FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

Report to Congress on Internet of Things

FEBRUARY 2017

FTA Report No. 0099
Federal Transit Administration

PREPARED BY
Federal Transit Administration

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Federal Transit Administration

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PREPARED BY

Office of Research Management,
Innovation and Outreach
Federal Transit Administration

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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13. ABSTRACT
The Fixing America's Surface Transportation Act (FAST Act) Section 3024 calls for FTA to submit a report to Congress on the potential of the Internet of Things (IoT) to improve transportation services in rural, suburban, and urban areas. This report was prepared to provide background information on IoT and how it relates to the provision of transportation services, and, as required by Sectio0n 3024, information related to 1) a survey of the communities, cities, and states that are using innovative transportation systems to meet the needs of aging populations, 2) best practices to protect privacy and security, as determined as a result of such survey, and 3) recommendations with respect to the potential of the IoT to assist local, state, and federal planners to develop more efficient and accurate projections of the transportation needs of rural, suburban, and urban communities.

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ABSTRACT

Section 3024 of the Fixing America's Surface Transportation Act (FAST Act), requires that the Secretary of Transportation submit a report to Congress on the potential of the Internet of Things (IoT) to improve transportation services in rural, suburban, and urban areas. This report was prepared by the Federal Transit Administration (FTA) to provide background information on IoT and how it relates to the provision of transportation services, and, as required by Section 3024, information related to (1) a survey of the communities, cities, and states that are using innovative transportation systems to meet the needs of aging populations, (2) best practices to protect privacy and security, as determined as a result of such survey, and (3) recommendations with respect to the potential of the IoT to assist local, state, and federal planners to develop more efficient and accurate projections of the transportation needs of rural, suburban, and urban communities.

EXECUTIVE SUMMARY

Introduction

Section 3024 of the Fixing America's Surface Transportation Act (FAST Act), calls for the Secretary of Transportation to submit a report to Congress on the potential of the Internet of Things (IoT) to improve transportation services in rural, suburban, and urban areas. Specifically, Public Transportation Law requires the report to include:

- I A survey of the communities, cities, and states that are using innovative transportation systems to meet the needs of aging populations;
- II Best practices to protect privacy and security, as determined as a result of such survey; and
- III Recommendations with respect to the potential of the IoT to assist local, state, and federal planners to develop more efficient and accurate projections of the transportation needs of rural, suburban, and urban communities.

IoT Defined

Although there is no single, universal definition for IoT, the term generally refers to a network of ordinary objects that are embedded with Internet-connected electronics, sensors, or software that can capture, exchange, and receive data. These "things" include items sold to and used by consumers, as well as broader cloud-enabled machine-to-machine communications that enable businesses and organizations to track energy use, functionality, or efficiency. IoT technology enables the creation, transmission, communication, and analysis of data generated by embedded sensors. Table ES-1 gives an overview of technologies facilitating the exchange between sensors embedded in "things" through the Internet.

For the purpose of this report, sensors in tablet and smartphone devices that transmit automatic vehicle location, destination, and speed are included in the analysis because they facilitate the transmission of real-time, actionable information that improves transit efficiency and safety or provides travelers with more transportation options.

Survey and Best Practices

To develop this report, the Federal Transit Administration (FTA) leveraged relationships with transportation providers and national organizations serving aging adults to collect information on communities, cities, and states that are using IoT technology to serve the needs of aging populations. Facilitating access to a robust set of transportation options is crucial to supporting the health and well-being of older adults. Mobility—whether on foot or bicycle, by private or shared car, bus, or shuttle—enables adults, including older adults, to connect with essential services and remain active, independent, and connected to their communities.

The results of the survey are organized into five categories: smartphone and tablet application (app) development; improving demand response services; open data and software initiatives; accessible bikeshare programs; and transportation network company (TNC) programs. The report reviews best practices in privacy and security and recommendations related to the potential for IoT to assist planners to develop more efficient and accurate projections of needs across all types of communities.

Table ES-1

Internet of Things Technology Overview

Technological Component	Description	Function
Sensors	Devices that convert non-electrical information about a physical condition or even to an electrical signal that can be sent to an electronic circuit.	A sensing system observes and creates data without the need for human observation. Sensors can collect information about position, occupancy, proximity, velocity, pressure, sound, temperature, light, biological elements, and more.
Gateways	Networking hardware and software components that connect one network to another (hubs, servers, routers, etc.).	Gateways allow for signals generated by sensors to be communicated to networks, and vice versa.; gateways facilitate bidirectional communication between the sensor and the network.
Networks	An infrastructure of hardware and software protocols that allow devices to share information (Ethernet, Bluetooth, Wi-Fi, cellular technologies such as 3G and 4G).	Networks transmit real-time data collected by sensors to other devices.
Standards	Requirements and specifications that define how machines identify and communicate with one another.	Data collected by sensors and transmitted over the network are aggregated so they can be analyzed; standards facilitate interoperable data handling, processing, and storage.
Data Analysis Tools	Data can be processed and analyzed for use by transit organizations through the application of statistics, computer programs, and modeling techniques; for example, algorithms can be designed that automatically process and analyze data generated and communicated by specific types of sensors.	Analyses of IoT data: • Aggregate and communicate information about individuals and their preferences, • Can be communicated back through the network to make adjustment in the physical world, • Provide information on patterns that can help us optimize safety, efficiency, and customer experience,

The survey methodology resulted in the selection of 24 case studies from 15 states representing at least one state from every FTA Region. These IoT-associated innovative solutions serve a cross section of communities, including urban, suburban, and rural.

The innovations that the IoT technology provided were vast. Some enhanced rider experience by providing information about street conditions, notes from other riders about routes, and availability of accessible rides. All provided real-time information on ride availability, and many had multiple ways to access the data—text, smartphone apps, websites, and telephone. Some case studies integrated travel training and other features that helped riders, and some had caregiver, mobility manager, or other types of support just a "click" away.

Because IoT-enabled technologies rely on automatic, machine-readable data, stakeholders generally agree that it is important to balance the increase in interoperable data and connected devices with the strategic use of available privacy and security safeguards to protect consumers. Interviews conducted for this report suggest a universal interest in implementing best practices in privacy and security. However, there is a lack of consensus about what those practices are and should be and who should define them and provide oversight.

IoT Advantages

As Internet-enabled sensors are increasingly embedded in the physical world—in everything from energy meters, home appliances, mobile phones, vehicles, infrastructure, wearables, and beyond—data about consumers, infrastructure, and asset health and real-time contextual data about weather, current events, and travel patterns are generated, stored, and analyzed at an alarming rate. The growing volume of data generated by IoT technology and Internet communications can provide new insights with the capacity to improve transportation safety, reduce the costs of operations, improve mobility, reduce environmental impacts, and allow planners to develop more accurate transportation projections. The volume, velocity (speed of acquisition), and variety (range of data types and sources) of these data—and approaches to mining, analyzing, and operationalizing these data—distinguish big data approaches from traditional data management and analysis.

Technology scans by ITS America and reports by USDOT suggest that we are in the nascent stages of understanding possible applications of big data frameworks to multimodal transportation planning efforts. Continued attention to and support of the application of big data capture, storage, visualization, and analysis to transportation planning in rural, urban, and suburban contexts will be necessary to preparing Federal, state, city, regional, and local planners to incorporate diverse emerging data sets into planning efforts.

Observations and Findings

The report concludes with some observations gleaned from the findings with a view toward the future of public transportation in an age of public/private partnerships and in a connected world.

Research on how IoT is being used to serve older adults uncovered a key fact—it is often not the technology at the center, it is the psycho-social element of rider and user experience and perspectives.

A major finding of this report is that ethnographic fieldwork—more specifically, rider experience and user experience research that helps transportation professionals understand which non-targeted services are popular among older travelers, and why—will be crucial to continuing to develop services that are attractive to and meet the needs of those travelers.

Another finding is the importance of ensuring equity of both technology access and data algorithms. Connected transportation systems as part of a broader web of connected systems can improve mobility for all riders, including older Americans. Improved traffic management and safety through connected vehicle technologies can improve the mobility of travelers regardless of whether those travelers are personally using IoT-enabled devices. But the ability of users to access real-time information and make informed, multimodal choices based on that data increasingly relies on access to a smartphone device or Internet-connected computer.

Just as the proliferation of connected devices and associated software increases, so does the volume of data we will be able to collect in connected cities and communities. This poses unique privacy and security challenges, yet there is no agreement to date on the best ways to address these challenges. The growing volume of data generated by IoT technology and Internet communications can provide new insights with the capacity to improve transportation safety, reduce the costs of operations, improve mobility, reduce environmental impacts, and allow planners to develop more accurate transportation projections. But it must be done with a clear understanding of how to ensure privacy and security.

There is no single way to define how IoT is transforming transportation. Objects connected to sensors generating data that are then analyzed to enhance operational and consumer services are transforming communities. IoT is no longer the wave of the future; today, these technologies enable the ebb and flow of people, goods, services, and utilities. Within these innovations, like many technology initiatives in the past, it is essential to understand the societal implications and issues of their use and proliferation. That is the key finding of this research: it is the human-machine interaction and ethics of big data that emerge as essential elements to include as IoT solutions are developed and implemented.

Appendix C of the report notes USDOT strategic research initiatives that support research, innovation, and demonstration projects associated with IoT and finding innovative ways to support the mobility needs of historically-underserved groups such as older adults, people with disabilities, veterans, and persons of limited incomes.

SECTION 1

Introduction

Section 3024 of the Fixing America's Surface Transportation Act (FAST Act) calls for the Secretary of Transportation to submit a report to Congress on the potential of the Internet of Things (IoT) to improve transportation services in rural, suburban, and urban areas. Further, Section 3024 requires the report to include:

- I A survey of the communities, cities, and states that are using innovative transportation systems to meet the needs of aging populations;
- II Best practices to protect privacy and security, as determined as a result of such survey; and
- III Recommendations with respect to the potential of the IoT to assist local, state, and federal planners to develop more efficient and accurate projections of the transportation needs of rural, suburban, and urban communities.

Defining the Internet of Things

The term "Internet of Things" was first used in 1999 to describe a system in which objects in the physical world could be connected to the Internet by sensors. Although there is no single, universal definition for IoT,[1] the term generally refers to a network of ordinary objects that are embedded with Internet-connected electronics, sensors, or software that can capture, exchange, and receive data. These "things" include items sold to and used by consumers, as well as broader cloud-enabled machine-to-machine communications that enable businesses and organizations to track energy use, functionality, or efficiency. Thermostats and lights that you can control remotely, fitness trackers that share the number of steps you take daily to your social network, and sensors allowing a hotel manager to automatically monitor and reduce energy use in a hotel are all examples of IoT technology. The "things" referred to in IoT generally do not include desktop or portable computers or their smaller counterparts, smartphones and tablets; however, these devices are crucial components to controlling or communicating with other "things." For the purpose of this report, we include sensors in tablet and smartphone devices that transmit automatic

[1] IoT is also commonly referred to by other names such as cyber-physical systems, the Industrial Internet, and, more recently, the Internet of Everything (IoE) to emphasize the connections between people, processes, and things, as well as the digital trails those interactions produce.

vehicle location, destination, and speed in our analysis because they facilitate the transmission of real-time, actionable information that improves transit efficiency and safety or provides travelers with more transportation options.

Approach

To develop this report, FTA leveraged relationships with transportation providers and national organizations serving aging adults to collect information on communities, cities, and states that are using IoT technology to serve the needs of aging populations. The examples relied heavily on a combination of snowball, chain-referral, convenience sampling methods[2] and voluntary interview research with organizations and programs identified by organizational contacts. FTA contacted each organization to confirm details about services offered. The survey results section of the report shares transportation initiatives that both:

- Specifically target older adults in the US and/or persons with disabilities
- Use or actively develop[3] one of the IoT technologies listed in Table 2 1.

The results of the survey are organized into five categories: smartphone and tablet application (app) development; improving demand response services; open data and software initiatives; accessible bikeshare programs; and transportation network company (TNC) programs. Based on the findings, the report reviews best practices in privacy and security and recommendations related to the potential for IoT to assist planners to develop more efficient and accurate projections of needs across all types of communities. Finally, the report concludes with some observations gleaned from the findings with a view toward the future of public transportation in an age of public/private partnerships and in a connected world.

Appendix C of the report identifies the US Department of Transportation (USDOT) strategic research initiatives that support research, innovation, and demonstration projects associated with IoT and finding innovative ways to support the mobility needs of historically-underserved groups such as older adults, people with disabilities, veterans, and persons of limited incomes. Appendix A contains a glossary of terms, and Appendix B overviews big data concepts.

[2] For a helpful discussion on these types of sampling methods, see article by Douglas D. Heckathorn, "Snowball versus Respondent-Driven Sampling," retrieved July 24, 2016, from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3250988/.

[3] The examples here approach but do not yet fully manifest the connected systems framework that characterizes the fullest embodiment of IoT frameworks. We expect to see examples that rapidly emerge over the next few years, and ongoing efforts to document and assess those projects will be necessary.

Limitations

Every effort was made to meet the request of Congress for this report. An early finding of this research was that it is just a beginning in noting how IoT programs are serving or could be used to serve older community members. We expect more options and programs will rapidly emerge. More entities are marketing on-demand mobility software platforms, more vehicles are outfitted with automatic vehicle location sensors, and transportation data are increasingly open, standardized, and interoperable. A future county-by-county complete survey of this emergent transportation landscape may be a useful next step. This fast-track report process has a number of limitations due to a number of factors, including:

- **Lack of a comprehensive databases** – there are no databases that register service types, populations served, and how technology enhances operations or connectivity
- **Consumer views** – even in the case of these example programs, the extent to which those programs do or do not meet the mobility needs of older populations as defined by those individuals rather than planners, providers, and research analysts remains largely unknown; filling this gap would involve intensive stakeholder engagement and a commitment to iterative design processes[4]
- **Pace of IoT innovation** – new products, platforms, and data services using IoT technology are constantly emerging
- **Lack of consensus regarding what constitutes IoT** – there is no agreement among stakeholders as to what constitutes using IoT technologies to serve underserved populations
- **Complex nature of the topic** – the emerging, broad, and complex nature of this topic makes it difficult to crosswalk solutions with only those that target specific populations such as older adults and people with disabilities

Due to these limitations, this report is not a representative sample all of US communities, cities, or states using IoT-related tools to broaden the mobility options or experience of transportation for older adults. However, this sample of 24 projects across 15 states does provide a beginning snapshot of market trends, and there is at least one case study from each of the 10 FTA regions.

To set context and important definitions, the report begins with definitional and background information on IoT technology and trends associated with older adult transportation needs. Because of the breadth of IoT, the early nature of the field, and the complexity of the issues of privacy and security, which are beyond the scope of this quick-study request, it is hoped that this report can provide a foundation for future research.

[4] Iterative design is a process of designing a product, route, app, program, etc., in which items are workshopped, tested, and evaluated repeatedly at different stages of design to address usability issues. Ethnographic fieldwork and customer experience research will be useful to collecting crucial information on what older adults define as their transportation wants and needs.

SECTION 2

Background

The following section provides information on IoT technology, aging populations in the United States, and the transportation needs of older adults. It also provides information about the context of these initiatives in terms of trends in technology and transportation sectors, as well as information about federal programs that have supported, stimulated, or catalyzed investments in connected transportation technology.

Internet of Things Technology

Recent estimates from component manufacturers and technology industry professionals predict rapid and dramatic growth in the number of objects that will acquire intelligence via sensors, processors, and internet transmitters. For example, some working in technology sectors predict that between 30[5] and 50[6] billion Internet-connected devices will be in use worldwide by 2020. We are in the nascent stages of exploring and predicting applications for these technologies, the large volumes of data they will produce, data analytics frameworks that will render those data useful, and best practices for approaching privacy and security in IoT network contexts.

Components of IoT Technology

IoT technology enables the creation, transmission, communication, and analysis of data generated by embedded sensors. Table 2-1 gives an overview of technologies that facilitate the exchange between sensors embedded in "things" through the Internet.

[5] ABI Research, "More Than 30 Billion Devices Will Wirelessly Connect to the Internet of Everything in 2020," press release, May 8, 2013, https://www.abiresearch.com/press/more-than-30-billion-devices-will-wirelessly-conne/.

[6] Cisco Internet Business Solutions Group (IBSG), "The Internet of Things: How the Next Evolution of the Internet Is Changing Everything," 2011, p. 3, retrieved from http://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf.

Table 2-1
Internet of Things Technology Overview[7]

Technological Component	Description	Function
Sensors	Devices that convert non-electrical information about a physical condition or even to an electrical signal that can be sent to an electronic circuit.	A sensing system observes and creates data without the need for human observation. Sensors can collect information about position, occupancy, proximity, velocity, pressure, sound, temperature, light, biological elements, and more.
Gateways	Networking hardware and software components that connect one network to another (hubs, servers, routers, etc.).	Gateways allow for signals generated by sensors to be communicated to networks, and vice versa.; gateways facilitate bidirectional communication between the sensor and the network.
Networks	An infrastructure of hardware and software protocols that allow devices to share information (Ethernet, Bluetooth, Wi-Fi, cellular technologies such as 3G and 4G).	Networks transmit real-time data collected by sensors to other devices.
Standards	Requirements and specifications that define how machines identify and communicate with one another.	Data collected by sensors and transmitted over the network are aggregated so they can be analyzed; standards facilitate interoperable data handling, processing, and storage.
Data Analysis Tools	Data can be processed and analyzed for use by transit organizations through the application of statistics, computer programs, and modeling techniques; for example, algorithms can be designed that automatically process and analyze data generated and communicated by specific types of sensors.	Analyses of IoT data: • Aggregate and communicate information about individuals and their preferences, • Can be communicated back through the network to make adjustment in the physical world, • Provide information on patterns that can help us optimize safety, efficiency, and customer experience,

IoT and the Big Picture: Toward Smart, Equitable Cities and Communities

USDOT's Intelligent Transportation Systems Joint Program Office defines a smart/connected community as "a system of interconnected systems, including employment, health care, retail/entertainment, public services, residences, and

[7] Chart adapted using Deloitte's resources on the Internet of Things along with interviews and scholarly research. For a more comprehensive overview of IoT technology, see J. Holdowsky, M. Mahto, M. Raynor, and M. Cotteleer, Inside the Internet of Things (IoT): A Primer on the Technologies Building the IoT, Deloitte University Press, 2016, retrieved April 14, 2016, from http://dupress.com/articles/iot-primer-iot-technologies-applications/?icid=interactive:not:aug15#iot_foundations.

transportation" in which these systems are "tied together by information and communications technology (ICT) that transmit and process data about all sorts of activities" within that community.[8] IoT technology provides the interface between physical and data worlds that will make connected communities possible. IoT in a connected community will be used to facilitate back-end (largely invisible to the user) and front-end (user-facing) improvements to improve both access to and the experience of transportation. In a connected community, open data and IoT technology facilitate the efficient coordination and use of mobility services in the system on the back end. From the user's perspective, travel options are simplified through applications and portals that provide personalized information and allow for seamless, real-time trip booking, planning, and payment.

Meeting the Mobility Needs of Older Adults

Facilitating access to a robust set of transportation options is crucial to supporting the health and well-being of older adults. Mobility—whether on foot or bicycle, by private or shared car, bus, or shuttle—enables adults, including older adults, to connect with essential services and remain active, independent, and connected to their communities.

