Exploring a Research Network of Urban Sustainability Observatories via Data-Enabled University-Community Partnerships

Sustainable Urban Systems "New Mobility and Cities" Workshop Report

prepared for

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Principal Investigator: Harvey Miller
Co-investigators: Gulsah Akar, Kelly Clifton, Sathya Gopalakrishnan, Kristen Tufte
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Contents

A. Executive Summary

On July 15-16 2019, a diverse group of university researchers and community stakeholders from Columbus, Ohio and Portland, Oregon participated in a workshop to explore issues surrounding new mobility technologies, Urban Sustainability Data Observatories (USDO) and urban sustainability science. Columbus and Portland are good candidates for USDOs due to engaged researchers at Ohio State and Portland State universities, aware and enlightened community leadership, smart mobility and smart city initiatives in both communities, and similar challenges in managing disruptive mobility technologies in high-growth regions. Participants discussed the following issues:

1. *USDO Functional Requirements:* including effective business models, ownership and control, data standards and needs, privacy concerns, ways to facilitate data accessibility, privacy and governance, use cases and how to use USDOs to create living laboratories.

2. *Opportunities for Innovation:* how to enable high risk – high reward pursuits in communities such as USDOs, creation of innovative funds, how to ask the right questions, how to engage the private sector, and how to create data collaboratories that are inclusive to a heterogeneous group of stakeholders and residents.

3. *Creating Successful (Community-University) Partnerships for Urban Sustainability Data Observatories:* how to institutionalize partnerships and build trust, education and capacity-building, technology transfer and dissemination of knowledge, technical advising and policy evaluation, and incentivizing faculty for community-engaged research.

Emerging from the discussion are the following key research questions that are critical for advancing the intersection of data-enabled SUS science and urban mobility.

1. How do individual values, attitudes, and behaviors influence mobility flows and the scale of new mobility technologies?
2. How should we conceive of and operationalize a theory of regional sustainability that incorporates both inter- and intra-generational equity?
3. How can we better understand cities as complex systems to anticipate unintended consequences?
4. What are the antecedents and consequences of data trust for SUS outcomes?
5. How will new markets enabled by digital technologies impact social equity?
6. How can growing regions balance the often-competing forces of economic growth and social equity?

Based on the knowledge gained from the workshop, we make the following recommendations for USDO-enabled SUS research:

1. *A need for concurrent, parallel observation and analysis.* Urban systems comprise a multitude of entities interacting over space and time that are strongly conditioned by context and history. The complexity of urban systems does not mean that scientific understanding and effective policy interventions are impossible. Rather, it means that we must observe more than one city to ascertain how urban processes play out in places with different contexts and histories, and the impacts of new mobility technologies and policy interventions on those processes. In this way, a research network of urban observatories can facilitate a new type of sustainable urban systems science that recognizes the complexity and uniqueness of cities.

2. *Engagement and governance.* USDOs should go beyond ongoing observation and analysis to engage stakeholders and citizens throughout the process, from the conceptualization and design of the observatory, through data collection and analysis, to how the information is represented and communicated. Required is research on how to build and integrate effective online platforms and offline processes that maximize engagement among highly heterogeneous stakeholders. There is also a need for greater understanding of how data-centric organizations and initiatives such as observatories can build trust.

3. *Integrating observatories, virtual laboratories and living laboratories.* Powerful synergies can be gained by combining empirical data collected via USDOs with powerful simulation techniques and the embeddedness enabled by treating the city as a living laboratory. Required is research on how to best integrate these technologies and processes to maximize their effectiveness in discovering new knowledge about sustainable urban systems and tailoring evidence-based policy for complex urban systems.

4. *Education and capacity building.* The types of new sustainable urban science enabled by USOs combined with new processes for engaging heterogeneous stakeholders implies a rethinking of education, both foundational and continuing. There is a need for cross-domain undergraduate and graduate education that facilitates meaning interactions and collaborations across disciplinary boundaries. There is also a need for continuing and professional education to build capacity at the organizational and community levels.

B. Overview

This report documents the proceedings and outcomes of the New Mobility and Cities workshop held at The Ohio State University in Columbus, Ohio on July 15-16, 2019. This event was funded by the NSF Dear Colleague Letter (NSF 19-032; "Concepts for Advancing Sustainable Urban Systems (SUS) Research Networks") released in December 2018. The following sections describe the participants of the workshop, guiding structure and rationale for the event, outcomes by discussion thematic area, fundamental and applied research questions that emerged, and synthesized recommendations from the workshop regarding the role of **urban sustainability data observatories** (USDOs) in advancing next-generation SUS science and its application to the challenges of urban transportation.

Motivation and Objectives

The overarching goal of this workshop was to develop a convergent SUS framework that can support the development of a **network of community-university research partnerships** by leveraging the concept of **urban sustainability data observatories** (USDO) to organize and make meaning out of exponentially increasing data streams. Two "nodes" in a possible future network came together to organize this workshop, Portland, OR and Columbus, OH, with universities, industry, agencies, and metropolitan planning organizations (MPOs) from each city represented. These cities are similar in size and growth patterns; both have strong university-community research/engagement partnerships; and both have recently implemented large-scale smart mobility enterprises with parallel data initiatives. Both cities are wrestling with the question, "how can we make sure that 'smart' gets us where we want to go in terms of achieving well-being improvements that are sustainable?" While there are many sustainability challenges and needs that an USDO ultimately can and should address, the workshop focused on **new mobility technologies and services**.

Increasing capabilities for persistent (ongoing) data collection, storage, and analysis has led to the possibility of creating urban observatories to help understand complex urban systems and manage interventions and policies. Observatory science has a long history in the physical sciences, although some pioneers have extended this concept to human phenomena such as demography, cities and public health (e.g., NSF's Social Observatories Coordinating Network). An urban observatory collects and analyzes the data associated with a community or region to generate an integrated, holistic perspective that can facilitate new scientific discoveries about complex urban systems. It also provides visualization and collaborative decision environments to support shared understanding and engagement on policy issues.

Urban observatories can enable new knowledge about complex human and coupled human-natural systems such as cities. Context-sensitivity and path-dependence means that history and geography matter in complex systems. Consequently, advancing scientific knowledge about complex urban systems requires ongoing observations of processes as they unfold in specific geographic contexts over time periods sufficient to elucidate temporal dynamics (Liu et al. 2007). Urban observatories can also facilitate a new type of opportunistic science based on leveraging real-world events to perform analysis based on natural and quasi-experimental designs. It can

also facilitate reflexive monitoring and social learning as policies adjust based on incremental knowledge gained on their outcomes over time (Sanderson 2002).

