader regional effort among Michigan, Ohio and Pennsylvania to establish a dynamic and proactive collaboration in this region for the development of connected and automated vehicles. The coalition brings together universities, transportation authorities and industry to foster dialogue and undertake specific projects that focus on informing the regulatory environment for the deployment of AV technologies.

These examples, and similar initiatives such as the NIST- supported Global Cities Challenge, are establishing a smart city tech transfer ecosystem that will help future research initiatives to yield tangible economic and social benefits.

ADVANCING SMART CITY INNOVATIONS THAT CAN ENHANCE THE DEVELOPMENT OF SMART CITY POLICIES

By bridging multiple regulatory jurisdictions, the RD&D networks mentioned above also help to advance the dialogue on policy issues, which is vital to widespread adoption of smart city applications.

Smart city technologies, by definition, thrive in the fabric of communities and hence depend upon the creation of a policy framework that can enable and accelerate scalable deployment. Some elements of this framework rest in major policy processes related to broadband, spectrum allocation and communications policies; standards and interoperability provisions.

Other elements of this policy framework spring from the research and innovation environment and can be shaped directly by federal science policy.

The first of these policy elements is the critical need to build the workforce and talent pipeline to support smart city development. This must include both a focus on specific technical degrees and fostering broad community capacity.

The experience derived from Carnegie Mellon's Metro21 Smart Cities Institute and the Mobility21 Transportation Center suggests that this requires a broad-based strategy. Elements of CMU's workforce pipeline strategy include the following:

- Infusion of smart city curricula and project experience across several disciplines at the university—computer science, engineering, business, public policy and the social sciences.
- The use of grand challenges and robust hackathons to foster cross-disciplinary education opportunities and stimulate early student engagement with community and governmental partners.
- The development of targeted initiatives to engage women and under-represented minorities in smart city research and career opportunities.
- Strategic support for robotics, transportation and other related smart city clubs and school-based initiatives in both urban and rural communities.

Research programs and initiatives across federal science agencies that incorporate educational components can have a catalytic impact on building the technical and community-based talent pipeline that smart city innovations depend on. The deployment of smart city innovation, from traffic signal improvements and infrastructure monitoring to predictive capabilities to improve city services, creates a natural pathway to engage communities and neighborhoods in STEM education.

A second major policy challenge that can be impacted by the design of federal science policy relates to the critical challenge of engaging rural and suburban communities in smart city innovations. From the very beginning of Carnegie Mellon's University Transportation Center activities, we have sought to initiate and perfect models for engaging communities outside of the urban core. For example, in the earliest phases of the adaptive traffic signal project, a suburban community was selected for a parallel deployment.

Two years ago, Mobility21 launched a smart city challenge competition specifically targeted to draw in participation from outlying suburban and rural communities. Awarding over $700,000 in projects in 10 communities in 4 counties, the competition has fostered capacity-building collaboration between the university and these communities.

Recently, with support from the Department of Energy, Carnegie Mellon has launched an initiative to bring a more systematic level of collaboration in smart transportation innovations to a rural county project. Greene County, a county that is more than 90% rural and has some of the highest poverty rates in Pennsylvania, will benefit from a collaboration among Mobility21, the county and Waynesburg University, located in the county seat. The goal is to develop mobility solutions that address problems ranging from job and healthcare access to food insecurity. The targeted outcome is the piloting of a Rural County Mobility Platform (RAMP) that can be replicated in other counties.

The key to each of these initiatives is the ability to form collaborations with partners in these communities, who bring both local domain and capacity-building expertise. As the Greene County project highlights, these partners can be units of government, academic institutions, private entities such as foundations, and private industry such as employers or service providers.

Federal research agencies can enhance the growth of these types of collaborations in rural areas by incorporating grand challenges into federal smart city research initiatives as well as supporting targeted education and outreach programs that incentivize urban/suburban/rural collaborations. As I mentioned earlier, these efforts will be greatly enhanced by national networking opportunities that foster best-practice learning, tech transfer and innovation across communities.

CONCLUSION: AN INFLECTION POINT FOR SMART CITY INNOVATION

The work of this Committee and the programs it has authorized have led to a technology revolution in computing, communications, autonomy and artificial intelligence. The application of these breakthroughs to cyber-physical systems creates the potential to fundamentally improve the economic, social and environmental fabric of urban, suburban and rural communities.

Support from the agencies authorized by this Committee has enabled my colleagues and me at Carnegie Mellon to begin to realize the potential of these innovations in Pittsburgh, Pennsylvania and the communities of our partners across the nation. It is very gratifying to me as a basic science researcher to be a partner with these agencies in ensuring that federal research funding in basic science is having both a broader and a more immediate impact on the lives of US citizens through innovative RD&D models.

By focusing on a three-pronged effort to (a) increase core investments in the foundational disciplines of smart city applications, (b) foster greater interagency collaboration to support research, development and deployment models, (c) support agency strategies that incorporate talent and workforce development, and bring urban, suburban and rural communities to collaborate in research programs, I believe this Committee and Congress can have a dramatic impact on scaling the deployment of these innovations across America.

Thank you.