Aging Adults in the US

Demographic Growth

The Older Americans Act of 1965 defines older adults as persons age 60 and above; however, other federal programs targeting older adults provide funding for services for individuals who are age 60 and above or age 65 and above. Thus, for the purposes of this report, we are interpreting "aging adults" as adults ages 65 or older because those individuals would be eligible for the federal programs that target older adults. Between 2010 and 2050, the United States[9] is projected to experience rapid growth in its older population. In 2050, the number of Americans age 65 and older is projected to be 88.5 million, more than double the population of 40.2 million in 2010.[10]

[8] M. Cuddy, A, Epstein, C. Maloney, R. Westrom, J. Hassol, A. Kim, et al., "The Smart/Connected City and Its Implications for Connected Transportation," US Department of Transportation, John A. Volpe National Transportation Systems Center and Intelligent Transportation Systems Joint Program Office, 2014.

[9] U.S. Census Bureau data used for this report include the 50 states and the District of Columbia, but do not include data for Puerto Rico.

[10] U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau, *The Next Four Decades. The Older Population in the United States: 2010 to 2050*, 2010 retrieved from https://www.census.gov/prod/2010pubs/p25-1138.pdf.

Differences between Age Cohorts

Research by the US Census Bureau suggests that the experiences and needs of individuals age 65 and above vary greatly within age groups. As a result, literature on aging often disaggregates cohorts into the "oldest old" (85 years and above), "middle old" (75–84), and the "youngest old" (65–74). The majority of older adults in the US are projected to be relatively young, ages 65–74, until 2034, when all "baby boomers"—individuals born between 1946 and 1964—will be above age 70. At this time, the age composition of the US will shift. In 2010, 14 percent of the older population was age 85 older, but by 2050 that proportion is expected to increase to more than 21 percent. This is significant because older adults in different stages of life have different travel needs and functional abilities (including but not limited to physical, cognitive, vision, and hearing) that impact whether they need (or want) alternatives to driving themselves or to conventional, fixed-route public transportation.

Mobility Needs

This report echoes the American Public Transportation Association's (APTA) suggestion[11] that, in considering the transportation needs for older adults across age cohorts, it is important to disaggregate individuals (1) with no functional limitations, (2) with some level of limitation who would benefit from incremental modifications to conventional services, (3) with significant limitations requiring alternative services, (4) with limitations that require American Disabilities Act of 1990 (ADA) paratransit, and (5) with limitations that require services that offer more assistance than ADA paratransit. US Census Bureau research found positive correlation between the risk of having a disability or chronic condition that would impact instrumental activities of daily living (IADLs)[12] and successively older age groups. Individuals age 80 or above were more than twice as likely to need assistance with instrumental activities of daily living than persons ages 65–69. However, between 2005 and 2010, disability rates decreased for people ages 55–69.[13] Thus, although this report treats the use of innovative technologies that serve persons with disabilities as crucial to serving older adults, it also emphasizes the fact that general technological advancements that promote active transportation and broaden mobility options, safety, and efficacy also serve travelers age 65 and above.

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[11] D. Koffman, R. Weiner, A. Pfeiffer, and S. Chapman, *Funding the Public Transportation Needs of an Aging Population*, American Public Transportation Association, 2016, p. 5, prepared by Nelson/Nygaard Consulting Associates, retrieved from http://www.apta.com/resources/reportsandpublications/Documents/TCRP_J11_Funding_Transit_Needs_of_Aging_Population.pdf.

[12] Activities of Daily Living (ADLs) include more basic functions such as eating, bathing, dressing, etc.). IADLs include light housework, laundry, meal preparation, transportation, grocery shopping, using the phone, medication management, and finance management and are useful in measuring independence and functional limitations.

[13] U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau, *Americans with Disabilities: 2010*, 2012, retrieved from http://www.census.gov/prod/2012pubs/p70-131.pdf.

In addition to data on mobility challenges and aging, the following demographic trends influenced the examples provided in this report.

Lack of Transportation Connectivity

- More than 20 percent of U.S. residents age 65 and above do not drive and rely on available fixed-route and demand-response transportation. This percentage increases in older cohorts.[14]
- In 2015, it was estimated that more than 15.5 million older adults in the U.S. live in communities with poor or no access to transportation.[15]
- Where public transportation options exist, a lack of safe pedestrian infrastructure can keep older adults and persons with disabilities from being able to those options.[16]
- The vast majority of older adults "age in place" in their neighborhoods; 56 percent of those communities are suburban and 23 percent are rural.[17]
- Only 14 percent of older adults living in rural areas report having transit service available within a half-mile of their home.[18]

Lack of Options Limits Independence

- More than 50 percent of the population age 65 and above who do not drive stay at home on any given day due to a lack of transportation.[19]
- A 2004 study found that older adults age 65 and above who do not drive make 15 percent fewer trips to the doctor, 59 percent fewer trips to shop or eat out, and 65 percent fewer trips to visit friends and family than drivers of the same age.[20]
- Closing the digital divide – in 2015, 27 percent of adults ages 65 and older owned smartphones or tablets capable of accessing transportation apps that provide real-time transportation data and on-demand ride-sharing services, compared with 85 percent of those ages 18–29.[21]

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[14] "Aging in Place, Stuck Without Options: Fixing the Mobility Crisis Threatening the Baby Boom Generation," Transportation for America, 2011, retrieved April 18, 2016, from http://t4america.org/docs/SeniorsMobilityCrisis.pdf.

[15] Ibid.

[16] M. Ball, "Aging in Place: a Toolkit for Local Governments," Community Housing Resource Center, Atlanta Regional Commission, 2016.

[17] "Aging in Place, Stuck Without Options: Fixing the Mobility Crisis Threatening the Baby Boom Generation," Transportation for America, 2011, retrieved April 18, 2016, from http://t4america.org/docs/SeniorsMobilityCrisis.pdf.

[18] TRIP, American Association of State Highway and Transportation Officials, "Keeping Baby Boomers Mobile: Preserving the Mobility and Safety of Older Americans," 2012, retrieved from http://www.tripnet.org/docs/Older_Drivers_TRIP_Report_Feb_2012.pdf.

[19] L. Bailey, "Aging Americans: Stranded Without Options. Surface Transportation Policy Project," 2004.

[20] *Ibid*.

[21] A. Smith and D. Page, "US Smartphone Use in 2015," Pew Research Center, 2015, retrieved from http://www.pewinternet.org/files/2015/03/PI_Smartphones_0401151.pdf.

- Older adults are statistically less likely to use the Internet than other age groups but show faster adoption rates.[22]

Together, these trends demonstrate that gaps in transportation connectivity significantly and negatively affect the quality of life of older Americans and that affordable, accessible alternatives to driving are necessary to support older adults living and thriving independently in their communities. At the same time, we are experiencing a rapid proliferation of Internet and sensor-enabled solutions to first/last mile transportation system gaps and challenges related to accessing real time, cross-regional transportation information. It is imperative to leverage these technologies to address mobility and connectivity challenges experienced by aging Americans and to ensure their access to the platforms and devices such as smartphones that offer access to expanded mobility options. Academic literature on the digital divide suggests that older adults continue to access Internet-enabled devices less than their younger counterparts. However, that research also found that this gap is narrowing and that "digital seniors" are developing new routines around their use of information and communications technologies. Moreover, financial stability,[23] pre-retirement use of connected devices, and the encouragement of friends and family are strong predictors of Internet and smartphone use in older cohorts.[24] Many of the examples of included in Section 3 of this report involve communities that leverage partnerships connect older adults to Internet-enabled transportation technologies.

Context

Other technology-enabled trends beyond the increasing prevalence of smartphone use influence the application of IoT technologies in transportation. These include Mobility on Demand and the travelers' experience, general transit feed specification (GTFS),[25] and real-time data feeds as well as the prevalence of transportation network companies (TNCs).

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[22] A. Perrin and M. Duggin, "Americans' Internet Access: 2000-2015," Pew Research Center, 2015, retrieved from http://www.pewinternet.org/files/2015/06/2015-06-26_internet-usage-across-demographics-discover_FINAL.pdf.

[23] U.S. Department of Commerce, "Exploring the Digital Nation: America's Emerging Online Experience," National Communications and Information Administration and Economics and Statistics Administration, 2013, retrieved from https://www.ntia.doc.gov/report/2013/exploring-digital-nation-americas-emerging-online-experience.

[24] A. Quan-Haase, K. Martin, and K. Schreurs, "Interviews with Digital Seniors: ICT Use in the Context of Everyday Life," *Information, Communication & Society*, 19(5), 2016, pp. 691-707, http://dx.doi.org/10.1080/1369118x.2016.1140217.

[25] For more information on GTFS, see https://developers.google.com/transit/gtfs/, retrieved July 24, 2016.

Mobility on Demand and Emphasis on Traveler Experience

Advances in vehicle and communications technology, including connected vehicle technology, are creating a shift in how riders think about their mobility options and in the meaning of "on-demand" transportation. We are moving toward a model in which individuals purchase trips rather than commit to one mode of public or private travel and can access those trips directly after booking. In the Mobility on Demand model, also sometimes referred to as "mobility as a service," individuals choose which modes to combine to make door-to-door trips across private, public, and shared vehicle modes. In most cases, those trips can be booked directly before travel. Whereas traditionally, dial-a-ride (or click-a-ride) demand response paratransit, Non-Emergency Medical Transportation (NEMT), and Human Services Transportation have been considered to provide "on-demand" transportation offices, "on-demand" now refers to portals and services that allow customers to plan, pay, and book trips in real time and wait under two hours to access them. For the purposes of this report, any service considered "on demand" provides same-day services to riders, in most cases within 1–2 hours of booking a ride. There are several demographic trends influencing the adoption of IoT technologies to provide on-demand mobility services, including an increase in millennials who value access to mobility over a commitment to any particular transit mode and the rise in the number of older Americans, as aging in place requires unique and broadened mobility options.[26]

GTFS and Real-Time Data Feeds

Many providers discussed in this report use IoT technologies such as Automatic Vehicle Location (AVL) sensors paired with open software and data exchange and standards initiatives to expand service times and areas, offer better information to their customers, or facilitate collaboration between providers that service older adults and persons with disabilities. The availability and interoperability of real-time data are crucial to facilitating these initiatives, because they make communications between systems in a connected community possible. Even at the most basic level, new transit apps rely on providers sharing GTFS data so those services show up to users trying to plan a trip. GTFS files contain agency information and define each trip on a route and the time each trip reaches each stop, providing a standardized medium for providers to represent their data to third-party services and apps (such as Google Maps or Open Trip Planner). The GTFS format provides a base feed that transportation agencies using IoT technologies to collect real-time updates about their fleet can use to share that data as a feed extension to the GTFS open data format.[27] Layering real-time,

[26] R. Sheehan, "Mobility on Demand," U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office, retrieved from http://innovativemobility.org/wp-content/uploads/2015/02/Robert-Sheehan-Mobility-on-Demand.pdf.

[27] Google Developers, "What is GTFS-realtime?" 2015, retrieved June 28, 2016, from https://developers.google.com/transit/gtfs-realtime/.

updated information about vehicle location, schedule, and service availability on top of existing GTFS feeds and allowing those feeds to communicate with data from other regional services provides the medium that enables travelers to plan, book, and schedule intermodal, on-demand trips.

Interview research completed for this report suggested increasing interest among private stakeholders in helping transportation providers develop and maintain open GTFS feeds in requiring transportation providers to offer that data. Additionally, survey research completed by the Transit Cooperative Research Program (TCRP) found that the availability of open transit data encourages innovation, assists researchers and providers in analyzing transportation network connectivity, and enhances customer ability to navigate and use transit services. Their research also found that standards and commonly-used formats are essential to systems interoperability and the generation and use of open data.[28]

Transportation Network Companies

TNCs are part of the emerging shared-mobility landscape. The term "shared mobility" includes various forms of ridesharing, bikesharing, carsharing, and on-demand rides with TNCs.[29] TNCs, also sometimes referred to as ridesourcing or hailed services, are defined by the California Public Utilities Commission as "prearranged transportation services for compensation using an online-enabled application (app) or platform to connect passengers with drivers using their personal vehicles."[30] Some TNCs, such as Lyft and Uber,[31] offer users a choice to split the cost of rides with other passengers on the same trip or to hail a shared ride with other passengers going in a similar direction. Another service that uses similar technology is mictrotransit, shuttles that use the same technology as TNCs to incorporate flexible scheduling and routing to provide on-demand shuttle service to groups of individual passengers (e.g., Bridj, Via). Unlike TNCs, some mictrotransit operators provide vehicles for use and pay drivers as employees rather than contractors (e.g., Bridj).

The use of smartphone technology and (in most cases) money saved through using contracted drivers and vehicles allows TNCs and microtransit to offer affordable, personalized, on-demand mobility options to a majority of riders.

[28] Transit Cooperative Research Program, *TCRP Synthesis 115, Open Data: Challenges and Opportunities for Transit Agencies*, 2016, retrieved from http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_syn_115.pdf.

[29] S. Shaheen, A. Stocker, and A. Bansal, "Shared Mobility: A Sustainability & Technologies Workshop. Retrospective from Caltrans Shared Mobility Workshop," 2015, retrieved from http://innovativemobility.org/wp-content/uploads/2015/11/Caltrans_SharedMobility_Synopsis_FINAL.pdf.

[30] http://www.leginfo.ca.gov/pub/15-16/bill/asm/ab_1351-1400/ab_1360_cfa_20150417_083406_asm_comm.html.

[31] Examples given in this report do not indicate an exhaustive list or a preference.

This affordability has caused many stakeholders to question whether the procurement of TNC technology or the services of TNCs could provide less-costly solutions to services that provide demand-response services for persons with disabilities despite a historic lack of commitment to ADA compliance among many of the largest TNCs. Additionally, over the past few years, alongside the growth of on-demand transportation technologies, there have been several TNC developments relevant to meeting the needs of aging populations, including targeted TNC startups, TNC-transit partnerships, and new TNC app features. The next section provides an overview of some of those initiatives and comments on controversies related to making sure these innovations are as accessible as possible to vulnerable populations.

SECTION

3

Part I: Improving the Mobility of Older Adults with Innovative Transportation Systems

The previous section described IoT technology and the demographic trends affecting the mobility needs of older Americans. Older adults benefit from innovative technologies that expand transportation service areas and times, provide more equitable access, reduce trip time and cost, or emphasize consumer choice for all riders. Consumer choice is achieved by including older adults and persons with disabilities in the design and planning process. This section applies these concepts to fulfill the requirement of a survey of the communities, cities, and states that are using innovative transportation systems to meet the needs of aging populations. This section gives examples of communities, cities, and states that are using IoT technology in one of five categories: smartphone and tablet app development, improving demand response services, open data and software initiatives, accessible bikeshare programs, and TNC programs serving older adults. Additionally, for a case study to be noted, it had to achieve one of three objectives: include older adults in the transportation planning process, develop the capacity to offer same-day demand response transportation, or promote access to data to improve rider experience, including older adult riders. The section concludes with a discussion of TNCs as transit agencies, healthcare and insurance providers, planners, researchers, and policymakers increasingly discuss partnership and technology procurement opportunities with those companies.[32]

Communities Using IoT Technologies to Serve Older Adults

Smartphone and Tablet App Development

Organizations have developed apps to make transportation planning more inclusive, collect information on rider experience, and leverage systems data to assist travelers with functional limitations plan and take trips. Although only one app in our sample is dedicated to serving older adult travelers, they can benefit

[32] As potential TNC-transit initiatives and partnerships designed to serve vulnerable populations appear to be developing rapidly and made public only when details are finalized, in part because such partnerships often are controversial, this report captures only what FTA researchers were able to confirm at the time the report was written.

from many of the apps designed for people with disabilities (listed below) and for the general public.

Project ERIC App, Knoxville, TN
Inclusive Planning and Communication

Knoxville-Knox County Community Action Committee (CAC) provides affordable and accessible demand-response public transportation services in Knox County and to and from surrounding areas. The University of Tennessee College of Engineering worked with CAC riders to develop the Project ERIC app, a tablet app that enables personalized communication between passengers with disabilities, drivers, and dispatchers. Older adults and persons with disabilities collaborated in the app's design and later were provided with tablets with the app to give real-time feedback about the app's functionality and their transit experience. The process of planning, building, and refining the communications and feedback app was inclusive, involving a stakeholder steering committee, inclusive and frequent planning meetings that focused on the input of older adults and persons with disabilities, hands-on tablet training, and what the team called "guerilla engagement" strategies, in which University of Tennessee researchers gathered data about the app by boarding community buses and riding with passengers. The app is now in its third development round, and researchers reported travelers have enjoyed using the tablets to communicate and have asked to use them to facilitate communication beyond the transit context.

TravelMate, Northern VA and Washington, DC

The Arc of Northern Virginia partnered with SpecialNeedsWare, Inc., to develop TravelMate, a tablet app that provides a personalized travel training curriculum for persons with intellectual and developmental disabilities. The app "walks" travelers through planning a trip, step by step, including photos of the traveler at transit stops, using transit applications on his/her smartphone and using his/her fare cards, and an emergency help button that can communicate when a traveler needs assistance. The app works with other TeachMate curricula and, because it is GPS-enabled, it can sense when a traveler reaches his/her her destination and brings up a new curriculum based on that context (e.g., work environments). Currently, there are curricula for bus rides and train rides in the Northern Virginia and Washington, DC areas, but developers are working on curricula that will walk passengers through taking travel via airplane, Uber, or taxi. The ability to customize a curriculum about a new transit option could benefit a broader audience, including older adults who want to navigate multimodal transit options independently.

Tiramisu, New York, NY and Pittsburg, PA

The Tiramisu transit app asks riders to provide real-time travel location information and document how many seats are available on fixed-route buses.

This helps individuals who need a seat or space for a wheelchair plan trips. The app also allows users to leave notes or give feedback about routes and stops that other riders can review. The free app is fully VoiceOver-enabled, allowing individuals with visual impairments to use the interactive tool.[33]

Roll with Me, Chicago, IL
Wheely and Accessway, New York, NY

These apps leverage open data feeds to give real-time transit directions to individuals who use wheelchairs and other mobility devices. They are included in this report because they include accessibility alerts that warn travelers about elevators that are out of service, sidewalk closures, and platforms that may be obstructed because of construction efforts.[34] Wheely is expanding services to include open-source, interactive maps with reviews and ratings of "accessible places" in New York City.[35] New York State's Metropolitan Transit Authority is also piloting the mobile app Accessway, which uses Bluetooth and Internet-enabled sensors to communicate to a user's device and deliver audio messages about their surroundings based on their current direction and location.

Improving Demand-Response Service

Various communities are pairing IoT technology such as AVL sensors with innovative demand-response software and tablet apps to offer more efficient and user-friendly door-to-door demand response services, in addition to expanding service times and areas. Whereas, typically, individuals have to book on-demand trips a day in advance, these tools allow riders to book same-day and sometimes last-minute door-to-door trips. Many of these providers use on-demand technology on the back end to improve services for their customers, who can use the same dial or click methods they are used to using for scheduling on-demand transportation. In each case, demand-response software that communicates with sensors in vehicles or in vehicle tablets can streamline reporting and pre/post-trip vehicle inspections, ensuring rider safety. Decreasing the cost of on-demand transportation, allowing paratransit customers to experience on-demand transportation technology through back-end improvements, and using connected technology to expand service times and areas serves older adults and riders with disabilities.