The workshop focused on the sustainability challenges and data and partnership needs with respect to new mobility technologies and services from two of the three SUS perspectives outlined in NSF's Advisory Committee for Environmental Research and Education (ACERE 2018) report on sustainable urban systems (SUS): (i) **single urban areas/metropolitan regions** where multiple sustainability outcomes are addressed from a multiscale systems perspective that connects homes, businesses, and communities to regional and global scales and (ii) **multiple cities and communities**, exploring inter-relationships among networks of cities and communities, and identifying city typologies for the study of cohort groups and comparison groups. We also identified how USDOs can integrate key elements identified by the National Science Foundation ACERE (2018) report as critical for advancing SUS science: new data and methods to understand current drivers and interactions, sustainability assessment, comparative studies and the science to model future SUS scenarios, and knowledge co-production among researchers, communities, and governments.

The workshop had the following set of objectives:

- Generate a convergent understanding of the frontier mobility-linked SUS research and practice questions facing cities, potentially to be asked of, answered by, and iteratively designed into a sustainability observatory;
- Explore ways that researchers, community research collaborators, and other urban stakeholders can leverage digital platforms to both meet community needs for mobility and access and drive toward a deeper understanding of the principles underlying SUS; and
- Lay the foundations for an open community of practice for participants to collaborate and share best practices in the coming years as they build out prototype USDOs.

Description of Events

The New Mobility and Cities workshop was held at the Ohio State STEAM Factory[1] in downtown Columbus, a vibrant collaborative space outside of the university's main campus designed to make interdisciplinary, inter-sector conversations productive and pleasant (see Figure 1). Sixty workshop participants represented the following groups:

- **University and Extension faculty, research staff, and students, primarily from Ohio State and Portland State.** Disciplines included: civil & environmental engineering; city & regional planning; computer science & engineering; public health; urban and environmental economics; food, agricultural & environmental sciences; forestry; geography; information & library science, mechanical engineering, and public affairs. Two keynote presenters, Shashi Shekhar (Department of Computer Science, University of

[1] The STEAM Factory is a diverse and inclusive grass-roots network in the Ohio State community that facilitates creative and interdisciplinary collaboration, innovation and dissemination. STEAM is an acronym for Science, Engineering, Art and Mathematics. See https://steamfactory.osu.edu/

Minnesota) and Piyushimita “Vonu” Thakuriah (Department of Urban Planning and Policy at Rutgers University), offered vignettes from prior/current projects at the start of each day to spike conversation.

- **Practitioners from local government, planning and service organizations.** Columbus and Portland examples include Mid-Ohio Regional Planning Commission (MORPC), Central Ohio Transit Authority (COTA), Portland Bureau of Transportation, Portland Bureau of Planning and Sustainability, Portland Metro, TriMet, and City of Columbus. A representative also attended from the Urban Sustainability Directors Network, a national network of local government professionals.

- **Businesses working in the smart/sustainable mobility space**. Examples include Honda R&D North America, Accenture, and Empowerbus, a Columbus social enterprise.

- **Other nonprofit community organizations**. Examples include Transit Columbus, the Columbus Foundation and Columbus 2030 District.

Figure 1: Scenes from the New Mobility and Cities workshop at The Ohio State University STEAM Factory space in downtown Columbus. Clockwise from upper left: i) Participants getting ready for the first day; ii) Prof. Piyushimita (Vonu) Thakuriah delivers her keynote talk; iii) Aaron Schill from the Mid-Ohio Regional Planning Commission leads a breakout discussion; iv) The Functional Requirements Design Challenge.

Agenda and Activities

The workshop steering committee (noted in participants list, Appendix A) collaborated with professional facilitator Donnalyn Roxey (KnowInnovation) to devise a series of engagement activities that maximized fruitful conversation among different combinations of diverse participants in order to meet our objectives.

Pre-workshop activities. In order to maximize the workshop event and "prime the pump", two virtual forums were established to provide opportunities for interaction and sharing. An event page was established on hub.ki that provided technical reading, online discussion, participant bios, and workshop logistics. One-week prior to the workshop on July 8, a ninety-minute virtual "microlab" convened workshop invitees to hear short talks on the motivations and aims for the workshop and short presentations urban sustainability, new mobility services, and data observatories. Participants had the opportunity to meet and engage with one another in breakout sessions around fundamental challenges and opportunities facing cities on these intersecting topics.

Workshop activities. Ms. Roxey provided the fundamental guidance before and after the sessions to organize and connect the discussions among the participants which helped to improve the understanding of the topic and consequently resulted in more fruitful outcomes. Multiple sessions allowed participants to interact with different people in every session.

WORKSHOP AGENDA	
Monday, July 15	**Tuesday, July 16**
Welcoming Remarks: Shannon Hardin, City of Columbus Council President	Welcome Day 2 - 9am
Keynote: *Transforming Smart Cities with Spatial Computing* Prof. Shashi Shekhar, McKnight Distinguished University Professor, University of Minnesota	**Keynote:** *Urban Informatics and Smart Mobility in Future Cities: Prospects and Challenges with New Forms of Data and AI* Prof. Piyushimita (Vonu) Thakuriah, Distinguished Professor and Dean of the Edward J. Bloustein School of Planning and Public Policy, Rutgers University.
1. Speed Networking: Three rounds of 5 minute talks with 2 minutes between each round, 10 mins at the end. Prompts focused on the biggest sustainability challenges, barriers and needs that Portland and Columbus face. **2. Trio Listening:** Groups of 3-4 people discussed the sustainability and mobility issues to understand the differentiation of priorities and challenges for different parties. **3. Functional Requirements Design Challenge**: An interactive session that enables	**1. Breakout:** Community-university partnerships. Prompts focused on the potential benefits of an urban sustainability network and ingredients for success. **2. Trio Listening**: Groups of 3-4 people discussed the sustainability and mobility issues to delve into the details of the similarities and differences between two USDO cities **3. Recommendations sessions:** People returned to their original group to see how their ideas improved throughout the workshop.

the participants to develop their own ideas regarding the data observatory concept **4. Lightning Talks:** 4 or 5 participants presented short presentations for the existing efforts on sustainable mobility both in Columbus, OH and Portland, OR	**4. Open Mic - Carry it Forward:** Volunteered people shared their thoughts and ideas for the next steps on sustainability and mobility. PIs shared the next steps after the workshop. **5. Taking it Forward:** Last session that fostered the final thoughts of the participants on major challenges about sustainability and mobility
Adjourn (4:30 pm)	Adjourn (3:30 pm)
Dinner and evening activities - Strongwater Gallery (6pm).	