[33] J. Zimmerman, A. Tomasic, C. Garrod, D. Yoo, C. Hiruncharoenvate, R. Aziz, et al., "Field Trial of Tiramisu: Crowd-Sourcing Bus Arrival Times to Spur Co-Design," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2011, pp. 1677-1686.

[34] Roll With Me, Smart Chicago, 2015, Smartchicagocollaborative.org, retrieved June 30, 2016, from http://www.smartchicagocollaborative.org/category/rollwithme/.

[35] Wheely, retrieved June 30, 2016, from http://www.wheelyapp.com/.

Via Mobility Services, Boulder and Denver, CO

Via Mobility Services is a non-profit organization that provides customers with mobility limitations with affordable, call-up, on-demand, door-to-door transportation. Via Mobility Services procured demand-response software and tablet devices for vehicles that enable real-time AVL and automated scheduling, routing, and dispatch. The service allows agencies in the region to use a coordinated system to book rides and transfer for customers across service areas. The project was built on open centralized and automatic data exchange, allowing providers to seamlessly share information about availability, location, capacity, rider needs, and real-time vehicle location. Riders experience automatic notifications for their rides with the option to cancel and experience expanded services times and areas and decreased waiting times simultaneously. Via Mobility Services estimates these improvements have added between 600 and 800 trips per month that they were previously unable to schedule.

Ride-On Transportation, San Luis Obispo, CA

Ride-On Transportation is a private organization operating as part of the non-profit United Cerebral Palsy of San Luis Obispo County. The organization provides affordable, door-to-door shuttle services for older adults, veterans, persons with disabilities, and dialysis and Medi-Cal/CenCal patients. It was a recipient of 2015 MSAA Deployment Planning Projects funding to design and implement a Ride Coordination Center for the county. This project links databases and services in real time, allowing customers to access more integrated service from the county's public, private, and non-profit providers through the procurement of automatic scheduling, routing, and dispatch software paired with tablets in vehicles that automatically transmit real-time data about AVL. This project also is being built on an open, centralized, and automatic data exchange portal, allowing providers to seamlessly share information about location, capacity, rider needs, and real-time vehicle location. Riders will receive automatic notifications for their rides with the option to cancel and will experience expanded services times and areas and decreased waiting times simultaneously.

Washington County Transit Department County Commuter, Hagerstown, MD

This public demand-response transportation agency operates both paratransit services and eight urban fixed routes. Washington County Transit procured demand-response software and outfitted its vehicles with AVL tablet devices. Like the examples highlighted above, the notification call process is automated, and automated scheduling, dispatching, and routing software gives the agency the ability to handle on-demand/real-time requests. The software also allows users to designate favorite trips when they call that are then automatically communicated when that rider calls to schedule service. These technologies have reduced denials from100–125 per month to 20 per month.

Project Amistad, El Paso, TX

Project Amistad is a non-profit organization that partners with rural and urban transit providers to serve older adults and persons with disabilities in six West Texas counties. Project Amistad procured demand-response software and tablet devices that use AVL and electronic data exchange to facilitate automatic, real-time trip scheduling and routing. Travelers can now book same-day trips. The project also has used a provider web portal and third-party data integration tools to streamline electronic data-sharing between transportation providers at the Texas Medicaid Healthcare Partnership, allowing it to submit claims and download and import Medicaid trips from the Texas Medical Transportation website to the dispatch software.

Community Transit of Western Community Action, Southwest MN

Community Transit of Western Community Action is a Community Action Agency that operates a five-county transit service in rural Minnesota. Increased demand of its 23 lift-accessible buses led to the procurement of tablets in vehicles that provide real-time AVL and pair with of demand-response software to offer automatic scheduling, routing, and dispatching. This reduced denials and allowed the agency to offer same-day booking to riders.

Northern Shenandoah Valley Public Mobility Program, VA

The Northern Shenandoah Valley Public Mobility Program is collaboration among human service agencies and non-profit organizations to provide on-demand demand-response transportation to older adults, persons with disabilities, and persons in welfare-to-work programs living in northern rural Virginia to access human service resources. Vehicles outfitted with AVL sensors and the procurement of demand-response software that facilitates automatic scheduling, routing, and dispatching allows human service agencies to book door-to-door transit for individuals using those services. The mobile data terminals also allow for the use of a smartcard, so individuals can combine fixed-route and demand-response services to access essential services. This project also includes the development of Medicaid bridge and billing software to streamline billing for NEMT.

FindMyRidePA, PA

FindMyRidePA is a smartphone-optimized website that aggregates data about transportation options across Pennsylvania. The portal was funded to aggregate and streamline all transportation options for users, with a specific emphasis on older adults and people with disabilities. It integrates NEMT, demand-response, and paratransit scheduling with fixed-route transportation, taxis, and shared-ride options and asks users to specify needs particular to their trip or circumstance to help them determine if they qualify for targeted transportation programs. The portal lists options that match a rider's needs and eligibility and transportation options by anticipated schedule, time spent in transit, and cost. Additionally, caregivers, doctors, and support coordinators can use the portal to schedule rides for patients or family members. Because this portal draws on data feeds from transportation providers as those providers move from static schedule feeds to real-time, AVL-enabled feeds, users of the portal will be able to view, plan, and potentially book trips in real time.

Issues

Many additional human services, NEMT, and demand-response paratransit providers are using software to assist with automated scheduling, routing, and dispatching, allowing them to offer more convenient and efficient services to their customers. However, they are not included above because, at the time of drafting this report, they did not offer what was defined as on-demand transportation such as same-day (within 1–2 hours) and last-minute service or real-time same-day scheduling and tracking. Many of those providers might currently be procuring software and AVL technology that would allow for this transition, which would make demand-response paratransit, NEMT, and human service more like the services offered by TNCs in terms of customer experience.

Open Data and Software Initiatives

Working toward multimodal, on-demand transportation requires a sustained commitment to interoperable, standardized, and secure data.[36] The following examples showcase communities that are:

- Embracing and encouraging innovative open-data initiatives to provide a better transportation experience to travelers
- Exploring promising and innovative ways to display that information to benefit older adults, individuals without smartphones, and persons with disabilities

[36] *TCRP Synthesis 115, Open Data: Challenge and Opportunities for Transit Agencies* (2015) found that "the most prevalent reason transit agencies are not providing open data is that it is too much effort to produce the data or the agency does not have the time or people to do the work required. The next most prevalent reason is that it takes too much effort to clean the data" (p. 36). Going forward, it will be important to allocate resources and training to assist transit providers with data management and processing. Information retrieved from http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_syn_115.pdf.

TriMet, Portland, OR

In 2005, TriMet worked with Google to develop the GTFS format by collaboratively preparing its data set in a format that would work for Google Maps. Since then, the agency has consistently advocated for the open sharing of GTFS data and maintained open-source developer resources, including real-time GTFS feeds (trip update feeds, vehicle condition feeds, update and alert information, timetable information) and GIS data about the service area, routes, and stops. TriMet also conducted a Pedestrian Network Analysis campaign that sent individuals out into the city to capture the quality and accessibility of walkways connecting to accessible transit across a seven-county area. This OpenTripPlanner initiative serves aging populations and persons with disabilities by collecting and layering crowd-sourced data from OpenStreetMap about the quality of pedestrian infrastructure on top of other transit and GIS data. OpenStreetMap sources crowd-generated data that are crucial to persons with functional limitations, tagging wheelchair accessibility with its WheelMap feature. This amplified information was for use in the multimodal trip planner and also allowed TriMet to develop a data-driven system for prioritizing places around the region to focus on needs and opportunities for accessible pedestrian infrastructure. Additionally, the OpenStreetMap entries indicate where a lack of infrastructure at bus stops creates a problem for LIFT paratransit buses that have been designed with ramps or lifts that anticipate sidewalks.

Ride Connection, Portland, OR

Ride Connection, a non-profit community service organization, works to connect accessible, responsive transportation with community needs throughout the Portland Tri-County area. Ride Connection serves and assists a network of more than 30 transportation providers with a focus on serving older adults and people with disabilities. It offers centralized information and referrals, travel training, and community-based transportation services and is supporting the application of innovative transportation technology to serve riders. The organization also spearheaded a six-month participatory planning process to identify existing challenges related to transportation for kidney dialysis patients, which identified the need to facilitate flexible, same-day NEMT ride requests. The organization responded by installing vehicle sensors to provide AVL and vehicle condition and driver behavior between the organization and its 30+ providers. Because of the investment in IoT sensors, Ride Connection currently provides Wheelchair Accessible Vehicle (WAV) service to Lyft on evenings and weekends.

Enhanced data interoperability and a cross-provider clearinghouse allow an organization to work toward accommodating last-minute ride requests. Ride Connection currently provides and maintains GTFS data for all of its services so service availability can be tracked using transportation applications. It also is building an open-source clearinghouse for moving trips between demand-response dispatch systems to facilitate better coordination among regional organizations. Because Ride Connection will freely and openly share the software code, other regional organizations and agencies will benefit from this effort. Additionally, the clearinghouse and GTFS feeds, with Ride Connection's existing investment in AVL sensors, will provide real-time information to customers and the ability to book across providers more easily. This will expand options for the older adults and persons with disabilities who use their services.

Transportation Resource Information Point Program (TRIP), MD

TRIP is a program of Central Maryland Regional Transit that helps people explore and use fixed-route, human services, and demand-response transit. Its website, call center, and travel training programs have been expanded to include transportation in all 23 Maryland counties. TRIP created and maintains GTFS feeds for 18 transit agencies in Maryland and is in the process of training each transit agency on how to update and maintain this information at no cost to the agencies. Developing static feeds will allow transit agencies to integrate real-time information as vehicles acquire AVL sensors and will allow the agencies to show up in apps and schedule builders that use GTFS data.

Audible Maps

Making transit maps accessible is important to ensure that older adults and individuals with disabilities can use those systems. One reason TRIP has pushed for GTFS feed maintenance is because GTFS feeds can be translated into more than 100 languages, interpreted through a screen reader, and represented either visually or descriptively. TRIP streamlined a process that outputs GTFS feed information into plain language, turn-by-turn directions to riders that can be read by a screen reader or printed. TRIP worked with the National Federation of the Blind in Maryland to integrate GTFS-enabled audio maps into the planning process that allow persons previously excluded from new route visualization to participate in audio and walks them through the proposed route change step by step.

Cape Cod Regional Transit Authority (CCRTA), MA

CCRTA has invested in public wireless network hotspots at transit hubs and GTFS and AVL data to improve traveler ability to plan trips and travel across modes (including trains and ferries) and across counties. AVL technology and mobile data terminals have been installed on all fixed-route, route-deviation, and dial-a-ride transportation. Additionally, CCRTA has procured software that connects with AVL sensors and mobile data terminals to allow scheduling and dispatching in real time and is working toward accommodating last-minute demand-response requests. CCRTA's long-term investment in ITS-infrastructure, open-data feeds facilitates the sharing of real-time inter-city transit information not only online and via third-party apps, but also at large screen displays and kiosks in terminals and major destinations throughout the region, including the Hyannis Transportation Center, Cape Cod Mall, Cape Cod Community College, and Barnstable. Additionally, CCTRA collaborated with Bridgewater State University to develop an Android, iPhone, and Windows phone app that displays the same real-time planning and bus location information and also features an emergency button that connects passengers with cognitive disabilities or memory loss with caregivers and family members using geographic location and video.[37]

TransitScreen and Cambridge Council on Aging, Cambridge, MA

TransitScreen is a startup company that builds screens and digital projections that show real-time arrival and departure time of buses, shuttles, and trains, the availability of shared vehicles and bicycles, and TNCs such as Lyft and Uber. The company draws on GTFS feeds, AVL feeds, and data shared by TNCs, bike and carshare companies, and more to provide multimodal information in multiple languages. TransitScreen addresses the digital divide by offering public real-time signage that gives riders usable information that normally would be available only on a smartphone. The City of Cambridge installed informational transit screens at three public buildings with support from a Healthy Aging Grant from the Massachusetts Association of Councils on Aging as part of the Mass in Motion program. Partnering with the Cambridge Council on Aging and Cambridge Public Health Department, the City's Community Development Department conducted a series of community meetings with older adults focusing on "usability, mobility, and accessibility" to transit. The goal was to engage older adults in a discussion about their experiences with public transit, including challenges, barriers, and opportunities. The company's founder referred to public TransitScreens as an "actuator layer" for the IoT that will enable communities to use "IoT data to change people's behavior."[38]

Toward Accessible Bikeshare

Over the past few years, there has been an increase in the popularity of bicycle-sharing system and in the number of individuals interested in bicycling to access essential services. According to USDOT's National Household Travel Survey (NHTS), the rise in biking among people ages 60–79 accounted for 22 percent of the total nationwide increase in bike trips between 1995 and 2009.[39] As

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[37] L. Harman, U. Shama, H. Standring, S. Gopalsamy, and A. Sadhu, "Sustainable Technology for Person-Centered Accessible Integrated Multimodal Information Systems," *Mathematics Faculty Publications*, 31, 2012, retrieved from http://vc.bridgew.edu/math_fac/31/.

[38] M. Caywood, public tweet: "Public TransitScreens are actuators for the Internet of Things, using IoT data to change people's behavior," https://t.co/7tDnJ9pSre, retrieved from https://twitter.com/MattCaywood/status/722882947854913536.

[39] http://nhts.ornl.gov/det/Extraction3.aspx.

new transportation options such as Internet-enabled bikeshare increase, it is imperative to ensure that those services are accessible to older adults and individuals with disabilities.

mBike, College Park, MD; Carmel Bike Share, Carmel, IN

The City of College Park and the University of Maryland College Park partnered with Zagster to offer accessible bikeshare services. The program, called mBike, currently has five bicycles in its fleet that target individuals with functional limitations or who prefer a different type of mobility offered by the traditional two-wheel bikeshare bicycle, such as three-wheeled tricycles, hand-propelled bicycles, and side-by-side cycles.[40] The City of Carmel Bike Share, also offered through Zagster, offers six adult three-wheeled bicycles in its fleet and advertises those bicycles to older adults.[41] Users register for the service either through Zagster's smartphone app or through using an online web portal. GPS beacons allow users to see the location of the bicycles through the website and smartphone app; users less comfortable with smartphone or web portals also can send a text message to reserve a bicycle through the system. Either way, GPS technology will allow bikeshare operators to collect data related to preferred bicycle routes and travel time that will assist in back-end planning, travel forecasting, and determining where new stations would best serve consumers.[42]

Transportation Network Companies

Over the past few years, alongside the growth of on-demand transportation technologies, there have been several TNC developments relevant to meeting the needs of aging populations, including targeted TNC startups, TNC-transit partnerships, and new TNC app features. The remainder of this section provides an overview of some of those initiatives and comments on controversies related to making sure these innovations are as accessible as possible to vulnerable populations.

[40] Zagster Bike Share for College Park, 2016, retrieved June 30, 2016, from http://zagster.com/mbike/.

[41] T. Mackin and J. Lauren, "Carmel Unveils New Bike Sharing Program" (video), WISH-TV, 2015, retrieved June 30, 2016, from http://wishtv.com/2015/04/14/carmel-to-unveil-new-bike-sharing-program/.

[42] Universities are increasingly offering accessible bicycles as part of their on-campus bikeshare programs. This report includes only IoT-enabled bikeshare solutions marketed to older adults and persons with disabilities.

TNC-Transit Partnerships

Dallas Area Rapid Transit, TX; Altamonte Springs, FL

Increasingly, regional multimodal transit apps such as Dallas Area Rapid Transit's GoPass app have begun integrate services from Uber or Lyft to streamline trip planning and purchasing that includes first/last mile trips. Other communities subsidize rides with specific TNCs to support hailed rides that fill gaps in areas and times served by public transportation. For example, Altamonte Springs, Florida, is piloting a program that will pay Uber up to $500,000 over the course of one year to subsidize rides at 20 percent for all rides that begin and end in the city or at 25 percent if the ride begins or ends at a local light rail station. At first, riders had to enter a code while traveling within the community to use it; now, any rider who opens the Uber app while in a service area is given details about the program and prompted to enter the code automatically. These examples provide subsidized on-demand transportation to riders that complement the use of public transportation.

Pinellas Suncoast Transit Authority (PSTA), Pinellas Park, FL

PSTA partnered with Uber, United Taxi, and paratransit operator CareRide to pilot the Direct Connect program in Pinellas Park. The program subsidizes demand-response, on-demand taxi, and TNC services that connect passengers to transit. During the six-month pilot, PSTA will pay half of a taxi or Uber fare up to $3 for passengers traveling to or from a PTSA transit stop. To serve individuals who do not use debit or credit cards or smartphones, PTSA has included services by United Taxi, which offer both an on-demand booking app and the ability to book through phone and pay in cash. They also have contracted CareRide to offer $3 wheelchair-accessible trips and have been able to offer same-day rides with a maximum of two hours advance notice. Initially, riders in Pinellas Park had to enter a code to access the subsidized rate; however, the PTSA option now shows up to anyone in the service area who enter the code and, upon verification that the trip starts or ends at an eligible bus station, receive the pilot rate. This program offers diverse options to customers to ensure on-demand first mile/last mile solutions are available to a broad customer base.

Southeastern Pennsylvania Transportation Authority (SEPTA), Philadelphia Region, PA

SEPTA is piloting a new partnership with Uber to boost transit ridership and address problems related to inadequate parking spaces at rail stations in the four counties surrounding Philadelphia. Riders who take Uber to or from 11 Regional Rail stations in those counties will receive 40 percent off of the cost of their ride, up to $10. The pilot will run from Memorial Day to Labor Day in 2016 and will give both entities valuable insights about how ridesharing could impact ridership and about the sustainability of longer-term partnerships. Uber will share data on trips taken with SEPTA, but that information will not be made available to the public, diverging from SEPTA's generally open policy about data sharing. This partnership will cost neither SEPTA nor Uber drivers any revenue directly, as SEPTA will compensate Uber in the form of marketing on SEPTA platforms to publicize the partnership. This partnership could help older adults and persons with mobility challenges to reach accessible rail services into the city. Ongoing communications with SEPTA regarding rider demographics, key challenges, and impact on revenue are recommended.

Niche TNCs

Lift Hero, San Francisco, CA

LiftHero is a licensed TNC in San Francisco designed for use exclusively by older adults and persons with disabilities. The company provides door-to-door service and optional full trip or errand accompaniment and assistance as well. All drivers are carefully screened and are provided with training specific to aging and health and in mobility and accompaniment; many drivers are health professionals or pre-health students. Travelers or their caregivers can schedule rides by phone, text message, or online at any point in time before the ride. If the traveler cannot be matched with a Lift Hero driver, Lift Hero will schedule an alternative ride on other TNC service providers. The concierge service is available throughout California and allows individuals to schedule rides on other TNCs in advance and receive email, text, and call reminders. Services are affordable, at $1 per mile, $25 per hour for accompaniment and assistance, or $4 and 2.9 percent of fare for the concierge service. Lift Hero works with older adult living centers in the San Francisco area to offer reduced price rides that supplement center transportation and plans to work with city and county collaborators in the future.

Liberty, Integrated Global Dimensions, NE

Liberty is a TNC platform designed by Integrated Global Dimensions to serve vulnerable citizens in rural and remote communities in the US. Liberty consists of a smartphone application connected to a multilayer trip management platform and call center staffed with mobility managers. The technology coordinates the resources of current transit agencies, non-profits, and community support associations to make transportation options more effective, efficient, and convenient. It will creates flexible job opportunities for individuals in rural communities to serve as private drivers who will use custom TNC software to set their desired schedule and accept trips. The Liberty trip request algorithm allows individuals to book transportation the same day or in advance and connects clients with drivers closest to the passenger first. One feature of Liberty is its ability to use low bandwidth signals to transfer data packets, which allows increased usability in rural contexts in comparison to other TNCs. Travelers on Liberty also can book transportation via smartphone, phone call, or the Caregiver Platform, which is accessible to human services agencies, medical organizations, etc. In the future, Liberty will pursue technology allowing health care providers to book non-emergency medical transportation for appointments in an environment that meets Health Insurance Portability and Accountability Act (HIPAA) guidelines and regulations. Liberty improves older-adult access to medical care and spontaneous travel to social activities, community events, and recreational activities. The TNC identified Scottsbluff, Nebraska and the Coastal Bend area of Corpus Christi, Texas for its initial launch areas.

Non-Emergency Medical Transportation

Lyft is currently pursuing partnerships with hospital provider networks and health insurance providers to offer non-emergency transportation rides on a national level. At the time of this report, public information about only one such partnership was available, the National Medtrans Network. This pilot allows health care providers to book non-emergency medical transportation for older adults through the Lyft platform.[43] The TNC claims it has been able to fulfill 2,500 rides per week, reducing missed appointments.[44] To ensure that travelers who do not currently use the app have access to this service, Lyft created Concierge (also called Dispatch), a web portal that allows third parties to input a passenger's name, pickup location, and drop-off location. To support this initiative and similar partnerships, Lyft will announce later in the year that the TNC is increasing driver-training requirements and data sensitivity measures to ensure that these partnerships are HIPAA-compliant. Passenger data will be treated as Protected Health Information,[45] and all drivers driving NEMT- and WAV-accessible vehicles will be required to complete HIPAA compliance training and training specific to serving older adults and persons with sensitive healthcare needs.

Accessible TNC and Taxi Services

UberACCESS, UberWAV, and UberASSIST

Two of the most well-known TNCs, Lyft and Uber, have started initiatives to increase accessible TNC options. UberACCESS, for example, is an umbrella term for two separate services that increase access to individuals with disabilities and older adults, UberASSIST and UberWAV. UberWAV is offered in at least eight US cities and operates with vehicles that have a ramp or hydraulic lift and drivers trained in operating mobility devices, cardiopulmonary resuscitation, and first aid. Most of the vehicles being used locally for UberWAV come through a

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[43] "Services Expanding Mobility for Aging Americans," Shared Use Mobility Center, 2016, retrieved June 30, 2016, from http://sharedusemobilitycenter.org/news/7-new-services-expanding-mobility-for-aging-americans/.

[44] "Lyft Partners to Give Patient Rides," Lyft Blog, 2016, retrieved June 30, 2016, from https://blog.lyft.com/posts/nationalmedtrans-concierge.

[45] U.S. Department of Health and Human Services, "What is PHI?" HHS.gov, 2015, retrieved June 30, 2016, from http://www.hhs.gov/answers/hipaa/what-is-phi/index.html.

partnership with national paratransit operators. In Portland, Oregon, a $0.25 surcharge is added to all TNC rides to subsidize WAV rides so they are the same price as the least-expensive base fare option Uber provides.

Additionally, Portland requires that the wait time for a WAV vehicle on any TNC cannot be more than twice the time as the wait for the company's base ride—in this case, UberX. In New York City, UberWAV dispatches an accessible taxi when there is no available contracted driver and vehicle. Thus, UberWAV's functionality in New York City, and possibly in other cities as well, depends on the continued health of already-existing WAV fleets. Critics have reported that when UberWAV is used to request a ride, riders often end up riding in accessible taxis and paying taxi fares instead, which is not an equivalent service.[46]

UberASSIST, available in 13 cities at the time this of report, offers standard private vehicles that can accommodate folding wheelchairs, walkers, and other storable mobility devices and has drivers who have received additional training on serving older adults and persons with disabilities. Uber has partnered with the Open Doors organization to offer training and certification in serving older adults and persons with disabilities.[47]

Accessible Dispatch, New Haven, CT, and New York, NY

New York City and New Haven's Accessible Dispatch program offers on-demand accessible taxis every day of the week at all hours. IoT technology allows for a ride to be hailed via telephone, text, website, or the Wheels on Wheels smartphone app without the need for an advance reservation. In Portland, Oregon, which already requires all taxi operators to provide accessible service on-demand, TNCs allowed to operate in the city will be required to provide accessible service at all times of day and will prohibit surge pricing for accessible service. TNCs appear to be working toward improving service availability after riders complained about a lack of availability of vehicles or excessive wait times.[48] Houston, Texas, also has established in its TNC ordinance an accessible fleet

[46] K. Greifeld, "UberWAV Falls Short of Accessibility Expectations," The Ink NYC, reetrieved June 30, 2016, from http://theink.nyc/uberwav-falls-short-of-accessibility-expectations/; I. Lapowsky, "Uber's Business Isn't Built to Help Disabled People," *WIRED*, 2015, retrieved June 30, 2016, from http://www.wired.com/2015/08/uber-disability/; V. Nigo, "Transportation Network Companies and the Ridesourcing Industry: A Review of Impacts and Emerging Regulatory Frameworks for Uber," City of Vancouver, 2015, retrieved from https://open.library.ubc.ca/media/stream/pdf/42591/1.0220795/4.

[47] J. Byzek, "Eric Lipp and Open Doors Organizations: Training Uber – New Mobility," *New Mobility*, 2016, retrieved June 30, 2016, from http://www.newmobility.com/2016/05/training-uber/.

[48] A.Templeton and J. Rosman, "Uber's Wheelchair-Accessible Option in Portland Doesn't Work 9-5," *OPB*, May 2015, retrieved from http://www.opb.org/news/article/ubers-wheelchair-accessible-option-in-portland-doesnt-work-9-to-5/; V. Nigo, "Transportation Network Companies and the Ridesourcing Industry: A Review of Impacts and Emerging Regulatory Frameworks for Uber," City of Vancouver, 2015, retrieved from https://open.library.ubc.ca/media/stream/pdf/42591/1.0220795/4.

requirement goal for the City to meet, requiring 3 percent of the entire vehicle-for-hire fleet (including taxicabs, limousines, TNCs, etc.) by 2015, increasing to 5 percent of the fleet by 2017. Houston incentivizes the increase in WAVs by relaxing age limits for vehicles that reduce the overall cost of procurement for the contracted drivers.[49]

Freedom in Motion, Gainesville, FL

Uber has partnered with local advocacy groups and with cities to subsidize rides from $1–$5 to individuals over age 60, depending on income. For example, the City of Gainesville's Freedom in Motion program subsidizes rides on Uber in collaboration with ElderCare of Alachua County and the Gainesville Area Chamber of Commerce. The program, which has now been extended to all older adults in Gainesville, includes technology tutorials and a mobility manager through ElderCare that can procure smartphones for individuals in need. Similar pilot partnerships with local older adult organizations to offer TNC training and subsidized rides are underway in several other cities including Columbus, Ohio; Tucson and Phoenix, Arizona; Miami-Dade County, Florida; and Ventura County, California.

LyftACCESS

Lyft has been working to expand and improve the services it offers to passengers with specific mobility needs. Previously, Lyft's Access Mode setting connected riders with accessible vehicle dispatches, but with the same wait times and regulations passengers booking directly with those dispatches would experience.[51] Now, however, Lyft currently is forging partnerships that would hire those drivers and vehicles to provide on-demand services to customers with specific mobility needs. The company expects public information about these pilots and partnerships, currently underway in New York City, parts of Southern California, and Portland but rapidly expanding, to be released later this year.

Issues and Controversies

Accessible Service and Promotional Codes

Many of the service enhancements developed by TNCs are available only through the use of a promotional code. While researching this report, several

[49] City of Houston, "FAQ: Chapter 46 Related to Vehicles-for-Hire Amendments Approved 8/6/2014," 2014, retrieved from https://www.houstontx.gov/ara/chapter46docs/vehicle_for_hire-faqs.pdf.

[50] Comments based on interview research with individuals implementing partnerships. See also E. Study, "Uber, Senior Living Team Up to 'Drive' Resident Mobility," *Senior Housing News*, 2015, retrieved June 30,2016, from http://seniorhousingnews.com/2015/07/13/uber-senior-living-team-up-to-drive-resident-mobility/; Uber Global, "More Options for Senior Mobility," 2016, retrieved from https://newsroom.uber.com/creating-more-options-for-senior-mobility/.

[51] https://help.lyft.com/hc/en-us/articles/213584508-Accessible-Vehicle-Dispatch.

(but not all of) such initiatives that were initially accessible only via promotional codes but were reprogrammed such that when an individual is within the subsidized promotional service area, the option appeared automatically through geofencing. These developments are promising and suggest that agile, user-oriented customer responsive design can improve service accessibility. At this time, UberACCESS products continue to rely on customers knowing about and entering codes specific to those services and the availability of WAVs to customers. If these service enhancements can be accessed only via smartphone and a promotional code in the Uber app, it is vital to address gaps in smartphone ownership, accessible app design, and outreach to ensure that vulnerable populations are able and know how to take advantage of new options.

WAV Vehicle Availability

Many commented that providing accessible service must go beyond offering a code or accessible portal on an app. Providing accessible TNC services in practice means that WAVs should be available to customers who need them when they need a ride and offer service comparable that available to other riders. Some stakeholders have reported a lack of availability of WAV vehicles or up to a two-hour wait, even when riders enter the code.[52] It is unclear at this time, in some cases, if the appearance of an accessible option in an app means an accessible vehicle is available for riders who need them.

TNCs, Taxis, and Accessible Demand-Response Services

Over the last few years, there has been increasing attention to the potential of TNCs to help transit agencies lower the cost of providing demand response services.[53] However, despite the increase in possible partnerships between TNCs and transit agencies, many believe that the business models typically used by TNCs through which they procure individual contractors who own their own cars make it difficult to guarantee equity of service availability for older adults and persons with disabilities. Additionally, in various US cities, disability rights advocates and transportation agencies have expressed concerns that the economic impact of TNCs already has or may produce a shortage of accessible taxi vehicles. Without ensuring TNCs offering the same access to WAVs as taxis, which have long been a part of assisting cities provide paratransit and recently

[52] J. Byzek, "Uber: Does the Transportation Revolution Include Us?" *New Mobility Magazine*, 2016, retrieved June 30, 2016, from http://www.newmobility.com/2016/05/uber-transportation-access/.

[53] L. Lazo, "Uber Flirts with Transit Agencies across the US for a Share of Paratransit Services," *Washington Post*, 2016, retrieved June 30, 2016, from https://www.washingtonpost.com/local/trafficandcommuting/uber-flirts-with-transit-agencies-across-the-us-for-a-share-of-paratransit-services/2016/03/05/5eb8b118-d751-11e5-9823-02b905009f99_story.html/; Shared-Use Mobility Center (SUMC), "Shared Mobility and the Transformation of Public Transit Research Analysis," APTA & TCRP, 2016, retrieved from http://www.apta.com/resources/reportsandpublications/Documents/APTA-Shared-Mobility.pdf.

also adopted IoT on-demand app and call dispatch solutions,[54] a decrease in taxi drivers or vehicles for hire could mean a decrease in options for travelers who need accessible ramp vehicles.

For example, the San Francisco Municipal Transit Authority reported that the increase in use of TNCs cut the number of rides on ramp taxis in half between March 2013 and July 2014,[55] causing the agency to incentivize increasing the ratio of accessible vehicles in existing fleets. TNCs also have affected accessible transportation in New York City, where there is a mandate for 50 percent accessible taxis, which means that a decrease in the number of taxis also leads to a decrease in the amount of accessible vehicles in the city. Thus, riders with disabilities and advocates who have worked to make sure accessible taxis are available to riders using mobility devices have raised concerns about the potential impacts of working with TNCs to provide cost-effective demand-response transportation.[56] Taxi companies are considered a means of public accommodation under ADA and have had to include accessible cars in their fleets; to date, TNCs have focused on making sure their apps, but not necessarily their vehicles, are accessible to persons with functional disabilities. No evidence was found that TNCs are considering cognitive differences or disabilities when designing these products, as accessibility solutions seem to focus primarily on mobility, vision, and hearing challenges. There are additional concerns about the ethics of awarding public contracts to companies who have not offered a similar level of service to travelers who need WAVs.[57]

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[54] Some taxi agencies have their own real-time dispatch apps, allowing them to pick up passengers on the go or to operate like TNCs. Additionally, there are apps such as Flywheel and Curb that aggregate taxi options for passengers.

[55] San Francisco Municipal Transportation Agency, "Taxis and Accessible Services Division: Status of Taxi Industry," San Francisco Municipal Transportation Agency Board Meeting, retrieved from https://www.sfmta.com/sites/default/files/agendaitems/9-16-14%20Item%2011%20Presentation%20-%20Taxicab%20Industry.pdf.

[56] Examples include New York: R. Harshbarger, "Uber Target of Protests by Cabbies, Disability Rights Advocates," *amNewYork*. retrieved June 30, 2016, from http://www.amny.com/transit/uber-target-of-protests-by-cabbies-disability-rights-advocates-1.11343063; L. Lazo, "Montgomery County Officials Oppose Metro Partnership with Uber, Lyft for Paratransit," *Washington Post*, 2016, retrieved June 30, 2016, from https://www.washingtonpost.com/news/dr-gridlock/wp/2016/03/24/montgomery-county-officials-oppose-metro-partnership-with-uber-lyft-for-paratransit/.

[57] L. Lazo, "Uber Flirts with Transit Agencies across the US for a Share of Paratransit Services," *Washington Post*, 2016, retrieved June 30,2016, from https://www.washingtonpost.com/local/trafficandcommuting/uber-flirts-with-transit-agencies-across-the-us-for-a-share-of-paratransit-services/2016/03/05/5eb8b118-d751-11e5-9823-02b905009f99_story.html; City of Portland Private For-Hire Transportation Innovation Task Force, "Recommendations on Taxis and TNCs," retrieved from https://www.portlandoregon.gov/transportation/article/540543.

These issues, along with increasing attention to the potential of TNCs to help transit agencies lower the cost of providing demand-response services,[58] have led to an increase in attention to, and controversies about, TNC initiatives that target older adults and persons with disabilities. A few jurisdictions have required TNCs to add a few cents to every trip to be dedicated towards an accessibility fund used to increase mobility options for passengers with functional limitations. Those fees typically go to offset the higher operational costs of accessible ride services for owners and operators and pass the cost of improving service for persons with disabilities on to all consumers of mobility products. Cities that have established an accessibility fund for TNCs include Seattle, Washington; Chicago, Illinois; Portland, Oregon; and Washington, DC.

Preparing Transit for Shifts in the Mobility Landscape

USDOT is actively involved in research and deployment projects that support transportation providers in a time of rapid change. The Mobility on Demand (MOD) Sandbox Demonstration Program, for example, seeks to support transit agencies and communities as they continue to strive to offer equitable services while navigating the dynamic, evolving landscape of personal mobility and integrated multimodal transportation networks. Additionally, feedback from MOD initiatives will assist FTA in addressing program and policy challenges that arise as a result of such partnerships. Stakeholders can view updated information about MOD research at FTA and USDOT at FTA's Mobility on Demand public website.[59] FTA's Innovative Coordinated Access and Mobility research initiative also will support the development of innovative, sustainable solutions to healthcare access challenges. The Notice of Funding Opportunity (NOFO) for these demonstration grants specifically encouraged using innovative transportation technologies. The NOFO was released in March 2016, and 11 projects were selected under for the MOD Sandbox Demonstration Program in October 2016. Information about the program can be found at public website.[60]

Case Study Analysis

The survey methodology resulted in the selection of 24 case studies from 15 states, representing at least one state from every FTA Region. Table 3-1

[58] L. Lazo, "Uber Flirts with Transit Agencies across the US for a Share of Paratransit Services," *Washington Post*, 2016, retrieved June 30, 2016, from https://www.washingtonpost.com/local/trafficandcommuting/uber-flirts-with-transit-agencies-across-the-us-for-a-share-of-paratransit-services/2016/03/05/5eb8b118-d751-11e5-9823-02b905009f99_story.html; Shared-Use Mobility Center (SUMC), "Shared Mobility and the Transformation of Public Transit Research Analysis," APTA and TCRP, retrieved from http://www.apta.com/resources/reportsandpublications/Documents/APTA-Shared-Mobility.pdf.

[59] U.S. Department of Transportation, Mobility on Demand (MOD) Sandbox Program, Federal Transit Administration, retrieved from https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program.html;

[60] Mobility on Demandhttps://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program.html

summarizes the FTA Region, state, and number of case studies noted by region, state, and whether the primary area covered was urban, suburban, or rural.

Table 3-1
Summary of Case Studies

FTA Region	State	# Case Studies*	Type of Area Served
Region 1	MA, CT	3	Urban/suburban/rural
Region 2	NY	3	Urban
Region 3	MD	3	Suburban/rural
	PA	3	Urban/suburban/rural (entire state)
	VA	2	Urban/suburban/rural
Region 4	FL	2	Urban/suburban
	TN	1	Urban/suburban
Region 5	MN, IL	2	Urban/suburban/rural
Region 6	TX	2	Urban/suburban
Region 7	NE	1	Rural
Region 8	CO	1	Urban
Region 9	CA	2	Urban
Region 10	OR	2	Urban/suburban

*Some case studies are supporting more than one city/state; however, 23 discrete case studies are referenced in this report.

These IoT-associated innovative solutions serve a cross-section of communities, including urban, suburban, and rural. In one case, Pennsylvania, the solution provides human services transportation—accessible transportation for older adults, persons of limited income, and people with disabilities—across the entire state. Less than half of the IoT-enabled transportation systems fielded used smartphone/apps and automatic vehicle location technology, with 38 percent of the case studies also using open data and 38 percent referencing public/private partnerships with a number of transportation network companies such as Uber and Lyft. GPS and GTF, along with smart cards and cloud-based electronic payments systems, also were elements of some of these transportation solutions. Interviews with the leaders of these innovative IoT transportation solutions often referenced partnerships across governmental agencies, non-profit organizations, and the private sector. Key public transportation partners were aging services organizations, disability organizations, health/wellness organizations, hospitals, and Medicaid. More than 20 percent of the case studies specifically noted connections to medical and healthcare. In terms of promising practices—types of IoT functionality used, characteristics of the IoT solution—most projects used 2–4 elements, with 3 case studies using 6 elements: TriMet and Ride Connection in Portland, OR and FindMyRide in Pennsylvania.