C. Workshop Outcomes by Discussion Theme

Humanity is at a critical, and historic, juncture of challenges and opportunities for sustainable communities and cities in the 21st century. For the first time in human history, a majority of the world's population lives in cities. By the end of this century, the vast majority of the predicted 10 billion people will crowd into cities; we will be an urbanized planet (Batty 2018). Given these pressures, there is a tremendous need to better understand and anticipate the development and growth of cities and the mechanisms that will allow cities to adapt and become more sustainable.

This workshop focused on the transformations that new mobility options and services are having on cities and their interactions with social, economic, and environmental systems. Mobility is a critical component of complex urban systems: transportation is how we organize our cities; consequently, new mobility technologies have profound impacts on urban morphology, economic performance, social equity and the natural environment (Anas, Arnott and Small 1998; Rodrigue, Comtois and Slack 2016; US DOT 2015). The transportation sector contributes approximately 30% to greenhouse gas emissions in the United States (US EPA 2019) and significant portion of urban land consumption is devoted to transportation (Manville and Shoup 2005). Mobility technologies are rapidly evolving and introducing new modes, fuel sources, and operational models for service delivery. New mobility services (e.g., vehicle sharing, hailing services, scooter/bikeshare) are disrupting the mobility landscape of cities, with even larger disruptions foreseen with the coming of connected, autonomous vehicles (Fagnant and Kockelman 2015). As city agencies are dealing with this disruption, there is an opportunity to interject SUS scientific approaches, exploit smart city technologies to collect and manage data for decision making, and create partnerships for knowledge creation and dissemination.

Our workshop generated a rich discussion of these challenges, needs, and opportunities along with a multitude of questions and ideas regarding the form and function of an urban data observatory organized around new mobility. We summarize these discussions here—often using the same words or phrases used by participants as to best retain their intended meaning.

Sustainability Challenges and Needs of Our Two Cities

Managing growth and its impacts: Both Columbus and Portland are growing cities and are expected to grow significantly over the next decade. Managing this population growth is a central concern, along with managing the increasing density, urban sprawl, traffic congestion, air quality, greenhouse gas emissions, and other environmental impacts of this growth. Rapid growth has already spurred high housing prices in Portland; this is quickly becoming an issue in Columbus too. Land use and development is more heavily regulated in the Portland region (e.g., with the urban growth boundary) relative to Columbus. As a result, Columbus has experienced more sprawl, less urban density, and greater decline of its urban core. Columbus is still recovering and rebuilding its downtown areas. Portland faces a challenge of increased migration to the Pacific Northwest, which is making it harder to adhere to the urban growth boundary as economic growth accelerates. Mobility options differ across the two cities. Columbus has no rail service whereas Portland has both light rail and streetcar, in addition to a strong cycling culture. Yet Portland is experiencing a growth in traffic congestion and suffers poor air quality.

Addressing economic and social inequity: Both cities have populations with substantial income gaps with significant concern over housing affordability for lower income populations. Columbus generally has affordable housing whereas Portland's average housing price is about double that of Columbus. Homelessness is a more pressing issue in Portland. Oregon has a recently passed rent stabilization law and a law that allows up to four family units to be built on any property in a city that is over 25,000 population. Yet, the rise in housing costs has resulted in spatial mismatch, longer commutes, and more automobile dependence. There are persistent patterns of unequal wealth, poverty, and racial segregation that make it challenging to ensure that new innovations, e.g., in mobility, benefit all residents and contribute to greater, not less, equality.

Balancing public needs with private gains: New digital technologies are leading to new business models and new opportunities for private firms to provide services, including mobility, to city residents for a fee. These services often compete with public sector services, e.g., fee-based mobility services versus public transit. As private firms compete for market share, declining public sector demand justifies public disinvestment, shrinking "lifeline services" to people who need them the most. With insufficient public revenues to make the needed investments, attempts to optimize expenditures run into difficult questions of who benefits and who pays, and why.

Achieving sustainable economic growth and innovation: Both cities have grown substantially since World War II with an economic base of knowledge and service economies. They both have a significant young demographic, e.g., of young professionals and college students. However, there are challenges in attracting enough talent and companies needed to create a critical mass for the tech industry. Neither city is a legacy city, and are not as burdened with legacy infrastructure and policies like other major cities.

Adapting to climate change impacts: Columbus and Portland face diverse challenges with respect to climate change impacts. Growing frequency and intensity of flooding and urban heat

stress are major concerns in Columbus. In Portland, wildfires and declining aquifers are primary concerns. Portland also has a declining tree cover due to land use changes.

Balancing urban and rural concerns: Both cities are situated in larger urban-rural regions in which rural areas are highly influenced by the economy and other activities of the urban area. Urban areas are progressive relative to the surrounding rural regions. Both cities have progressive city and county governments and non-profit organizations. However, programs and investments that seek to address racial, income or age equity goals may conflict with geographic equity, e.g. balancing investments across urban, suburban and rural areas.

Addressing problems of behavior, political will, and community engagement: Public preferences and the political will needed to solve large problems is lacking. Inertia is one of the greatest challenges. Changes in people's perceptions, beliefs, and habits are slow and often triggered by a big disruptor that forces change. In addition, political and economic power is concentrated and decisions are made to advance the interests of a few, and not of the community. There are problems with engaging communities due to a lack of trust and history of disenfranchisement. Public trust needs to be built, but need the tools to do so. A new approach to community engagement that uses community wisdom in more effective, genuine and transparent ways is needed. Technology may play a role here, but there are issues of privacy and access.

Designing Urban Sustainability Data Observatories:

What are the Functional Requirements?