The innovations that the IoT technology provided were vast. Some enhanced rider experience by providing information about street conditions, notes from other riders about routes, and availability of accessible rides. All provided real-time information on ride availability, and many had multiple ways to access the data—text, smartphone apps, websites, and telephone. Some case studies integrated travel training and other features that helped riders, and some had caregiver, mobility manager, or other types of support just a "click" away. The case studies represent a cross-section of capabilities serving many diverse communities with many different governance structures. This sampling of IoT innovative transportation projects provides a strong snapshot of the various types of solutions being implemented across the country. All of these case studies previewed a constantly-evolving series of services and partnerships. A few years from now, it will be interesting to see where each of these cities, states, and communities are with their IoT-based human services transportation options. For a summary matrix on the case study projects, including information on the various approaches and characteristics used, please see Appendix A.

In interviews with the leaders of these projects, it was clear that transportation providers have to account for constant shifts in the mobility landscape. The opportunities and challenges of IoT-enabled technology and the use of more open, machine-readable data pose issues with how to access, store, integrate, and use data. Based on the interviews conducted on these projects and supporting interviews with experts, combined with research into these issues, the following section discusses useful practices for safeguarding consumer privacy and security, followed by an overview of big data analytical frameworks enabled by IoT technologies and if they hold promise to assist planners and transportation operations professionals provide better service to riders.

SECTION 4

Part II: Addressing Privacy and Security

The previous section shared the results of a survey scan of the communities, cities, and states using IoT technologies to serve older adults. This section fulfills Part II of the report objectives by commenting on "best practices to protect privacy and security, as determined as a result of such survey."

Overview

Because IoT-enabled technologies rely on automatic, machine-readable data, stakeholders generally agree that it is important to balance the increase in interoperable data and connected devices with the strategic use of available privacy and security safeguards to protect consumers. Interviews conducted for this report suggest a universal interest in implementing best practices in privacy and security. However, there is a lack of consensus about what those practices are and should be and who should define them and provide oversight.

Generally, interviewees who have received public funding commented that some funding entities insert requirements for addressing privacy and security questions into NOFO and procurement documents. However, those requirements often suggest consulting industry best practices, or guidance from one or more of three entities:

- US Federal Trade Commission
- National Institute of Standards and Technology at the US Department of Commerce
- National Association of State Chief Information Officers

Some respondents also commented that from both liability and practicality perspectives, when they work with partners in the health and financial sectors, they allow those partners to take the lead in assuring the implementation of data privacy and security measures, in part because those partners already have established platforms that balance utility and data interoperability with security and customer privacy provisions appropriate to legal frameworks regulating those industries. Additionally, if new IoT-enabled transportation services rely on sensitive, personal information, providers will need to ensure the following of regulatory guidelines and legislation related to the treatment of that data. For example, NEMT partnerships must ensure that Protected Health Information (PHI) is collected, stored, and used as stipulated by HIPAA and the Health

Information Technology for Economic and Clinical Health (HITECH) Act.[61] Additionally, all stakeholders consulted expressed an interest in protecting and de-identifying Personally Identifiable Information (PII), as discussed below.

As mentioned earlier, the broader IoT vision is one in which information collected and shared by transportation infrastructure, vehicles, and systems cooperates with other systems to provide synergistic benefits. Thus, the communication and integration of data between heterogeneous systems raises questions about network security on a broader scale than reviewing the application of IoT technologies in the transportation sector will allow at this time, or on its own.

One interviewee noted that "the larger world of IoT already deals pretty extensively with privacy and security," noting uncertainty that there is anything that unique in the transit-related space.

Respondents generally referred to Federal Trade Commission (FTC) recommendations regarding privacy in IoT contexts and its emphasis on Fair Information Practice Principles (FIPs) and privacy-by-design principles for guidance on how to maintain privacy-friendly, consumer-oriented data collection practices. However, there is some disagreement about how the FTC recommends implementing those principles that are addressed below.

In terms of broader security, or ensuring the protection of devices and networks against external threats, respondents mentioned the National Institute of Standards and Technology (NIST) Cybersecurity Framework, Cyber-Physical Systems (CPS) Framework, and NIST's current transnational collaboration to establish an IoT-Enabled Smart City Framework. However, in terms of network-wide security, there is a lack of consensus about the utility of best practice guidelines that offer what could be perceived as overly-standardized or prescriptive approaches to security. This is because overly-standardized safeguards may further enable, rather than safeguard against, security threats because they produce opportunities for standardized and replicable threats.

The remainder of this section provides a brief overview of privacy and security practices provided in FTC and NIST frameworks. Where appropriate, it also provides an overview of controversies related to those practices as shared with FTA staff during the course of the survey/scan.

[61] Rural Transit Assistance Program, Federal Transit Administration, "The Health Insurance Portability and Accountability (HIPPA) Rule's Affect on Rural Transit Agencies," retrieved from http://www.ctaa.org/webmodules/webarticles/articlefiles/hipaabrief.pdf.

Privacy

Privacy refers to:

- the right of an individual to decide what information should be emitted, collected, or stored about that person, to which entities, and under what circumstances;
- the individual consumer's ability to understand or, in some definitions, control what happens with private information once communicated.[62]

PII and SPII

A central concept in privacy analysis is Personally Identifiable Information (PII), information that could be used (alone or in combination with other data) to distinguish a person's identity, and a subset of PII, Sensitive Personally Identifiable Information (SPII). SPII is PII that if lost, compromised, or disclosed could result in substantial harm, embarrassment, inconvenience, or unfairness to the individual.[63] Each respondent interviewed about privacy and security emphasized the sensitive and secure treatment of PII and the importance of encrypting PII/SPII and de-identifying or "cleaning" data of PII/SII in stored data sets.[64]

USDOT is committed to ensuring that its recipients institute sufficient data privacy controls to mitigate the risk associated with the improper handling or disclosure of personal information. PII/SPII are not specific to any type of data or any specific use of technology; rather, each particular case should be analyzed to determine data elements that are provided or obtainable and associated risks.

FTC Guidance

The FTC has been addressing privacy challenges as new IoT technologies and business models associated with those technologies rapidly grow and evolve. In 2012, it released the report "Protecting Consumer Privacy in an Era of Rapid Change: Recommendations for Businesses and Policymakers." Since this report, FTC has released a number of documents providing insight, advice, or recommendations with the respect to addressing privacy and security concerns when implementing IoT technologies and associated business or analytics frameworks. These include "The Internet of Things: Privacy and Security in a

[62] Aggregate definition from S. Gutwirth, Y. Poullet, and P. Hert, *Data Protection in a Profiled World*, Dordrecht: Springer, 2016.

[63] U.S. Department of Transportation, "Smart City Challenge Phase 2: Notice of Funding Opportunity," retrieved from https://www.transportation.gov/smartcity/nofo-phase-2.

[64] *TCRP Synthesis 115, Open Data: Challenge and Opportunities for Transit Agencies*, found that "the most prevalent reason transit agencies are not providing open data is that it is too much effort to produce the data or the agency does not have the time or people to do the work required. The next most prevalent reason is that it takes too much effort to clean the data" (p. 36). Going forward, many respondents said it might be important to prioritize resources and training to assist transit providers with data management and processing. Information retrieved from http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_syn_115.pdf.

Connected World" (2015),[65] which was drafted as the result of a workshop (2013) by the same name, and a related report for businesses, "Careful Connections: Building Security in the Internet of Things" (2015).[66] Tables 4-1 and 4-2 summarize recommendations made in those documents,[67] but this report suggests reviewing ongoing publications by the FTC for updated insights that may be applied in state contexts by transportation, service, and technology providers.

Table 4-1

Federal Trade Commission Privacy Recommendations Overview: "The Internet of Things: Privacy and Security in a Connected World" (2015)

Thematic Area	Recommendation
Security by Design	Conducting a privacy or security risk assessment
	Minimizing consumer data collected and/or retained; de-identifying data by stripping it of identity markers.[68]
	Testing security measures before launching products.
Institutional Culture	Train all employees about good security.
	Ensure security issues are addressed at the appropriate level of responsibility within the organization.
	Retain service providers that are capable of maintaining reasonable security and provide reasonable oversight for these service providers.
Risk Mitigation	When companies identify significant risks within their systems, they should implement a defense-in-depth approach, in which they consider implementing security measures at several levels.
	Companies should consider implementing reasonable access control measures to limit the ability of an unauthorized person to access a consumer's device, data, or even the consumer network.
	Companies should continue to monitor products throughout the life-cycle and, to the extent feasible, patch known vulnerabilities.
Consumer Notice and Choice	While the traditional methods of providing consumers with disclosures and choices may need to be modified as new business models continue to emerge, FTC staff believes that providing notice and choice remains important, as potential privacy and security risks may be heightened due to the pervasiveness of data collection inherent in the IoT. Notice and choice are particularly important when sensitive data are collected.

[65] Federal Trade Commission, "Internet of Things: Privacy and Security in a Connected World," FTC Staff Report, 2013, retrieved June 9, 2016, from https://www.ftc.gov/system/files/documents/reports/federal-trade-commission-staff-report-november-2013-workshop-entitled-internet-things-privacy/150127iotrpt.pdf. Commissioner Wright dissented from the issuance of this report on the grounds that "the Workshop Report includes a lengthy discussion of industry best practices and recommendations for broad-based privacy legislation without analytical support to establish the likelihood that those practices and recommendations, if adopted, would improve consumer welfare." https://www.ftc.gov/system/files/documents/public_statements/620701/150127iotjdwstmt.pdf.

[66] Federal Trade Commission, "Careful Connections: Building Security in the Internet of Things," 2015, retrieved June 7, 2016, from https://www.ftc.gov/system/files/documents/plain-language/pdf0199-carefulconnections-buildingsecurityinternetofthings.pdf.

[67] Recommendations repeated in both documents were not repeated in the table for the sake of efficiency.

[68] For more, see commissioner Julie Brill's remarks on de-identification https://www.ftc.gov/system/files/documents/public_statements/202151/140220princetonbigdata_0.pdf; also see J. Deighton and P. Johnson, "The Value of Data: Consequences for Insight, Innovation & Efficiency in the US Economy," DMA, Data-Driven Marketing Institute, October 8, 2013, available at http://ddminstitute.thedma.org/#valueofdata.

Table 4-2

Federal Trade Commission Privacy Recommendations Overview: "Protecting Consumer Privacy in an Era of Rapid Change: Recommendations for Businesses and Policymakers" (2012)

Thematic Area	Recommendation
Privacy by Design	Companies should build in consumer privacy protections at every stage in developing their products. These include reasonable security for consumer data, limited collection and retention of such data, and reasonable procedures to promote data accuracy.
De-Identified Data	Companies should ensure that data are de-identified, commit to not re-identifying the data, and contractually prohibit third-parties from re-identifying the data.
Simplified Choice for Businesses and Consumers	Companies should give consumers the option to decide what information is shared about them and with whom. This should include a Do-Not-Track mechanism that would provide a simple, easy way for consumers to control the tracking of their online activities.
Greater Transparency	Companies should disclose details about their collection and use of consumers' information, and provide consumers access to the data collected about them.

FTC Commissioner Joshua Wright's dissenting statement accompanying the 2015 report suggested,[69] there are individuals who believe some of these proposed best practices have the capacity to stifle innovation or have a disproportionately negative impact on smaller businesses.[70] Additionally, research done for this report suggested a lack of consensus among data policy researchers related to the benefits of minimizing consumer data collected, even if those same stakeholders agreed with the FTC's recommendations that that data should be de-identified when and where possible.[71] This controversy has to do with innovation and exploring yet-unrealized potential of IoT-enabled connected communities. In data-rich environments, systems will be increasingly able to share, use, and leverage new datasets to address complex challenges or improve current operations and capabilities. Analytics create value from the data that is collected from connected devices and from internet transactions and accounts. Because analytics that use data from varied sources have potential to identify new insights and potential solutions/interventions, according to some stakeholders, the collection of exploratory data should be seen as central to the

[69] J. Wright, "Dissenting Statement of Commissioner Joshua D. Wright Issuance of The Internet of Things: Privacy and Security in a Connected World Staff Report, US Federal Trade Commission, retrieved from https://www.ftc.gov/system/files/documents/public_statements/620701/150127iotjdwstmt.pdf.

[70] D. Castro, "FTC Report on Consumer Privacy Misses the Mark," *The Innovation Files*, 2012, retrieved June 29, 2016, from http://www.innovationfiles.org/the-ftc-report-on-consumer-privacy-misses-the-mark/.

[71] *Ibid*. See also "White House Big Data Report," supra note 114, at 54. "Because the logic of collecting as much data as possible is strong … focusing on controlling the collection and retention of personal data, while important, may no longer be sufficient to protect personal privacy."; PCAST Report at x-xi, "[A] policy focus on limiting data collection will not be a broadly applicable or scalable strategy—nor one likely to achieve the right balance between beneficial results and unintended negative consequences (such as inhibiting economic growth)."

Connected City/Connected Community framework discussed earlier.[72] Limiting the collection and storage of exploratory data or data that are not necessary to the operation at hand would reduce the amount of exploratory data collected by IoT-enabled infrastructures.

Additionally, some respondents commented on the relationship between consumers choosing to limit data shared when using IoT-enabled products and a reduction in capacity to provide them with personalized, consumer-profile tailored services and products.[73] If and when consumers are allowed to indicate they do not want data collected, through a "Do Not Track" mechanism or other opt-in/opt-out mechanisms, this will limit the benefit a user can derive from connected technologies that would aggregate information about that user's preferences over time and share that data with other systems.[74] On the other hand, client-side personalization or machine learning and profiles enabling consumers to apply their privacy preferences to new devices or systems seamlessly may enable consumers more control of their private information.[75]

Security and Defense in Depth

Security in the IoT context refers to safeguarding software applications, devices, servers, and networks against external threats.[76] Cybersecurity in intelligent

[72] M. Strohbach, H. Ziekow, V. Gazis, and N. Akiva, "Towards a Big Data Analytics Framework for IoT and Smart City Applications," *Modeling and Processing for Next-Generation Big-Data Technologies*, 2015, pp. 257-282. http://dx.doi.org/10.1007/978-3-319-09177-8_11; C. Aggarwal, *Managing and Mining Sensor Data*, New York: Springer, 2013; B. Escribano, "Privacy and Security in the Internet of Things: Challenge or Opportunity," Olswang, 2014, retrieved from http://www.olswang.com/media/48315339/privacy_and_security_in_the_iot.pdf.

[73] For a review of risks related to personalization from "profiling" see Executive Office of the President, "Big Data: A Report on Algorithmic Systems, Opportunity, and Civil Rights," 2016, retrieved from https://www.whitehouse.gov/sites/default/files/microsites/ostp/2016_0504_data_discrimination.pdf, and J. Ziegeldorf, O. Morchon, and K. Wehrle, "Privacy in the Internet of Things: Threats and Challenges," *Security and Communication Networks*, 7(12), 2013, pp. 2728-2742, http://dx.doi.org/10.1002/sec.795.

[74] J. Riedl, "Personalization and Privacy," *IEEE Internet Computing,* 5(6), 2001, pp. 29-31, http://files.grouplens.org/papers/Riedl-PersonalizationandPrivacy.PDF; E. Toch, Y. Wang, and L. Cranor, "Personalization and Privacy: A Survey of Privacy Risks and Remedies IN Personalization-Based Systems," *User Model User-Adap Inter*, 22(1-2), 2012, pp. 203-220, http://dx.doi.org/10.1007/s11257-011-9110-z.

[75] A. Kobsa, "Privacy-enhanced Web Personalization," in P. Brusilovsky, A. Kobsa, and W. Nejdl, *The Adaptive Web* (1st ed.), Springer-Verlag, pp. 628–670.

[76] See also report by ITS Joint Program Office, Research and Innovative Technology Administration, US Department of Transportation, which identifies the type, probability, and potential impact of security risks or threats to the communications system on connected transportation systems and users. Crash Avoidance Metrics Partnership and the John A. Volpe National Transportation Systems Center, "An Approach to Communications Security for a Communications Data Delivery System for V2V/V2I Safety: Technical Description and Identification of Policy and Institutional Issues," U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology ITS Joint Program Office, 2016, retrieved from http://ntl.bts.gov/lib/43000/43500/43513/FHWA-JPO-11-130_FINAL_Comm_Security_Approach_11_07_11.pdf.

transportation requires the same commitment to "defense in depth"[77] approach that ICT systems generally deploy. According to a Connected Vehicle Technology Scan by ITS America, a three-fold approach that combines "constructive, operational, and reactive" cyber-defense strategies to create "defense in depth" that promotes general system security in connected transportation contexts.[78] That approach is summarized in Table 4-3, using conclusions drawn in that report.

Table 4-3

Summary of Three-Fold "Defense in Depth" Approach

Constructive Strategies	Use a lifecycle approach to software development that seeks to reduce likelihood of vulnerabilities being introduced in product development phase, before systems are deployed to end users.
Operational Strategies	Focus on continual remediation—patching vulnerabilities quickly and implementing and maintaining strong authentication and access control, while applying mitigation—proactively shrinking systems' total attack surface by reducing exposure of critical elements.
Reactive Strategies	Assume the inevitability of compromise and, instead, seek to actively outsmart and shut out attacking adversaries through real time operational intelligence and analytics.

The ITS America report cited above also explains that cybersecurity best practices or requirements can be principal-based or rules-based. Whereas rules-based requirements are concrete and thus easier to apply and audit, they tend to be more transparent and, in part, because they are more prescriptive in a consistently shifting security landscape, are often less sustainable. Interviews conducted for this report corroborated this perspective and revealed that in terms of network-wide security there is a lack of consensus about the utility of rules-based best practice guidelines. These guidelines may offer what could be perceived as overly-standardized or prescriptive approaches to security.[79] Critics of uniform, rules-based best practices fear that overly-standardized rules

[77] Protecting a computer network with a series of security mechanisms such that if one mechanism fails, another will already be in place to respond to a threat. For further details, see: US Department of Commerce National Institute of Standards and Technology, "Guide to Industrial Control Systems (ICS) Security Supervisory Control and Data Acquisition (SCADA) systems, Distributed Control Systems (DCS), and other control system configurations such as Programmable Logic Controllers (PLC) Recommendations of the National Institute of Standards and Technology," U.S. Department of Commerce, National Institute of Standards and Technology, 2016, retrieved from http://csrc.nist.gov/publications/nistpubs/800-82/SP800-82-final.pdf.

[78] S. Bayless, S. Murphy, and A. Shaw, "Connected Vehicle Assessment: Cybersecurity and Dependable Transportation, System Assurance, Operations and Reactive Defense for Next Generation Vehicles and Intelligent Highway Infrastructure," ITS America, 2012, retrieved from http://www.itsa.org/knowledgecenter/technology-assessment/cyber-security-and-dependable-transportation/1660.

[79] See also CTIA, "Mobile Cybersecurity and the Internet of Things: Empowering M2M Communication," CTIA–The Wireless Association, 2014, retrieved from http://www.ctia.org/docs/default-source/default-document-library/ctia-iot-white-paper.pdf.

may further enable, rather than safeguard against, security threats because they produce opportunities for standardized and replicable threats.[80]

Research published by ITS America, in addition to interview responses from transit providers and research/industry stakeholders, suggested that some "failures in security are not the result of lack of best practices, guidelines, tools, and security controls, but often a lack of organizational policy [or culture] establishing those measures, or where policy does exist, or [*sic*] lack of effective implementation."[81] Additionally, a failure or inability to allocate enough resources to reduce risks by designing and implementing a three-fold "defense in depth" approach or by investing in training to foster organizational cultures committed to "good cyberhygiene,"[82] can increase risk.