Business model. Defining the financial and business model for data observatories was a key concern for participants, as it sets the foundation for funding, long-term viability, data ownership and access, and community engagement. Private interests – companies and firms such as Google, Apple, telecommunications providers, etc. – have assembled proprietary, large-scale "big" data around mobility that offer advantages over traditional transportation sources, such as household travel surveys. They offer the advantages of much larger temporal, spatial, and population samples, which allow for longitudinal study and natural experiments. However, they often have a much narrower focus, documentation is opaque, often have use and access restrictions, and are expensive. The question of how a data observatory, comprising multiple data sources and serving multiple stakeholders, is funded also raises questions of access if a fee-for-service model is part of the financial model.

Ownership and control. Participants raised questions about where such a data observatory would reside, who owns this resource, and manages/maintains/disseminates data. As this is a public good, there was a case for data observatories to be owned and controlled by a public agency. However, officials from the cities also expressed concerns about their internal capacity and skills to take on such responsibilities and looked for support from universities and faculty. Further, a data observatory formed with the objective of sustainable mobility will have complex data needs from a variety of sources. How does it intersect with other data observatories and their ownership, control, and business models? Participants also expressed the need for ways to

encourage (or mandate) data sharing from private entities that benefit from public investments and operate on public right of way.

Data standards. Creating standards for data helps with documentation, dissemination and sharing across a network of users, and potential use in widespread applications. Data have different sources, formats, spatial and temporal resolution, and restrictions. Standards can help resolve some, but not all, of these differences and enable better integration and pooling across data sets and locations.

Data needs. An urban observatory focusing on the relationships between mobility and all three dimensions of sustainability (environmental, social and economic) will encompass a wide range of data. These data should include the mobility technologies and services within a community, the infrastructure supporting these technologies, the natural and built environments, social attributes, health and wellness, and economic activities. Some of the relevant data identified by workshop participants include:

1. *Infrastructure* -e.g., road network, public transit networks, sidewalks, bicycle infrastructure, built environment
2. *Social* - e.g., demography, socioeconomic status, housing, crime
3. *Mobility* - e.g., real-time traffic sensor, mobile phone data, public transit schedules and real-time vehicle locations, public transit ridership, pedestrian counts, bicycle counts, travel behavior preferences and surveys
4. *Health* - e.g., neighborhood health indicators, emergency room visits
5. *Safety* - e.g., crash data, injuries, deaths
6. *Energy and environment* - e.g., climate, weather, emissions, air quality, energy usage (vehicle, residential, commercial)

These data have their greatest value when they are “de-siloed.” Integrated data affords a holistic view and can illuminate trade-offs and indirect effects of mobility interventions on community sustainability.

Participants also expressed concerns about potential data biases. Measured data can have biases, but also important are biases due to lack of data collection, especially data that we do not or cannot easily collect. To date, smart city and smart mobility data efforts tend to focus on “low-hanging fruit,” i.e., data that can be easily measured or sensed, such as infrastructure, mobility patterns and other physical properties of the system. Difficult to measure social concepts such as equity, social capital, neighborhood stability and well-being have not received as much attention. Also, many of these data collection efforts focus on quantitative data. Qualitative and unstructured data, such as text, video, social media posts and sound can also be illuminating, potentially providing deeper understanding of the conditions superficially illuminated by quantitative data. Finally, there is a particular need to be cognizant of marginalized individuals, neighborhoods and communities: these entities are vulnerable to transportation deprivation as well as these communities may not be included in existing data collection efforts having the impact of making those communities invisible in existing data sets.

Privacy concerns. Building trust with the community was a strong theme throughout the workshop and ensuring privacy was a key component to success. Communication with the public about what the data are, how they can be used, and guaranteeing good stewardship of the public's information. Managing data privacy is both critical and complex requiring accounting for continually changing technology, different perceptions of the meaning of privacy and managing historic distrust of public agencies. Cities are starting to address these issues, e.g., the City of Portland has recently developed and passed a set of Data Privacy Principles[2], but there are still many unanswered questions (see Khatoun and Zeadally 2017).

Accessing data: user concierge. There are multiple potential users of data from a data observatory - the agencies that aim to make better policies; researchers building knowledge and science around sustainable mobility; private firms developing innovative products; and the public seeking information. These groups have different needs, capabilities, and interests. Participants discussed the idea of a "data concierge" – a primary contact person who is familiar with the data and can work with researchers and stakeholders to solve their data and analysis needs, such as helping them navigate and access the data at the appropriate level of detail, ensuring privacy/security, and providing some education/documentation about what they are.

Outputs/use cases. Desired outputs from the observatory include: modeling and analysis tools, visualization and mapping, policy and plan evaluation tools, mechanisms for engagement and discussion across multiple stakeholders.

Observatories as platforms for virtual laboratories. The increasing amount of data available about cities is fostering a revolution in urban sustainability science, as well as urban and transportation sciences more broadly. However, data alone is not always sufficient. In some cases, we may need to infer behavioral and other processes that are not easily measured. In addition, also needed is are capabilities for conducting sensitivity analysis to understand data limitations and scenario modeling to explore the range of future possibilities based on decisions and actions in the present. A *digital twin* is a high-resolution, high-fidelity digital simulation of real-world processes. Originating in industry to model complex technical systems such as devices, machines, buildings and utility networks, this concept has recently spread to transportation and urban science (Mohammadi and Taylor 2017). Coupled data-simulation processes can help analysts understand how mobility technologies and other interventions will likely perform under various economic, environmental, and social conditions, and identify the drivers of possible disruptions to the urban system.

Opportunities for Innovation

Opportunities for initiatives that enable high risk – high reward pursuits. Often academics and city planners focus on long-term plans and outcomes. To promote innovative projects at smaller scales, there is a need to shift the time horizon and create opportunities for testing novel ideas. Whereas hackathons are growing in popularity for rapid idea generation, they may be less

[2] https://www.smartcitypdx.com/privacy-principles

effective in leading to implementable projects. Challenge pitches do not always need to be technical/data-solutions, but could also include tactical bus lanes, public transit options, low-income fare programs etc.[3]. Beyond short time bound events such as hackathons and Smart City challenges, we need a pipeline of innovation opportunities that that incorporates diverse perspectives, allows for prototyping, and brings in a range of investors. Opportunities need to mitigate the consequences of testing, failure and iteration - especially for the public sector. For the academic sector, cross-disciplinary work and collective contributions must be incentivized. We need to enable ways to build on early ideas to develop longer term projects leading to globally recognized awards such as the MacArthur Genius Grant or the ArtPrize.

Creation of an innovation fund. Through partnerships between cities, industry, and universities, an innovation fund for metropolitan areas can provide competitive funding to implement innovative ideas. These funds would support test cases that allow for innovation within the public sphere. Larger funding for partnerships to solve big problems is necessary; funding needs to be at a level that it can be effectively used by multi-disciplinary, multi-partner initiatives. Innovation needs to be driven by incentives to support applications in local contexts and needs to be supported by mechanisms for sharing of findings. Community challenges that are backed with funding through the innovation fund can serve as incubators for start-ups.

Asking the right questions. The nature of infrastructural investments in mobility technologies are often hard to reverse. For example, the development of roads, bike lanes, or parking lots involve high costs and large investments, sometimes spent toward solving the wrong problem. It is important that we find ways to partner with multiple cities on experiments to bring new ideas to market and explore potential spillover effects via quasi-experimental studies. Similarly, we need to better understand the opportunity cost of inaction and delays in implementing policy interventions.

Data collaboratives. A variety of public and private entities collect data that is relevant for understanding rapidly evolving mobility technology and the impact of cities. For innovative local solutions, we need to find ways to provide access to available data, and for people living in communities to engage and inform what's happening with the data and we need their buy-in to use the data that is collected. We need investment in human-centered design approaches that are centered in communities with the greatest need to create novel data solutions. We need a process that invites people from the communities to surface problems and start a conversation and we need a way for people living in these communities to contribute.

Engaging the private sector. We need to enlist the private sector as the innovation engine: develop an innovation pipeline that incorporates diverse perspectives, allows for prototyping, and

[3] For example, in November 2018, a transportation innovation weekend event held in Columbus, hosted by the national organization Purple Aisle and attracting over 100 local residents, neighborhood leaders and transit experts resulted in the City of Columbus and the Central Ohio Transit Authority experimenting with a tactical, "pop-up" bus lane in the downtown; see https://www.columbusunderground.com/city-and-cota-looking-into-pop-up-bus-lane-other-ideas-from-pitch-event-bw1

brings in a range of investors. Start-ups may engage with community to seek innovative solutions ("community challenges as an incubator for small businesses").

Creating Successful (Community-University) Partnerships for Urban Sustainability Data Observatories

Institutionalize partnerships. To create and sustain a successful partnership, institutions and agencies require long-term commitments of resources, time, and staff. Current models for community-university partnerships tend to be informal arrangements based upon individual relationships or project-specific efforts that are vulnerable to dissolution with personnel changes or at the conclusion of a grant or project. Further, universities and city agencies are complex organizations with very different hierarchies, operating principles, and needs. It takes time to gain mutual understanding in order to capitalize on the benefits. There are a few examples of successful commitments to these partnerships (Hennepin County-University of Minnesota; Chattanooga-University of Tennessee at Chattanooga). In these cases, common elements are: a staff liaison embedded in the university (or vice versa); financial commitments to fund projects of mutual interest; engagement with students and faculty; and regular meetings to set agenda, share progress, and create ideas. Extension faculty and staff can also be highly effective in serving as trusted liaisons between the university and community partners.

Building trust in the community. Many cities need meaningful, long-term community engagement and lack of trust in government is often cited as a common issue. Although universities traditionally have been well-regarded by community members, this trust has eroded in more recent years among some constituents as belief in science has become a political issue. University partnerships with communities are also often inconsistent, e.g., the partnership may end after research projects are completed or if those at the university failed to follow through on promises made. With the launch of data collection via smart cities technologies, there are also concerns over privacy, ownership and stewardship of data, and communication. Successful partnerships will need to find ways to overcome these deficiencies. New approaches to community engagement are necessary to use community wisdom in more effective, genuine and transparent ways. Co-production of knowledge, citizen science collaborations, and community-led initiatives benefit public policy and university research, alike, and are products of trusting relationships.

Workforce education and capacity building. Given the wealth of new data emerging from sensors, new mobility providers, and other technologies, staff of public agencies are struggling to keep place and are in need of a new skill set with respect to database management, data science/analytics, and visualization techniques, in addition to specific knowledge about transportation and land use planning, engineering, environmental science, etc. Universities are in a unique position to redesign degree programs, teaching modules, and workshops to help provide the education and training for the future and current workforce for public agencies. Partnerships can help to inform professional education programs by improving responsiveness of university programs to labor needs. Further, the broader public needs more help in understanding their rights, how their data are used, and what the possibilities are for their communities to participate, collect, and use data themselves.

Technology transfer and dissemination of knowledge. One benefit of creating network of community-university partnerships, beyond any individual city or institution, is broader and faster dissemination of knowledge and findings from research, use cases, innovative technologies, and policy approaches. While the context of urban mobility issues differs from location to location, there are many common themes, including the need to understand rapidly evolving technologies. There are several existing networks for cities (National Association of City Transportation Officials, National League of Cities, e.g.), universities (Association for the Advancement of Sustainability in Higher Education, Council of University Transportation Centers, e.g.) and both (Transportation Research Board, MetroLab, e.g.). Creating Sustainable Research Networks around themes help to build specific collaborations motivated around a common issue to advance the sharing of information and lead to smarter implementation.

Technical advising and policy evaluation. Public agencies are often challenged by technical questions or issues that are out of the scope of staff expertise as well as consultant services. In addition, these issues are often subject to political debate and opinion. Faculty experts can provide objective analysis and policy advising to help navigate many short-term investments/decisions that have long-term consequences. Further, most cities don't have the capacity to conduct their own policy evaluation. Jointly-developed research questions and agreed-upon approaches can help foster trust and encourage debate based upon evidence and science, rather than starting from subjective positions.

Cities as living laboratories. Research benefits greatly from the ability to conduct quasi-natural experiments, pilot projects, and sensor deployments on a large scale, outside of the controlled university environment. Understanding complex urban systems requires that university research be embedded in the realities of cities. Community-university partnerships can be an important mechanism for facilitating access for faculty research, as well as ensuring that research designs engage community and address relevant public policy questions.

Incentivize faculty for community-engaged research. Traditional promotion and tenure processes rarely provide adequate encouragement or incentives for faculty to build partnerships with communities and engage in civic-led, transdisciplinary research. If partnerships are to be meaningful and sustained, faculty need to get due credit for these activities, which currently fit outside the norm of expected activities for tenure-track faculty. Changing this paradigm will require buy in from the larger academy, not just individual institutions, as it relates to guidelines for peer-review publications and promotion packages.