National Institute of Standards and Technology Recommendations

Cities, communities, and states are bound by state and local laws regulating security, privacy, including proper responses to security breaches. Many refer to the NIST documents on cybersecurity, cyber-physical systems, and privacy that, through a process of collaboration between NIST, technology and privacy industry stakeholders, academia, and U.S. government partners, provide voluntary guidelines, best practices, and best practices to safeguard critical infrastructure against security risks. Those documents include NIST Framework for Improving Critical Infrastructure Cybersecurity (2012), Draft Framework for Cyber-Physical Systems (2015), and Report on Strategic U.S. Government Engagement in International Standardization to Achieve U.S. Objectives for Cybersecurity (2015). Whereas the NIST framework provides a general, overarching structure, grounded in consensus best practices that address organizational security while providing adaptability and flexibility to meet the needs of many sectors as new threats emerge, the cyber-physical systems framework will provide more detailed, technical specifications for building secure products.[83]

[80] *Ibid.*

[81] S. Bayless, S. Murphy, and A. Shaw, "Connected Vehicle Assessment: Cybersecurity and Dependable Transportation, System Assurance, Operations and Reactive Defense for Next Generation Vehicles and Intelligent Highway Infrastructure," ITS America, 2012, retrieved from http://www.itsa.org/knowledgecenter/technology-assessment/cyber-security-and-dependable-transportation/1660.

[82] Center for Infrastructure Assurance and Security, University of Texas, San Antonio, http://cias.utsa.edu/assets/cyber_hygiene_handout.pdf; U.S. Department of Defense, "Department of Defense Strategy for Operating in Cyberspace," 2011, retrieved from http://csrc.nist.gov/groups/SMA/ispab/documents/DOD-Strategy-for-Operating-in-Cyberspace.pdf.

[83] Additionally, NIST provides guidance on protecting PII and guidance related to security and big data analytical frameworks associated with the Internet of things. Those reports include Special Publication 800-122 (*Guide to Protecting the Confidentiality of PII*), which provides guidelines for a risk-based approach to protecting the confidentiality of PII. Additional information about privacy and security safeguards for PII can be found in Appendix J to NIST Special Publication 800-53. Furthermore, NIST provides guidance regarding big data architectures and security requirements in NIST Special Publication 1500-1 and NIST Special Publication 1500-4.

The NIST framework provides an overarching structure, grounded in proven international standards and consensus best practices, to address organizational security across all critical infrastructure sectors, while providing adaptability and flexibility to meet the unique needs of each sector and address new threats. The cyber-physical systems framework will provide additional technical details for building secure products. These frameworks are applicable to organizations across IoT infrastructure sectors, including those public and private transportation organizations seeking to enhance security through risk management best practices and standards. This report recommends that policy-makers and other stakeholders engaging with the application of IoT-enabled technologies in transportation contexts track the NIST Smart Cities Architecture Community[84] and the Cyber-Physical Systems Public Working Group for updates to living frameworks as they unfold and emerging, transnational frameworks, recommendations, and guidance.[85]

Just as the proliferation of connected devices and associated software increases, so does the volume of data we will be able to collect in connected cities and communities. As explored in this section, this poses unique privacy and security challenges. However, as the next section discusses, IoT technologies also provide new opportunities to increase operational efficiency and assist planners forecast transportation and development needs through big data analytics, and provide more personalized services to consumers.

[84] U.S. Department of Commerce, National Institute of Standards and Technology, "IoT-Enabled Smart City Framework Public Working Group Overview," retrieved from https://s3.amazonaws.com/nist-sgcps/smartcityframework/files/IoT-EnabledSmartCityFrameworkWP.pdf.

[85] Cyber-Physical Systems Public Working Group, U.S. Department of Commerce, National Institute of Standards and Technology (NIST), retrieved June 29, 2016, from https://pages.nist.gov/cpspwg/.

SECTION
5

Part III: Potential of IoT to Assist Planners

This section fulfills Part III of the report objectives by offering "recommendations with respect to the potential of the IoT to assist local, state, and federal planners to develop more efficient and accurate projections of the transportation needs of rural, suburban, and urban communities." IoT technologies and the data they generate and share hold potential to assist planners from both a system and rider perspective. From a system perspective, IoT can be used to improve travel and ridership forecasting as well as transportation systems monitoring and management. From a rider perspective, IoT personalizes transportation experiences and provides traveler incentives with gamification. This section discusses these IoT benefits that can help planners, but also reviews limitations and concerns with the use of big data, especially as it relates to algorithm discrimination. Thus, FTA's recommendation is to first assess some of these ethical questions surrounding the algorithms used by IoT systems before finalizing specific suggestions for planners' use of IoT.

Internet of Things and Big Data

According to the USDOT's Intelligent Transportation Systems Joint Program Office, "big data" is a process of knowledge generation that features the following approaches:[86]

- *Data Capture* that includes massive datasets encompassing all or most of the population being studied (as opposed to small samples); use of data from both purpose-specific and repurposed data collection; and utilization of crowdsourced and "electronic breadcrumb" data.
- *Data Management* that features storage in decentralized and virtual locations (i.e., the cloud) and handles both structured and unstructured data.
- *Data Analysis* that is often automated, with computers doing more of the work to find complex patterns among a large number of variables

Appendix B of this report provides more information on various technologies and techniques related to big data collection, management, and analysis.

[86] U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, "Big Data's Implications for Transportation Operations: An Exploration," USDOT Intelligent Transportation Systems Joint Program Office, 2016, retrieved from http://ntl.bts.gov/lib/55000/55000/55002/Big_Data_Implications_FHWA-JPO-14-157.pdf.

As Internet-enabled sensors are increasingly embedded in the physical world—in everything from energy meters, home appliances, mobile phones, vehicles, infrastructure, wearables, and beyond—data about consumers, infrastructure, and asset health and real-time contextual data about weather, current events, and travel patterns are generated, stored, and analyzed at an alarming rate. The growing volume of data generated by IoT technology and Internet communications can provide new insights with the capacity to improve transportation safety, reduce the costs of operations, improve mobility, reduce environmental impacts, and allow planners to develop more accurate transportation projections. The volume, velocity (speed of acquisition), and variety (range of data types and sources) of these data—and approaches to mining, analyzing, and operationalizing these data—distinguish big data approaches from traditional data management and analysis.[87]

The proliferation of IoT technologies alongside the increase in data generated by the use of smartphones, social media networks,[88] and search engines[89] will provide valuable context data with the ability help communities:

- enhance transportation system monitoring and management
- develop traveler-centered transportation strategies

The data collected through passive circulation (e.g., GIS capabilities enabled by cellphones, sensors that can provide passenger counts) or active engagements with technology (purchasing trips on TNC software, using crowdsourcing apps such as Waze, and generating transactional data from our purchases) will increasingly provide real-time location information for travelers, data on means, modes, and speeds of travel on multimodal trips, demographic information, and information about what travelers do when they arrive at a destination. For example, it is already possible for a traveler to book and pay for a trip using a smartphone, which also has access to a range of that individual's consumer preferences, and then use that smartphone to pay for a coffee at a local coffee store. Simultaneously, the diversity of IoT sensors producing contextual information related to climate, congestion, time of day, and beyond will allow analysts to draw previously-unseen connections between certain conditions and the likelihood of problems with asset health, accidents, or the need to reroute traffic. The speed and volume of data generated by these technologies will allow for shortened time between generating feedback on traveler experiences and infrastructural safety and quality and the ability for entities to use that feedback to improve transportation networks.

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[87] *Ibid*.

[88] J. Constine, "How Big Is Facebook's Data? 2.5 Billion Pieces of Content and 500+ Terabytes Ingested Every Day," *TechCrunch*, 2012, retrieved June 29, 2016, from https://techcrunch.com/2012/08/22/how-big-is-facebooks-data-2-5-billion-pieces-of-content-and-500-terabytes-ingested-every-day/.

[89] Google, "Facts about Google and Competition, http://www.google.com/competition/howgooglesearchworks.html, accessed September 18, 2013.

Potential Uses of IoT-Generated Data by Planners

Technology scans by ITS America and reports by USDOT suggest that we are in the nascent stages of understanding possible applications of big data frameworks to multimodal transportation planning efforts. Continued attention to and support of the application of big data capture, storage, visualization, and analysis to transportation planning in rural, urban, and suburban contexts will be necessary to preparing federal, state, city, regional, and local planners to incorporate diverse emerging data sets into planning efforts.

Transportation System Monitoring and Management

The large-scale generation of data from mobile devices, connected vehicles, and sensors will produce a paradigm-changing increase in data on where travelers go and when and how they get there. Simultaneously, analytical systems and models capable of automatically processing data from various unrelated sources will offer the opportunity to visualize and analyze communities through the analysis of previously disparate and data sets. Additionally, as the IoT expands, there will be an increase in the types of data variables that will be available, including transportation information such as real-time data on braking, acceleration, lane behavior, passenger number, congestion, and variables that are not directly related to transportation, such as broad climate data and data about room use from smart home technologies, that may be found to be statistically-significant in transportation forecasting or managing transportation systems. We are in the nascent stages of exploring and predicting applications for the large and diverse volumes rendered by data IoT technologies.

Travel and Ridership Forecasting

Travel forecasting models provide information that can be used to make transportation planning decisions. Transportation professionals use various inputs when creating transportation forecast models and transportation connectivity models. It is common for planners to use available data on:

- Populations and households, employment and workplace location, and network data, including pedestrian, vehicle, and bicycle infrastructure
- Facility type and area type; mode and route choice
- Travel times and fares, trip generation, trip distribution
- Passenger counts
- More

This report focuses on new opportunities afforded by data generated by IoT technologies; it does not provide a comprehensive review of the processes and inputs already used for transit ridership forecasting and service planning. For a detailed discussion of travel demand forecasting, readers should refer to TCRP and National Highways Cooperative Research Program (NCHRP) synthesis reports.[90]

The availability of real-time, GPS-data enabled by IoT technologies has the potential to significantly improve the accuracy and utility of travel demand models.[91] Not only will these technologies enhance the ability of transportation providers to more efficiently collect fine-grained information on their riders' actual travel patterns and preferences, they will also permit transit agencies to leverage system-wide information about travelers collected from non-transportation stakeholders as well. The data collected will be more accurate, more specific, and more diverse, allowing inputs to existing and emerging models to produce more useful models.

Companies already have demonstrated an interest in procuring real-time information about where people go, and when, to make more efficient travel projections. For example, agencies are already using data collected by AirSage, a company that collects data on the position of cell phones relative to nearby cell towers, not on GPS or Bluetooth. Because as much as 91 percent of the US population owns a cellphone, AirSage is able to collect 15 billion data points per day and has been hired by various planning entities to produce actionable insights on service areas. However, cell phone location can only be triangulated to within 150 meters, which is far less precision than GPS, and individual data are often not available in real time and do not reflect mode of travel (Calabrese 2011). Thus, cities and transportation providers increasingly express interest in partnering with companies such as Waze that collect or crowdsource real-time, location-specific data and can communicate information about travel conditions directly to users through their cell phones.[92] Waze, now owned by Google, collects information about users and recommends the fastest routes based on real-time driving and data from millions of users. In 2014, Waze launched the Connected Citizens[93] program, allowing cities and states globally to partner with Waze to share data bi-directionally at no financial cost. As of April 2016, public information was available about Waze partnerships with the Regional Transportation Commission of Southern Nevada and various cities and states,

[90] *TCRP Synthesis 66, Fixed-Route Transit Ridership Forecasting and Service Planning Methods: A Synthesis of Transit Practice*, Transportation Research Board, retrieved from http://www.tcrponline.org/PDFDocuments/tsyn66.pdf.

[91] NCHRP Report 176, Travel Demand Forecasting: Parameters and Techniques, Transportation Research Board.

[92] C. Shu, "Nav App Waze Says 36M Users Shared 900M Reports, While 65K Users Made 500M Map Edits, *TechCrunch*, 2013, retrieved June 29, 2016, from https://techcrunch.com/2013/02/06/nav-app-waze-says-36m-users-shared-900m-reports-while-65k-users-made-500m-map-edits/.

[93] N. Ungerleider, "Waze Is Driving into City Hall," Fast Company, 2015, retrieved June 29, 2016, from http://www.fastcompany.com/3045080/waze-is-driving-into-city-hall.

including Los Angeles, San Jose, Boston, Florida, Washington, DC, Rio de Janeiro, Tel Aviv, Sydney, and Mexico City. These partnerships are representative of the sustained interest transportation planners have in anonymized, real-time traveler data with the potential to more accurately predict transportation needs and address possible connectivity and reliability issues.

Transportation Systems Monitoring and Management

Applying big data analytical approaches to real-time data can also potentially assist planners in predicting breakdowns in the transportation system. For example, currently, fixed traffic detectors are currently used to detect incidents by identifying problems once they occur. Big data analytical approaches that process a large number of variables for possible correlations help planners accurately predict breakdowns in flow before they occur. These factors could include anything from sun angle, day of the week, time of day, to lane-changing and braking data. This could enhance the safety and mobility of travelers by allowing transportation operators to act before traffic flow breaks down, and planners to assist in promoting alternative corridors to be available at times of anticipated breakdowns.[94]

Connecting to Riders

The increasing use of smartphones coupled with big data analysis frameworks also has the potential to shift the relationship between transportation providers/public entities and the riding public. Thus, discussions of the IoT's potential to shift transportation planning efforts go beyond the prediction of need to speculations about the capacity of IoT to allow entities to personalize transportation experiences for riders, and using IoT technology to incentivize shifts in traveler behavior.

Personalizing Transportation Experiences

As discussed in Section 2, services offering on-demand origin-to-destination transportation have become more prevalent over the past few years. Services offering rideshare matching and car/bikesharing services are likely to grow in market share as more individuals use smartphones, those services become more widely accessible, consumer acceptance of mobility as a service grows, and policy measures around issues of insurance, regulation, and taxation become more standardized. These services collect important information related to traveler preference, and network connectivity simultaneously. On a micro level, traveler profiles will allow for personalized travel routing, planning, and purchasing. For example, in a future scenario, travelers would be able to select preferences

[94] U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, "Big Data's Implications for Transportation Operations: An Exploration," U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office, 2016, retrieved from http://ntl.bts.gov/lib/55000/55000/55002/Big_Data_Implications_FHWA-JPO-14-157.pdf.

(types of car, routes, music) and mobility needs (space for a walker or service animal, or door-to-curb service) and use multimodal transportation planning apps to plan a door-to-door trip without having to re-enter crucial information beyond origin and destination each time they travel. This same technology could allow travelers to give real-time feedback on their trips. Interconnected or "smart" communities in which transportation networks communicate with other networks could provide even more, currently unimaginable benefits to travelers moving throughout the city. On a macro level, aggregated volumes of traveler profile data put into conversation with service area data about trips made and mode selection will provide a crisper picture of preferences and how travelers across different demographic groups experience travel.

Traveler Incentives and Gamification

Additionally, smartphone-based applications that keep track of where, when, and how individuals use transportation and link that data to other factors will assist analysts in predicting future travel choices, analyze factors that influence those choices, and potentially influence those choices through offering rewards in transit apps or through gamification. Gamification is the use of game thinking and mechanics to incentivize voluntary contributions from consumers in non-game contexts. A common use of gamification is FitBit, which awards "trophies" for physical activity, allows consumers to see their own contributions compared to other people, and sets personal goals for fitness. Gamification in transportation contexts allows companies and organizations to measure customer mode choice and reward particular departure times and modes of travel by offering virtual points and "badges," rewards in the forms of coupons, or event tickets, or virtual points to purchase gift cards at popular retailers.

Examples of Gamification in Transportation

Société de Transport de Montreal (STM) worked with a local software developer to create a transit app that pairs real-time location information of transit riders with a profile of their commercial activities and activity preferences. The app uses segmented marketing to provide offers exclusive to transit riders based on their preferences and locations and offers more rewards to travelers who use transit more frequently. The partnership benefits riders, consumers, and retailers alike. Retailers boost sales, while the agency encourages transit ridership.[95] The agency is targeting a 40 percent increase in ridership by 2020.[96] This is relevant to anticipating how these partnerships can take shape in the U.S.

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[95] B. Winterford, "How Montreal Transport Skirted Privacy Laws," iTnews. 2013, retrieved June 29, 2016, from http://www.itnews.com.au/blogentry/how-montreal-transport-skirted-privacy-laws-360480/page0.

[96] K. Murphy, "Société de transport de Montréal (STM) Aims to Boost Ridership by 40% with a Mobile App," SAP Insider, 2014, retrieved June 29. 2016, from http://sapinsider.wispubs.com/Assets/Case-Studies/2014/January/STM.

despite limitations on data that transit agencies themselves can collect. STM could not collect and store information about commercial preferences from its riders. Thus, partner software company STM collected voluntary personalization information from consumers, stored that data using cloud technology, and applied analytical frameworks to match consumer preference data and real-time transit use inputs to generate coupons, offers, and rewards for riders. Thus, STM did not need to retain non-critical information and could still benefit from the application of big data frameworks to generate targeted offers. This strategy drove customer engagement with reward offers up to 67 percent.

MetropiaMobile has partnered with various U.S. cities (New York City, Austin, Tuscon, El Paso) to incentivize commuters to choose certain departure times, routes, and modes to significantly reduce traffic congestion. This app uses real-time traffic data analytics to provide route options and mode options for riders who then choose which they would like to use for travel. Different options will award users with different numbers of points, which users can then use to purchase gift cards at popular retailers. GPS-enabled smartphones allow drivers and transit riders to confirm which mode and route they took automatically. More importantly, the options provided to users allow them to see how the choices they make impact how long they will spend in traffic and the environmental impact of their travel.

The outcomes of gamification initiatives will be important to measure, as gamification might present a novel opportunity to use IoT technologies to promote sustainable transportation choices and reduce time spent in traffic.[97] Although it is too soon to predict all potential applications for gamification in transportation, it is reasonable to expect it to play a role in how emerging planning and transit professionals approach public participation and civic engagement.[98] This year, an app that uses geocaching that can sense when individuals with smartphones are near a proposed transportation project and allows them to interact with that project digitally and give feedback won George Mason University's Hays Outside the Box Competition. During their presentation, the winning team mentioned using seed investments to integrate gamification that will incentivize riders to interact with the planning proposal, give voluntary and anonymous demographic data, and share their thoughts about

[97] S. Maartje, "The Use of Gamification to Drive Behavioural Change—Lessons from the Strategic Platform for its (SPITS) and Scania," ITS America, 2012; S. Buningh, R. Martijnse-Hartikka, and J. Christiaens, "Mobi - Modal Shift through Gamification," Institut Francais des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux (IFSTTAR), 2014.

[98] S. Hosio, J. Goncalves, V. Kostakos, and J. Riekki, "Crowdsourcing Public Opinion Using Urban Pervasive Technologies: Lessons from Real-Life Experiments in Oulu," *Policy & Internet*, 7(2), 2015, pp. 203-222, http://dx.doi.org/10.1002/poi3.90; S. Thiel, "Gamified Participation: Investigating the Influence of Game Elements in Civic Engagement Tools," *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, pp. 527-53; F. Escribano, "Smart Cities, Citizen Participation & Gamificación," *Fundación Iberoamericana del Conocimiento*, 2015, retrieved June 29, 2016, from http://gecon.es/smart-cities-gamification/.

the proposal.[99] This report recommends continued and enhanced attention to the use of gamification in transportation demand management, participatory planning efforts, and beyond.