Other Steps Proposed by Participants

An "open mic" session concluded the workshop, where participants shared a pitch or invitation for specific further collaborations beyond the workshop. Twelve, two-minute pitches from a variety of participants included the following suggested collaborative opportunities:

- Discussions toward one or more literature reviews/perspective pieces for the *Journal of Planning Literature* “Will New Mobility Technologies Make Cities More Sustainable?” (Harvey Miller, Ohio State)
- Envisioning and modeling the potential for creating low-stress, rapid-build, complete bicycle networks in Columbus to provide safe options for people to use bike rather than car for short trips (Stephen Patchan, Mid-Ohio Regional Planning Commission)
- Participating in an existing network of urban field stations with a track record of long-term socioecological research, knowledge co-production, and positive public engagement (Sarah Hines, US Forestry Service)
- Brainstorming what a “Schoolhouse Rocks” series of catchy musical videos might look like for basic data science concepts to raise baseline data science fluency among decision-makers in government and their advisors. (Anne Hill, City of Portland)
- Convening with others in the GIS-informed research and practice community: gauging interest among the other agencies in offering a regional data conference. Perhaps to socialize/gain insight into the idea of a regional data platform. (Aaron Schill, MORPC)
- Gathering data leading to the potential establishment of Columbus as a member of the 2030 District initiative, a commitment to a set of compact development and other principles that lead to dramatically reduced environmental footprint. (Eric Boxer, Columbus 2030 District)
- Collaboration on research with Ohio State’s Center for Automotive Research, which seeks to have its intra-vehicle research converge with the needs of all of the social, environmental and economic systems that surround vehicles today and in the future (Danny Freudiger, Ohio State Center for Automotive Research)

D. Synthesis of SUS Research Questions

The following research themes and questions emerged from the workshop, reflecting both fundamental and applied research needs. We organize these by the six key elements of for next-generation SUS science, as articulated in the ACERE (2018) report.

1. How do individual values, attitudes, and behaviors influence mobility flows and the scale of new mobility technologies?

- What is the role of individual identities associated with various forms of transit use (including bus, scooter, car, bicycle) in transportation decisions, and the impact of specific mobility interventions on these decisions? Will there be a perception of loss of independence, and if so what does that imply for adoption? How will the introduction of shared-mobility systems and new technologies (i.e. e-scooters, bike-share) affect mobility decisions?

2. How should we conceive of and operationalize a theory of regional sustainability that incorporates both inter- and intra-generational equity?

- The standard theoretic approach to sustainability in economics focuses on welfare changes over time assuming a closed economy in which there are no flows of people, capital, goods, pollution, or services across boundaries. While this is clearly the case at a

global scale, it is impossible to ignore these flows and their potential impacts on sustainability at a regional scale. Regions are open economies, and therefore any theory of regional sustainability must address how these flows should be incorporated and the trade-offs among these flows assessed. For example, some subnational regions are likely to experience persistent in-flows of savings while others experience persistent out-flows. Persistent out-flows of savings are more likely in hinterland regions. Does this mean that these regions are not sustainable?

- Traditional sustainability theory is based on a theory of intergenerational equity. Building on the foundations of the Rawlsian theory of justice, advances in sustainability theory have focused largely on identifying pathways to maintain increasing, or non-declining capital stocks over long time horizons. Whereas the role of proper accounting of natural capital is now well-understood, the role of social capital and intro-generational equity in sustainability science is largely unexamined. In the context of urban systems, does economic and social inequality limit the set of viable paths for sustainable growth? Should intra-generational equity be considered a necessary condition for long-term sustainable development?

3. How can we better understand cities as complex systems to anticipate unintended consequences?

- Cities are complex systems. Well-intentioned sustainable technology or policy innovation are subject to both positive and negative feedbacks that can result in uneven impacts that play over multiple time and spatial scales (Pollock 2016).
- Emerging mobility technologies and services such as vehicle and bicycle sharing, ride hailing services, and e-scooters, are grand, real-world experiments that are currently playing out in cities. Will they result in more sustainable cities? How will they impact land use and mobility across city neighborhoods and the urban-rural gradient? What are their impacts on accessibility and social mobility? Given the complexity of cities, these questions are difficult to answer using traditional urban scientific and management approaches.
- What are the unintended consequences of new mobility technologies and services? For example, those associated with autonomous vehicles (AVs): With the conveniences of AVs, what are the new functions that cars may take on, e.g., will they become mobile offices and spur additional demand for automobile travel? What are the environmental impacts, including congestion, pollution and urban sprawl? What are the management needs and implied trade-offs? For example, dedicated AV lanes may be necessary for transportation management, but imply reduced access for non-AV drivers and the potential to exacerbate inequality.

4. What are the antecedents and consequences of data trust for SUS outcomes?

- How does urban context shape individuals' data privacy attitudes, perceptions, and preferences? How do these change with experiences of new data-engaged technologies, e.g., mobility services?
- Local, state and federal policies regarding data accessibility are critical for determining the extent to which data are treated as a public good versus protected by firms and used for

private gain. How are data trust and trust in government related? What is the role of privacy policy in individual perceptions of privacy? How does data privatization and potential exploitation of data for private gain influence these perceptions? What are the implications of data for private gain versus public benefit for sustainability and social equity?

- Ideally the role of data will be to ensure that public goals are served by transport system-management and investment decisions; and to enable more responsive predictive ability to suggest public response in system management and investment. However, this depends on data sharing by private firms with the public sector. What are the hybrid models that will incentivize private sector firms to collaborate with the public sector to achieve mutually beneficial approaches to data sharing and use?
- Individuals generate an enormous quantity of data via their digital footprint that can be used to track their activities. What are the data ethics for SUS research and modeling? What mechanisms are there to feedback SUS information to these individual data donors?

5. How will new markets enabled by digital technologies impact social equity?

- How will new markets enabled by new digital technologies, e.g., for mobility, provide profit opportunities for firms and compete with public services, e.g., public transit? Diminishing public services have a disproportionate impact on poor households, and erode the very public assets on which private firms depend (e.g., roads). If unregulated firms will gain market share and erode public share and users, how will declining public financing and investment impact SUS outcomes, including social equity?
- Declining public users and revenues reduce the ability of the public sector to manage the system that is its responsibility to manage. How can governments respond to the pace of innovation and disruptive technologies? What are the public sector innovations that are needed, and how do they become ingrained?
- In the absence of public investments to support technology-enabled data collection and sharing, private firms will use fee-for-service models and mobility solutions will be based on a fee-for-service model. What are the implications for social equity and other SUS outcomes?
- Technological innovation has alleviated resource constraints over time, but unintentionally often exacerbated social inequality. This suggests a fundamental trade-off associated with new technologies between greater resource efficiency versus greater social equity. Why does innovation often lead to greater social inequity?
- What is the role of data biases, e.g., data that underrepresents marginalized neighborhoods or people or algorithms that perpetuate data biases? What are the biases implicit in our data collection systems and how do we account for these? What is the relationship between these biases and social inequality?
- With growing cities, we have increasing density and users but a fixed amount of public right of ways. What are the implications for management given that these are akin to common pool resources. How do we avoid the tragedy of the commons?
- What are the lessons that we can learn from past experiences with new digital technology systems in cities, e.g., in terms of internet accessibility or Intelligent Transportation Systems?

6. How can growing regions balance the often competing forces of economic growth and social equity?

- A systems approach to understanding the sustainability impacts of new mobility technologies and services underscores the importance of three interdependent processes that are critical to addressing the sustainability challenges of growing cities: mobility, land use, and housing. This also underscored the fundamental connection between managing these problems of growth while also addressing the social equity issues that arise in growing cities. For example, smart growth policies that constrain new outward development and protect natural resources also bid up housing prices and rents, which may lead to greater social inequities. Balancing these competing forces is a critical dimension of sustainable cities located in growing regions.

E. Recommendations for SUS Data-Enabled Research

1. A need for concurrent, parallel observation and analysis

As noted above, Columbus and Portland have similarities and differences that make them comparable but nevertheless unique with respect to sustainability needs and challenges. During the workshop, participants often made these types of comparisons, highlighting how these cities arrived in their current situation with respect to opportunities and barriers to more sustainable mobility. These observations and discussions reflect a deeper truth about cities. It is likely that universal principles underlie urbanization and urban processes (see, e.g., West 2017). However, due to emergent properties, this does not mean it is possible to use these fundamental principles to predict the behavior of a city in detail (Andersen 1972). Cities comprise a multitude of entities interacting over space and time (Batty 2007). The patterns and intensity of these interactions are shaped by the context in which they occur, meaning that overall behavior of cities is context dependent. In addition, path-dependency are also characteristic of complex systems: the past behavior of system, sometimes impacted by random events, determines future development paths. The influence of context and history also means that policy interventions and unplanned disruptions can play out differently in different places and times.

The complexity of urban systems does not mean that scientific understanding and effective policy interventions are impossible. Rather, it means that we must observe more than one city to ascertain how urban processes play out in in places with different contexts and histories, and the impacts of disruptive technologies and policy interventions on those processes. In this way, a research network of urban observatories can facilitate a new type of sustainable urban systems science that recognizes the complexity and uniqueness of cities. We can use parallel observations using the same definitions and protocols as stepping stones to general theories of urban sustainability. This will also help achieve deeper understanding of the role of context and history on urban processes. We can also use the network to tailor policy in an iterative manner and share best practices as knowledge is gained based on feedback and experience of outcomes in different places and times.

2. Engagement and governance

A clear message from workshop is the crucial role of engagement and governance. Participants observed that "we must listen to what communities want, especially [marginalized] communities" and seek a "democratization of data." Similarly, in constructing an observatory we must be confident that we are "actually measuring what we think we are measuring." An USDO should go beyond ongoing observation and analysis to engage stakeholders and citizens throughout the process, from the conceptualization and design of the observatory, through data collection and analysis, to how the information is represented and communicated. An urban observatory should be "accessible to all" – data scientist, urban planner, and the general public. There also needs to be mechanisms for effective multilateral communication across different stakeholder groups throughout these processes. Indeed, an urban observatory can serve as the virtual town halls, virtual classrooms, and virtual citizen science platforms of the future. Research is required on how to build and integrate effective online platforms and offline processes that maximize engagement among highly heterogeneous stakeholders.

There is also a need for greater understanding of how data-centric organizations and initiatives such as observatories can build trust. Clarity, transparency and open source tools are necessary to avoid proprietary, "black box" solutions (see Townsend (2013) for a similar argument about smart city technologies). Security is also crucial: there is a need to define different levels of access both in terms of security and application. Given likely - and justifiable – privacy concerns by community residents, there are needs for better understanding of data privacy issues, especially for spatio-temporal and mobility data for which privacy protocols are not well developed.

Observatories also need an institutional structure to assure effective management of a complication, multifaceted enterprise. It is important that this structure is not rigid. Efforts must be taken to ensure that the institutional structure is empowered to be nimble, flexible, adaptable, and self-learning. This includes using agile techniques that embrace iteration, self-review and self-learning. The observatory should be a *learning organization* that continuously learns and transforms itself (Pedler, Burgogyne and Boydell 1997).

3. Integrating observatories, virtual laboratories and living laboratories

Powerful synergies can be gained by combining empirical data collected via an urban observatory with the simulation environment provided by digital twins and the embeddedness enabled by treating the city as a living laboratory. A USDO can provide empirical, longitudinal data that can maximize the fidelity of the urban digital twin. In turn, the urban digital twin can allow researchers and stakeholders to test disruptions and scenarios in a safe, virtual environment. Protocols for testing interventions in the real world and receiving feedback via the observatory can allow verification of the urban digital twin and assessment of the intervention itself before it is scaled-up or transferred to a different setting. Required is research on how to best integrate these technologies and processes to maximize their effectiveness in discovering new knowledge about sustainable urban systems and tailoring evidence-based policy for complex urban systems

4. Education and capacity building

The types of new sustainable urban science enabled by the data-rich and computation-rich methodologies combined with new processes for engaging scientists, domain experts, practitioners and heterogeneous stakeholders implies a rethinking of education, both foundational and continuing. While it is unlikely that a single person can embody the wide range of knowledge and expertise required to build and utilize the system we are describing, there is a need for cross-domain undergraduate and graduate education that facilitates meaning interactions and collaborations across disciplinary boundaries. There is also a need for continuing and professional education: the science and technologies in this area are evolving rapidly, and will likely accelerate in the future. Additionally, there is a need to build capacity at the organizational and community level through short courses, workshops, activities and other innovative educational techniques so that partners and stakeholders can interact meaningfully with the systems and each other.