Limitations to Big Data Approaches

As the field of big data analytics grows, so do concerns about the data divide.[100] Just as policymakers and advocates increasingly address the digital divide—or disadvantages that might result due to a lack of access to specific technologies—some now question challenges that might result from either a lack of access to data or the lack of data gathered about a community. If we increasingly rely on big data to offer insights about systems, operations, and consumer preferences and to predict need, we need to address potential weaknesses in big data science. For example, what happens when some places and people generate more the data we analyze to make decisions than others?[101] Others have pointed out that the algorithms used to analyze, visualize, and operationalize big data insights, likewise, might produce differential benefits for over-represented communities. Moving forward, transparency regarding which algorithms are used to make value from data and which data inputs those algorithms are using will be important to benefitting from the use big data frameworks while ensuring that they do not create unintended discriminatory consequences. Just as some top-down urban design frameworks have, at times, unwittingly reproduced inequity, big data frameworks and algorithms potentially could, if left unchecked, also have unintended consequences for our communities for decades to come.[102] These questions are even more important to big data contexts than traditional data contexts, as it can be mistakenly assumed that data used as inputs and the algorithms used to analyze that data are objective or representational.[103]

Discussing these limitations does not imply that we should reject the potential of aggregated, anonymized data to give us more information about community needs; instead, it highlights the importance complementary research, policy,

[99] George Mason University School of Policy, Government, and International Affairs, "Hays Outside the Box Competition," 2015, retrieved from http://schar.gmu.edu/current-students/scholarships-funding/cameron-rian-hays-outside-box-competition/.

[100] D. Castro, "The Rise of Data Poverty in America," Center for Data Innovation, 2014, retrieved from http://www2.datainnovation.org/2014-data-poverty.pdf.

[101] K. Crawford, "The Hidden Biases in Big Data," *Harvard Business Review*, 2013, retrieved June 29, 2016, from https://hbr.org/2013/04/the-hidden-biases-in-big-data; K. Crawford, "Can an Algorithm be Agonistic? Ten Scenes from Life in Calculated Publics," *Science, Technology & Human Values, 41*(1), 2015, pp. 77-92, http://dx.doi.org/10.1177/0162243915589635.

[102] Executive Office of the President, "Big Data: A Report on Algorithmic Systems, Opportunity, and Civil Rights," 2015, retrieved from https://www.whitehouse.gov/sites/default/files/microsites/ostp/2016_0504_data_discrimination.pdf.

[103] L. Gitelman, *Raw Data is an Oxymoron*, Cambridge, Massachusetts: The MIT Press, 2013.

and program initiatives to address what Kate Crawford, a principal researcher at Microsoft, calls the "hidden biases in big data."[104] For example, the Oregon Department of Transportation (ODOT) was the first state transportation agency to partner with Strava, a website and app used by consumers to track their bike rides via GPS. Strava's dataset offers time-stamped GPS travel information about 17,000+ riders and 400,000 bicycle trips that procuring agencies can map onto OpenStreetMap. This data set gave ODOT a much richer understanding about popular routes through the city, connectivity issues, and origin/destination data for riders and helped it identify problem intersections. However, project managers found that Strava users represent only a small percentage of bicyclists in Portland who tended to be serious riders on training rides. Even so, this partnership has given ODOT access to better user insights and motivated it to undertake complementary outreach and research efforts to capture data about and serve under-represented and potential riders.[105]

Social scientists working in the fields of human-machine interaction, ethics, and big data analysis suggest that, in addition to algorithmic transparency, qualitative or "thick data" approaches that complement big data sets will be useful to more equitably operationalizing data insights.[106] Thick data leverages community-based fieldwork to explore the social context of connections between data points, analyzes which populations are over-represented in large data sets, and asks why and how individuals act or think the way they do (rather than just showing what they do and when). In transportation planning, thicker, or smaller-scale, qualitative research about why individuals make the trips they do instead of others and whether potential riders would take more trips if different options were available to them will be especially important to understanding subjective connectivity barriers and addressing the priorities of underserved travelers. Thinking more broadly, policies and programs in Smart Community- or IoT-

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[104] K. Crawford, "The Hidden Biases in Big Data," *Harvard Business Review*, 2013, retrieved June 29, 2016, from https://hbr.org/2013/04/the-hidden-biases-in-big-data/.

[105] J. Maus, "ODOT Embarks on 'Big Data' Project with Purchase of Strava Dataset," BikePortland.org, 2014, retrieved June 29, 2016, from http://bikeportland.org/2014/05/01/odot-embarks-on-big-data-project-with-purchase-of-strava-dataset-105375; A. Davies, "Strava's Cycling App Is Helping Cities Build Better Bike Lanes," WIRED, 2016, retrieved June 29, 2016, from https://www.wired.com/2014/06/strava-sells-cycling-data/.

[106] T. Shelton, A. Poorthuis, M. Graham, and M. Zook, "Mapping the Data Shadows of Hurricane Sandy: Uncovering the Sociospatial Dimensions of 'Big Data'," *Geoforum*, 52, 2014, pp. 167-179; A. Halavais, "Home Made Big Data Challenges and Opportunities for Participatory Social Research," *First Monday*, 18(10), 2013, http://dx.doi.org/10.5210/fm.v18i10.4876; K. Crawford, "Can an Algorithm be Agonistic? Ten Scenes from Life in Calculated Publics," *Science, Technology & Human Values*, 41(1), 2015, pp. 77-92, https://hbr.org/2013/04/the-hidden-biases-in-big-data; L. Forlano, "Ethnographies of Future Infrastructures. EPIC: Advancing the Value of Ethnography in Industry," *Series: Data, Design and Civics: Ethnographic Perspectives*., 2016, retrieved June 29, 2016, from https://www.epicpeople.org/ethnographies-of-future-infrastructures/; B. Jordan, (Ed.), *Advancing Ethnography in Corporate Environments*, Walnut Creek, CA: Left Coast Press, 2014; D. Boyd, "Privacy and Publicity in the Context of Big Data," WWW, 2010, Raleigh, NC.

enabled contexts that rely on digital channels could disadvantage individuals who either need or prefer analog platforms or face-to-face engagement, whether due to questions of ability, resource, cultural background, or preference. Thus, a sustained commitment to inclusive planning, community engagement, and promoting the importance of ethnographic research as these new technologies are implemented and to addressing the limitations of big data head-on can help planners avoid unintentionally using big data to make planning decisions that do not address community-level concerns or that exacerbate, rather than alleviate, existing inequalities.[107]

[107] For more on the importance of human-centered and ethnographic research in the development of Smart Cities, see the following article, written by researchers at New York City's Public Policy Lab, which provides more in-depth commentary about how ethnography is helpful specifically in "smart" or IoT-enabled urban contexts, C. Mauldin, and N. Radywyl, "Human-Centered Research in Policy Making," EPIC: Advancing the Value of Ethnography in Industry, retrieved June 30, 2016, from https://www.epicpeople.org/human-centered-research-in-policymaking/.

SECTION 6

Conclusions

This report covers a wide swath of technologies, issues, and trends in IoT. Tying together these loosely-coupled concepts is challenging. What can we learn from case studies that demonstrate how IoT drives innovative transportation systems for older adults with the commensurate privacy and security issues? And how do these case studies inform recommendations on how IoT can help planners have more efficient and accurate predictions? Research on how IoT is being used to serve older adults uncovered a key fact—it is often not the technology at the center, it is the psycho-social element of rider and user experience and perspectives. For example, in New York City, the TNC Via is popular with travelers ages 65 and older because, according to some journalistic accounts, passengers find it easy to use and the shared shuttle charges no more than $5 for rides within its service area (compared to companies such as Lyft and Uber that charge surge pricing rates based on demand).[108] Thus, a major finding of this report is that ethnographic fieldwork[109]—more specifically, rider experience and user experience research that helps transportation professionals understand which non-targeted services are popular among older travelers, and why—will be crucial to continuing to develop services that are attractive to and meet the needs of those travelers.

Another finding is the importance of ensuring equity—both the equity of technology access and the equity of data algorithms. Connected transportation systems as part of a broader web of connected systems can improve mobility for all riders, including older Americans. Improved traffic management and safety through connected vehicle technologies can improve the mobility of travelers regardless of whether those travelers are personally using IoT-enabled devices. But the ability of users to access real-time information and make

[108] A. Kadet, "Getting Around the City with the Elderly," *Wall Street Journal*, 2013, retrieved June 29, 2016, from http://www.wsj.com/articles/getting-around-the-city-with-the-elderly-1459544107; L. Schwartzberg, "Early-Adopter Seniors Have Totally Taken Over the Ride-Sharing App Via," *New York Magazine*, 2015, retrieved June 29, 2016, from http://nymag.com/daily/intelligencer/2015/12/via-ride-sharing-app-seniors.html.

[109] Ethnographic research and user experience research becomes increasingly important to transportation sectors as transportation services increasingly rely on smartphone applications, customer-facing software, and IoT enabled on demand services. User experience researchers commonly work in iterative product design, testing, and development. More recently, technology and automobile/mobility companies such as Ford Motor Company, Intel, Google, Microsoft, and beyond have worked with ethnographers and user experience researchers to conduct applied participant observation research on usability, accessibility, and customer satisfaction. Research done during the course of this report suggests that trend likely will continue to be more important to transportation and transit research, innovation, and demonstration as internet-enabled devices are increasingly important to transportation services.

informed, multimodal choices based on that data increasingly relies on access to a smartphone device or Internet-connected computer. Thus, continued efforts to address the digital divide and promote accessible site, app, and device design are crucial to harnessing the potential of these technologies to improve the mobility of all Americans. Mobility-on-demand platforms, services, vehicles, and digital pages and apps, likewise, need to be affordable. These platforms also must be accessible to older adults and persons with disabilities. Research suggests that algorithms may have inherent bias with under- or over-represented populations, so essential social contexts may be missed. This makes finalizing recommendations for specific IoT uses for planners challenging until there is further study on algorithms and big data.

IoT is transforming transportation and communities. Technology is improving transportation services for older adults. However, the broader IoT vision is one in which information collected and shared by transportation infrastructure, vehicles, and systems cooperates with other systems to provide synergistic benefits for all members in a community across other industries in addition to the transportation industry. Because intelligent infrastructure is connected to the Internet, components can collect multi-source, contextual data and work together to provide more seamless experiences for residents. For example, IoT monitoring systems can detect and learn behavioral patterns in the home (such as location of the resident at different times of day, cooking frequency and times, leaving home and returning, turning on/off a faucet, biofeedback markers such as heart rate, etc.). Significant behavioral or physiological shifts could be communicated to an individual's medical care professional,[110] who could automatically reach out to the patient and simultaneously schedule a medical appointment and door-to-door transportation to that appointment. Transportation is a crucial part of the infrastructural landscape in connected communities, but, in the future, analysts expect transportation systems to be securely communicating with other systems to provide maximum benefit to consumers and industry.[111] As this occurs, smartphone and tablet app development, improved demand-response services, open data and software initiatives, accessible bikeshare programs, and TNC programs can form a backbone to this broader IoT infrastructure.

[110] For more on IT, aging, and improving chronic disease management, see P. R. Dexter, D. K. Miller, D. O. Clark, M. Weiner, L. E. Harris, L. Livin, et al., "Preparing for an Aging Population and Improving Chronic Disease Management," *AMIA Annual Symposium Proceedings*, 2010, pp. 162-166.

[111] M. Cuddy, A. Epstein, C. Maloney, B .Westrom, J. Hassol, A. Kim, et al., "The Smart/Connected City and Its Implications for Connected Transportation," U.S. Department of Transportation, John A. Volpe National Transportation Systems Center and Intelligent Transportation Systems Joint Program Office, 2014, retrieved from http://www.its.dot.gov/itspac/Dec2014/Smart_Connected_City_FINAL_111314.pdf.

Just as the proliferation of connected devices and associated software increases, so does the volume of data we will be able to collect in connected cities and communities. As explored earlier, this poses unique privacy and security challenges, yet there is no agreement to date on the best ways to address these challenges. The growing volume of data generated by IoT technology and Internet communications can provide new insights with the capacity to improve transportation safety, reduce the cost of operations, improve mobility, reduce environmental impacts, and allow planners to develop more accurate transportation projections. But it must be done with a clear understanding of how to ensure privacy and security.

Just as there is no single universal definition for IoT, there is no single way to define how IoT is transforming transportation. Objects connected to sensors generating data that are then analyzed to enhance operational and consumer services are transforming communities. IoT is no longer the wave of the future, but, today, these technologies enable the ebb and flow of people, goods, services, and utilities. Within these innovations, like many technology initiatives in the past, it is essential to understand the societal implications and issues of their use and proliferation. That is the key finding of this research: it is the human-machine interaction and ethics of big data that emerge as essential elements to include as IoT solutions are developed and implemented.

APPENDIX

A

IoT Innovative Technologies Expanding Older Adult Transportation Case Studies Characteristics Matrix

Key Characteristics of IoT Solutions % of Approaches & Characteristics Used	Information	IoT-Based Approaches Used											Notes
		A	B	C	D	E	Project directly connects transportation services with healthcare services & providers	Older adults included in transportation planning process	Project developing capacity for same-day demand-response rides	Project promoting access to data to improve rider experience	Total		
Project Eric	Knoxville, TN	1	1					1	1	1	5	56%	Riders like communication capability of tablets
TravelMate	Northern VA	1								1	2	22%	App provides personalized and GPS-enabled travel training, acts as travel companion for riders who want it, including riders with cognitive disabilities
Tiramisu	New York City; Pittsburgh, PA	1								1	2	22%	App lets users leave notes or give feedback about routes and stops that other riders can review
Roll with Me	Chicago; New York City	1		1						1	3	33%	App includes accessibility alerts that warn travelers about elevators that are out of service, sidewalk closures, and platforms that may be obstructed because of construction efforts
Via Mobility Services	Boulder, CO		1	1					1	1	4	44%	Riders receive automatic notifications with the option to cancel. Service resulted in expanded service times and decreased wait times
Ride-on	San Luis Obispo, CA		1				1	1	1	1	5	56%	Project links databases and services in real-time allowing customers to access more integrated service from county's public, private, and nonprofit providers
Washington Co. Transit Dept, County Commuter	Hagerstown, MD		1						1	1	3	33%	System records customer favorite trips

Key Characteristics of IoT Solutions % of Approaches & Characteristics Used	Information	IoT-Based Approaches Used											Notes
		A	B	C	D	E	Project directly connects transportation services with healthcare services & providers	Older adults included in transportation planning process	Project developing capacity for same-day demand-response rides	Project promoting access to data to improve rider experience	Total		
Project Amistad	El Paso, TX		I				I		I		3	33%	Uses provider web portal and third-party data integration tools to streamline electronic data sharing between transportation providers and Texas Medicaid Healthcare Partnership
Community Transit of Western Community Action	Southwest MN		I						I		2	22%	Denials reduced, agency able to provide same-day booking for riders
No. Shenandoah Valley Public Mobility Program	Shenandoah Valley, VA		I				I		I		3	33%	Mobile data terminals allow use of smartcards so individuals can combine fixed-route and demand -response services to access essential services
FindMyRide	All PA	I	I	I			I		I	I	6	67%	Transportation options listed by schedule, time spent in transit, cost
TriMet	Portland, OR		I	I		I		I	I	I	6	67%	Tri-Met helped Google develop GTFS format and OpenTripPlanner initiative that serves older adults and people with disabilities by collecting and layering crowd-sourced data from Open StreetMap about quality of pedestrian infrastructure.

Key Characteristics of IoT Solutions % of Approaches & Characteristics Used	Information	IoT-Based Approaches Used											Notes
		A	B	C	D	E	Project directly connects transportation services with healthcare services & providers	Older adults included in transportation planning process	Project developing capacity for same-day demand-response rides	Project promoting access to data to improve rider experience	Total		
Ride Connection	Portland, OR		I			I	I	I	I	I	6	67%	Currently provides and maintains GTFS data for all services so service availability can be tracked using transportation applications. Also building open source clearing house for moving trips between demand-response dispatch systems to facilitate better coordination between regional organizations
Transportation Resource Information Point Program	Central MD		I	I					I		3	33%	Website, call center, and travel training programs now include transportation in all 23 MD counties
Cape Cod Regional Transit Authority	Cape Cod, MA	I	I	I						I	4	44%	Collaborated with Bridgewater State Univ. to develop Android, iPhone, and Windows phone apps that display same real-time planning and bus location information and features emergency button to connect passengers with cognitive disabilities or memory loss with caregivers and family members using geographic location and video
TransitScreen and Cambridge Council on Aging	Cambridge, MA		I	I				I	I	I	5	56%	Addresses digital divide by offering public real-time signage to give riders usable information available only on smartphone; City of Cambridge installed informational Transit Screens at three public buildings

Key Characteristics of IoT Solutions % of Approaches & Characteristics Used	Information	IoT-Based Approaches Used											Notes
		A	B	C	D	E	Project directly connects transportation services with healthcare services & providers	Older adults included in transportation planning process	Project developing capacity for same-day demand-response rides	Project promoting access to data to improve rider experience	Total		
mBike	College Park, MD	1		1	1					1	4	44%	GPS beacons allow users to see location of bicycles through website and smartphone app; users less comfortable with smartphone or web portals can send text message to reserve bicycle through system; either way, GPS technology will allow bikeshare operators to collect data related to preferred bicycle routes and travel time that will assist in back-end planning, travel forecasting, and determining where new stations would best serve consumers
Dallas Rapid Area Transit	Dallas, TX	1				1			1		3	33%	Provides subsidized on-demand transportation to riders that complements use of public transportation
Pinellas Suncoast Transit Authority	Pinellas Park, FL					1			1		2	22%	To serve individuals who do not use debit or credit cards, or smartphones, has included services by United Taxi, which offers on-demand booking app and ability to book through phone and pay in cash; contracted CareRide to offer $3 wheelchair-accessible trips, offer same-day rides with max. 2 hours advance notice; program offers diverse options to customers to ensure on-demand first mile/last mile solutions are available to a broad customer base

Key Characteristics of IoT Solutions % of Approaches & Characteristics Used	Information	IoT-Based Approaches Used											Notes
		A	B	C	D	E	Project directly connects transportation services with healthcare services & providers	Older adults included in transportation planning process	Project developing capacity for same-day demand-response rides	Project promoting access to data to improve rider experience	Total		
Southeastern Pennsylvania Transportation Authority	Philadelphia, PA					1			1		2	22%	Partnership will not cost SEPTA or Uber drivers any revenue directly; SEPTA will compensate Uber with marketing on SEPTA platforms to publicize partnership; could help older adults and persons with mobility challenges get to accessible rail services into city
Lift Hero	San Francisco, CA					1	1		1		3	33%	Concierge service available throughout state, allows individuals to schedule rides on other TNCs in advance and receive email, text, and call reminders; services are affordable - $1/mile and $25/hour for accompaniment and assistance or $4 and 2.9% of fare; Lift Hero works with senior living centers in area to offer reduced price rides that supplement center transportation

Key Characteristics of IoT Solutions % of Approaches & Characteristics Used	Information	IoT-Based Approaches Used											Notes
		A	B	C	D	E	Project directly connects transportation services with healthcare services & providers	Older adults included in transportation planning process	Project developing capacity for same-day demand-response rides	Project promoting access to data to improve rider experience	Total		
Liberty, Integrated Global Dimensions	Scottsbluff, NE	I		I		I	X		I		4	44%	Trip request algorithm allows individuals to book transportation same day or in advance, connects clients with closest drivers; can use low bandwidth signals to transfer data packets, allowing increased usability in rural contexts in comparison to other TNCs; travelers can book transportation via smartphone, phone call, Caregiver Platform, also accessible to human services agencies, medical organizations, etc.; will pursue technology allowing health care providers to book non-emergency medical transportation for appointments in environment that meets HIPPA guidelines/regulations
Accessible Dispatch	New Haven, CT; New York City	X				I			I		2	22%	Offers on-demand accessible taxis every day, all hours; IoT technology allows ride to be hailed via telephone, text, website, or Wheels on Wheels smartphone app without need for advanced reservation

Key Characteristics of IoT Solutions % of Approaches & Characteristics Used	Information	IoT-Based Approaches Used											Notes
		A	B	C	D	E	Project directly connects transportation services with healthcare services & providers	Older adults included in transportation planning process	Project developing capacity for same-day demand-response rides	Project promoting access to data to improve rider experience	Total		
Freedom in Motion	Gainesville, FL	1				1		1	1		4	44%	Program subsidizes rides on Uber in collaboration with ElderCare of Alachua County and Gainesville Area Chamber of Commerce; program extended to all older adults in Gainesville, includes technology tutorials and mobility manager through ElderCare that can procure smartphones for individuals in need
TOTALS		10	13	9	1	9	6	6	19	13			
% of case studies associated with above characteristics		42%	54%	38%	4%	38%	25%	25%	79%	54%			

*Information for case studies derived from interviews; in many cases, solutions may have evolved such that other characteristics will apply.
A = Smartphone and Tablet Application Development
B = Improving Demand Responsive Service through Automatic Vehicle Locator Technology
C = Open Data and Software Initiatives
D = Accessible Bikeshare
E = Transportation Network Companies

APPENDIX

B

Glossary of Key Non-transportation Terms

Citizen/Community Experience (CX) Research – the application of human-centered usability and UX research principles to improve the public experience of projects, programs, and portals funded or created by governmental entities.