Appendix A: Full Participant List

PARTICIPANT NAME	TITLE	ORGANIZATION
Aaron Schill	Director of Data & Mapping	MORPC
Adam Porr	GIS Project Manager	The Ohio State University
Alana Shockey	Assistant Director, Sustainability	City of Columbus
Amber Woodburn McNair	Assistant Professor, City and Regional Planning	The Ohio State University
Andrew Neutzling	Service Planner	COTA
Anish Arora	Professor, Computer Science & Engineering	The Ohio State University
Anne Hill	Program Development	Portland Bureau of Transportation
Antoinette WinklerPrins	Program Officer	National Science Foundation
Arnab Nandi	Associate Professor, SBS-Biomedical Informatics; Associate Professor, Computer Science & Engineering	The Ohio State University
Avinash Unnikrishnan	Co-Director, Transportation Technology and People Lab; Associate Professor, Department of Civil and Environmental Engineering	Portland State University
Ayaz Hyder	Assistant Professor, Environmental Health Sciences	The Ohio State University
Basar Ozbilen	Ph.D. Student, Graduate Research Associate, City and Regional Planning	The Ohio State University

Brian Cultice	Ph.D. Student, Graduate Research Associate, Agricultural, Environment, and Development Economics	The Ohio State University
Charlene Brenner	Project Coordinator, The STEAM Factory	The Ohio State University
Conor Willis	Director of Operations	Empowerbus
Courtney Falato	Smart Columbus liason; Director, Corporate Relations	The Ohio State University
Danny Freudiger	Ph.D. Student, Graduate Research Associate, Center for Automotive Research	The Ohio State University
Darrick Hamilton	Director, Kirwan Institute; Professor, John Glenn College of Public Affairs	The Ohio State University
Duane Detwiler	Division Director of Strategic Research Operations and Chief Engineer	Honda
Elena Irwin	Director, the Sustainability Institute; Professor College of Food, Agricultural and Environmental Sciences	The Ohio State University
Eric Boxer	Energy Efficiency Engineer	Columbus 2030 District
Harvey Miller	Director, Center for Urban and Regional Analysis; Professor, Geography	The Ohio State University
Huyen Le	Assistant Professor, Geography and the Sustainability Institute	The Ohio State University
Jason Cervenec	Director of Education and Outreach, Byrd Polar and Climate Research Center	The Ohio State University
Jason Reece	Assistant Professor, City and Regional Planning	The Ohio State University
Jeff Frkonja	Director	Portland Metro
Jinhyung Lee	Ph.D. Student, Graduate Research Associate, Geography	The Ohio State University

Joanna Pinkerton	President/CEO	COTA
John MacArthur	Research Associate, Transportation Research and Education Center	Portland State University
Jordan Davis	Director	Smart Cities, Columbus Partnership
Josh Lapp	Co-founder	Transit Columbus
Josh Sadvari	Geospatial Information Librarian	The Ohio State University
Julie Fox	Associate Professor; Associate Chair, Department of Extension; OSU Extension Urban Metro Program Leader and Central Regional Director	The Ohio State University
Katie Phillips	Outreach Coordinator, Center for Urban and Regional Analysis (CURA)	The Ohio State University
Kelly Clifton	Associate Dean of Research, Professor, Civil and Environmental Engineering	Portland State University
Kerry Ard	Assistant Professor, Environmental and Natural Resource Sociology	The Ohio State University
Kevin Martin	Smart City PDX Director	Portland Bureau of Planning & Sustainability
Kristin Tufte	Research Assistant Professor, Computer Science	Portland State University
Mackenzie King	Smart Columbus	Accenture/Pillar Technology
Mandy Bishop	Smart Columbus	City of Columbus
Marcello Canova	Associate Professor, Mechanical and Aerospace Engineering	The Ohio State University

Mark Patton	Vice President	Smart Cities, Columbus Partnership
Maryn Weimer	Senior Associate Director of the Center for Automotive Research and the Director of Mobility	The Ohio State University
Matt Martin	Community Research and Grants Management Officer	The Columbus Foundation
Maureen Langlois	Proposal Development Specialist	The Ohio State University
Michael Kerr	Division Manager, Strategy, Innovation, and Performance	Portland Bureau of Transportation
Michael Stevens	Chief Innovation Officer	The City of Columbus
Mindy Justis	Vice-Chair	Transit Columbus
Morgan Grove	Scientist and Team Leader	US Forest Service, DC
Nicole Sintov	Assistant Professor of Behavior, Decision Making and Sustainability	The Ohio State University
Piyushimita (Vonu) Thakuriah	Dean of the Edward J. Bloustein School of Planning and Public Policy	Rutgers, The State University of New Jersey
Sarah Hines	Project Coordinator	US Forest Service, DC
Sathya Gopalakrishnan	Director, the STEAM Factory; Associate Professor, Agricultural, Environmental & Development Economics	The Ohio State University
Shannon Hardin	City Council President	City of Columbus
Shashi Shekhar	McKnight Distinguished University Professor; Distinguished University Teaching Professor, Department of Computer Science	University of Minnesota

Shoreh Elhami	GIS Manager	City of Columbus
Sirisha Kothuri	Senior Research Associate, Civil and Environmental Engineering	Portland State University
Steve Chang	Technology Solutions Engineer, Translational Data Analytics Institute	The Ohio State University
Steven Patchan	Assistant Director of Planning & Environment	MORPC
Terri Eyerman	Director of Finance	COTA
Tijs van Maasakkers	Assistant Professor, City and Regional Planning	The Ohio State University
Tim McHugh	Chief Information Officer	TriMet
Tracy Morgenstern	Transportation Lead	Urban Sustainability Directors Network
Wu-chi Feng	Professor, Computer Science	Portland State University
Xiaoyu (Amelia) Li	Ph.D. Student, Graduate Research Associate, Agricultural, Environment, and Development Economics	The Ohio State University
Zachary Davidson	Legislative Aide, Office of Columbus City Council President Shannon G. Hardin	City of Columbus

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