Community-Based Participatory Research (CBPR) – a collaborative approach to research that seeks to equitably involve all partners in the research design, implementation, and evaluation process. CBPR begins with a topic of importance to a community as identified by a community and seeks to combine knowledge with action and application and improve the lives of community members involved.

Ethnography – research and description of cultural experiences based on participant observation and in-depth interviews, most commonly used in the social sciences and product/web design fields.

Gamification – As noted in an article on transportation gamification, "Wikipedia defines gamification as the use of game thinking and game mechanics in non-game contexts to engage users in solving problems." For more information on gamification in transportation and examples, see the Mobility Lab Article at http://mobilitylab.org/2014/06/17/gamification-technology-and-improving-transit-rider-satisfaction/, retrieved July 27, 2016.

Iterative Design Process – a cyclical design methodology based on prototyping, testing in the field, analyzing, and refining a process, project, or product. Design improvements are based on results of testing the most recent iteration of that item.

User Experience (UX) Research – research that focuses on understanding user behaviors, needs, and motivations through observation techniques, task analysis, and other methodologies. Although UX research is most typically associated with product, web, and app design, it currently is being applied more broadly outside of digital contexts.

APPENDIX

C

Big Data Collection, Management, and Analysis Techniques

The following list of big data techniques and technologies is excerpted from a McKinsey Global Institute report, "Big Data: The Next Frontier for Innovation, Competition, and Productivity," published in June 2011. This appendix also was reproduced in "Big Data's Implications for Transportation Operations: An Exploration," published by the Intelligent Transportation Systems Joint Program Office at the USDOT in December 2014. As of May 2016, the report was available at http://www.mckinsey.com/~/media/McKinsey/Business Functions/Business Technology/Our Insights/Big data The next frontier for innovation/MGI_big_data_full_report.ashx.

Techniques for Analyzing Big Data

There are many techniques that draw on disciplines such as statistics and computer science (particularly machine learning) that can be used to analyze datasets. In this section is a list of some categories of techniques applicable across a range of industries. This list is by no means exhaustive. Indeed, researchers continue to develop new techniques and improve on existing ones, particularly in response to the need to analyze new combinations of data. Of note is that not all of these techniques strictly require the use of big data; some can be applied effectively to smaller datasets (e.g., A/B testing, regression analysis). However, all techniques included here can be applied to big data, and, in general, larger and more diverse datasets can be used to generate more numerous and insightful results than smaller, less diverse ones.

A/B testing – a technique in which a control group is compared with a variety of test groups to determine what treatments (i.e., changes) will improve a given objective variable, e.g., marketing response rate. This technique is also known as split testing or bucket testing. An example application is determining what copy text, layouts, images, or colors will improve conversion rates on an e- commerce website. Big data enables huge numbers of tests to be executed and analyzed, ensuring that groups are of sufficient size to detect meaningful (i.e., statistically-significant) differences between the control and treatment groups (see Statistics). When more than one variable is simultaneously manipulated in the treatment, the multivariate generalization of this technique, which applies statistical modeling, often is called A/B/N testing.

Association rule learning – a set of techniques for discovering interesting relationships—"association rules"—among variables in large databases. These techniques consist of a variety of algorithms to generate and test possible rules. One application is market basket analysis, in which a retailer can determine which products are frequently bought together and use this information for marketing (a commonly-cited example is the discovery that many supermarket shoppers who buy diapers also tend to buy beer). Used for data mining.

Classification – a set of techniques to identify the categories in which new data points belong, based on a training set containing data points that already have been categorized. One application is the prediction of segment-specific customer behavior (e.g., buying decisions, churn rate, consumption rate) where there is a clear hypothesis or objective outcome. These techniques often are described as supervised learning because of the existence of a training set; they stand in contrast to cluster analysis, a type of unsupervised learning. Used for data mining.

Cluster analysis – statistical method for classifying objects that splits a diverse group into smaller groups of similar objects whose characteristics of similarity are not known in advance. An example of cluster analysis is segmenting consumers into self-similar groups for targeted marketing. This is a type of unsupervised learning because training data are not used. This technique is in contrast to classification, a type of supervised learning. Used for data mining.

Crowdsourcing – a technique for collecting data submitted by a large group of people or community (i.e., a "crowd") through an open call, usually through networked media such as the web (Howe 2006). This is a type of mass collaboration and an instance of using Web 2.0 (Chui et al. 2009).

Data fusion and data integration – a set of techniques that integrate and analyze data from multiple sources to develop insights in ways that are more efficient and potentially more accurate than if they were developed by analyzing a single source of data. Signal processing techniques can be used to implement some types of data fusion. One example of an application is sensor data from the IoT being combined to develop an integrated perspective on the performance of a complex distributed system such as an oil refinery. Data from social media, analyzed by natural language processing, can be combined with real-time sales data to determine what effect a marketing campaign is having on customer sentiment and purchasing behavior.

Data mining – a set of techniques to extract patterns from large datasets by combining methods from statistics and machine learning with database management. These techniques include association rule learning, cluster analysis, classification, and regression. Applications include mining customer data to determine segments most likely to respond to an offer, mining human resources data to identify characteristics of most successful employees, or market basket analysis to model the purchase behavior of customers.

Ensemble learning – using multiple predictive models (each developed using statistics and/or machine learning) to obtain better predictive performance than could be obtained from any of the constituent models. This is a type of supervised learning.

Genetic algorithms – a technique used for optimization that is inspired by the process of natural evolution or "survival of the fittest." In this technique, potential solutions are encoded as "chromosomes" that can combine and mutate. These individual chromosomes are selected for survival within a modeled "environment" that determines the fitness or performance of each individual in the population. Often described as a type of "evolutionary algorithm," these algorithms are well-suited for solving nonlinear problems. Examples of applications include improving job scheduling in manufacturing and optimizing the performance of an investment portfolio.

Machine learning – a subspecialty of computer science (within a field historically called "artificial intelligence") concerned with the design and development of algorithms that allow computers to evolve behaviors based on empirical data. A major focus of machine learning research is to automatically learn to recognize complex patterns and make intelligent decisions based on data. Natural language processing is an example of machine learning.

Natural language processing (NLP) – a set of techniques from a subspecialty of computer science (within a field historically called "artificial intelligence") and linguistics that uses computer algorithms to analyze human (natural) language. Many NLP techniques are types of machine learning. One application of NLP is using sentiment analysis on social media to determine how prospective customers are reacting to a branding campaign.

Neural networks – computational models, inspired by the structure and workings of biological neural networks (i.e., the cells and connections within a brain) that find patterns in data. Neural networks are well-suited for finding nonlinear patterns and can be used for pattern recognition and optimization. Some neural network applications involve supervised learning and others involve unsupervised learning. Examples of applications include identifying high-value customers that are at risk of leaving a particular company and identifying fraudulent insurance claims.

Network analysis – a set of techniques used to characterize relationships among discrete nodes in a graph or a network. In social network analysis, connections between individuals in a community or organization are analyzed, e.g., how information travels or who has the most influence over whom.

Examples of applications include identifying key opinion leaders to target for marketing and identifying bottlenecks in enterprise information flows.

Optimization – a portfolio of numerical techniques used to redesign complex systems and processes to improve their performance according to one or more objective measures (e.g., cost, speed, reliability). Examples of applications include improving operational processes such as scheduling, routing, and floor layout and making strategic decisions such as product range strategy, linked investment analysis, and R&D portfolio strategy. Genetic algorithms are an example of an optimization technique.

Pattern recognition – a set of machine learning techniques that assigns some sort of output value (or label) to a given input value (or instance) according to a specific algorithm. Classification techniques are an example.

Predictive modeling – a set of techniques in which a mathematical model is created or chosen to best predict the probability of an outcome. An example of an application in customer relationship management is the use of predictive models to estimate the likelihood that a customer will "churn" (i.e., change providers) or the likelihood that a customer can be cross-sold another product. Regression is one example of the many predictive modeling techniques.

Regression – a set of statistical techniques to determine how the value of the dependent variable changes when one or more independent variables are modified. Often used for forecasting or prediction. Examples of applications include forecasting sales volumes based on various market and economic variables or determining what measurable manufacturing parameters most influence customer satisfaction. Used for data mining.

Sentiment analysis - application of natural language processing and other analytic techniques to identify and extract subjective information from source text material. Key aspects of these analyses include identifying the feature, aspect, or product about which a sentiment is being expressed and determining the type, "polarity" (i.e., positive, negative, or neutral) and the degree and strength of the sentiment. Examples of applications include companies applying sentiment analysis to analyze social media (e.g., blogs, microblogs, and social networks) to determine how different customer segments and stakeholders are reacting to their products and actions.

Signal processing – a set of techniques from electrical engineering and applied mathematics originally developed to analyze discrete and continuous signals, i.e., representations of analog physical quantities (even if represented digitally) such as radio signals, sounds, and images. This category includes techniques from signal detection theory, which quantifies the ability to discern between signal and noise. Sample applications include modeling for time series analysis or implementing data fusion to determine a more precise reading by combining data from a set of less precise data sources (i.e., extracting the signal from the noise).

Spatial analysis – a set of techniques, some applied from statistics, that analyze the topological, geometric, or geographic properties encoded in a data set. Often, the data for spatial analysis come from geographic information systems (GIS) that capture data including location information such as addresses or latitude/longitude coordinates. Examples of applications include the incorporation of spatial data into spatial regressions (e.g., how is consumer willingness to purchase a product correlated with location?) or simulations (e.g., how would a manufacturing supply chain network perform with sites in different locations?).

Statistics – the science of the collection, organization, and interpretation of data, including the design of surveys and experiments. Statistical techniques often are used to make judgments about what relationships between variables could have occurred by chance (the "null hypothesis") and what relationships between variables likely result from some kind of underlying causal relationship (i.e., that are "statistically significant"). Statistical techniques also are used to reduce the likelihood of Type I errors ("false positives") and Type II errors ("false negatives"). An example of an application is A/B testing to determine what types of marketing material will most increase revenue (Ghemawat et al. 2003).

Supervised learning – the set of machine learning techniques that infer a function or relationship from a set of training data. Examples include classification and support vector machines. This is different from unsupervised learning (Cortes and Vapnik 1995).

Simulation – modeling the behavior of complex systems, often used for forecasting, predicting, and scenario planning. Monte Carlo simulations, for example, are a class of algorithms that rely on repeated random sampling, i.e., running thousands of simulations, each based on different assumptions. The result is a histogram that gives a probability distribution of outcomes. One application is assessing the likelihood of meeting financial targets given uncertainties about the success of various initiatives.

Time series analysis – a set of techniques from both statistics and signal processing for analyzing sequences of data points, representing values at successive times, to extract meaningful characteristics from the data. Examples include the hourly value of a stock market index or the number of patients diagnosed with a given condition every day. Time series forecasting is the use of a model to predict future values of a time series based on known past values of the same or other series. Some of these techniques, such as structural modeling, decompose a series into trend, seasonal, and residual components, which can be useful for identifying cyclical patterns in the data. Examples of applications include forecasting sales figures, or predicting the number of people who will be diagnosed with an infectious disease.

Unsupervised learning – a set of machine learning techniques that finds hidden structure in unlabeled data. Cluster analysis is an example of unsupervised learning (in contrast to supervised learning).

Visualization – techniques used for creating images, diagrams, or animations to communicate, understand, and improve the results of big data analyses.

Big Data Technologies

An ever-increasing number of technologies exist to aggregate, manipulate, manage, and analyze big data. Following are of the more prominent technologies, but this list is not exhaustive, especially as more technologies continue to be developed to support big data techniques.

Big Table – proprietary distributed database system built on the Google File System. Inspiration for HBase.

Business intelligence (BI) – a type of application software designed to report, analyze, and present data. BI tools often are used to read data that have been previously stored in a data warehouse or data mart. BI tools can also be used to create standard reports that are generated on a periodic basis or to display information on real-time management dashboards, i.e., integrated displays of metrics that measure the performance of a system.

Cassandra – an open source (free) database management system designed to handle huge amounts of data on a distributed system. This system was originally developed at Facebook and is now managed as a project of the Apache Software foundation.

Cloud computing – a computing paradigm in which highly-scalable computing resources, often configured as a distributed system, are provided as a service through a network.

Data mart – subset of a data warehouse, used to provide data to users usually through business intelligence tools.

Data warehouse – specialized database optimized for reporting, often used for storing large amounts of structured data. Data are uploaded using ETL (extract, transform, and load) tools from operational data stores, and reports often are generated using business intelligence tools.

Distributed system – multiple computers, communicating through a network, used to solve a common computational problem. The problem is divided into multiple tasks, each of which is solved by one or more computers working in parallel. Benefits of distributed systems include higher performance at a lower cost (because a cluster of lower-end computers can be less expensive than a single higher-end computer), higher reliability (because of a lack of a single point of failure), and more scalability (because increasing the power of a distributed system can be accomplished by simply adding more nodes rather than completely replacing a central computer).

Dynamo – proprietary distributed data storage system developed by Amazon.

Extract, transform, and load (ETL) – software tools used to extract data from outside sources, transform them to fit operational needs, and load them into a database or data warehouse.

Google File System – proprietary distributed file system developed by Google; part of the inspiration for Hadoop.

Hadoop – an open source (free) software framework for processing huge datasets on certain kinds of problems on a distributed system. Its development was inspired by Google's MapReduce and Google File System. It was originally developed at Yahoo! and is now managed as a project of the Apache Software Foundation.

HBase – an open source (free), distributed, non-relational database modeled on Google's Big Table. Originally developed by Powerset, it is now managed as a project of the Apache Software foundation as part of the Hadoop.

MapReduce – a software framework introduced by Google for processing huge datasets on certain kinds of problems on a distributed system (Dean & Ghemawat 2004). Also implemented in Hadoop.

Mashup – an application that uses and combines data presentation or functionality from two or more sources to create new services. These applications often are made available on the web and frequently use data accessed through open application programming interfaces or from open data sources.

Metadata – data that describe the content and context of data files, such as means of creation, purpose, time and date of creation, and author.

Non-relational database – a database that does not store data in tables (rows and columns), in contrast to relational database.

R – an open source (free) programming language and software environment for statistical computing and graphics. The R language has become a de facto standard among statisticians for developing statistical software and is widely used for statistical software development and data analysis. R is part of the GNU Project, a collaboration that supports open source projects.

Relational database – a database made up of a collection of tables (relations), i.e., data are stored in rows and columns. Relational database management systems (RDBMS) store a type of structured data. SQL is the most widely-used language for managing relational databases (see below).

Semi-structured data – data that do not conform to fixed fields but contain tags and other markers to separate data elements. Examples of semi-structured data include XML or HTML- tagged text. Contrast with structured data and unstructured data.

SQL – originally an acronym for "structured query language," SQL is a computer language designed for managing data in relational databases. This technique includes the ability to insert, query, update, and delete data, as well as manage data schema (database structures) and control access to data in the database.

Stream processing – technologies designed to process large real-time streams of event data. Stream processing enables applications such as algorithmic trading in financial services, RFID event processing applications, fraud detection, process monitoring, and location-based services in telecommunications. Also known as event stream processing.

Structured data – data that reside in fixed fields. Examples of structured data include relational databases or data in spreadsheets. Contrasted with semi-structured data and unstructured data.

Unstructured data – data that do not reside in fixed fields. Examples include free-form text (such as books, articles, bodies of e-mail messages), untagged audio, image and video data. Contrasted with structured data and semi-structured data.

Visualization – technologies used for creating images, diagrams, or animations to communicate a message that are often used to synthesize the results of big data analyses.

Acronyms and Abbreviations

ADA	American with Disabilities Act
APTA	American Public Transportation Association
AVL	Automatic Vehicle Location
CPS	Cyber-Physical Systems
FAST	Fixing America's Surface Transportation Act
FTA	Federal Transit Administration
FTC	Federal Trade Commission
GTFS	General Transit Feed Specification
IADL	Instrumental Activities of Daily Living
ICT	Information and Communications Technology
IoT	Internet of Things
ITS	Intelligent Transportation Systems
MSAA	Mobility Services for All Americans
NEMT	Non-Emergency Medical Transportation
NIST	National Institute of Standards and Technology
NOFO	Notice of Funding Opportunity
PHI	Protected Health Information
PII	Personally Identifiable Information
SPII	Sensitive Personally Identifiable Information
TMCC	Travel Management Coordination Centers
TCRP	Transit Cooperative Research Program
TNC	Transportation Network Company
TRIP	Transportation Resource Information Point
USDOT	U.S. Department of Transportation
WAV	Wheelchair Accessible Vehicle

U.S. Department of Transportation
Federal Transit Administration

U.S. Department of Transportation
Federal Transit Administration
East Building
1200 New Jersey Avenue, SE
Washington, DC 20590
http://www.fta.dot.gov/research