Assessing Changes in Travel Behavior Data Collection

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FOREWORD

Travel behavior data programs in the United States have evolved significantly in response to recent technological advances. In particular, the move to smaller, more frequent data collection efforts combined with data obtained through passive data sources have changed the data landscape and provided new opportunities to the transportation policy and planning programs reliant on that data. The purpose of this report is to summarize recent changes in data collection methods and approaches, assess the implications of such changes and discuss the Federal and State privacy laws and regulations as related to travel behavior data collection.

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16. Abstract This report summarizes recent advances in the collection and compilation of travel behavior data, the implications and opportunities associated with these changes, and the Federal and State rules and regulations regarding privacy that might impact future programs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		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
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ABS	address-based sampling
B2C	business to consumer
CCPA	*California Consumer Privacy Act*
DAA	Digital Advertising Alliance
EAR	Exploratory Advanced Research
EU	European Union
FHWA	Federal Highway Administration
FISMA	*Federal Information Security Modernization Act*
GDPR	General Data Protection Regulation
GPS	Global Positioning System
IAB	Internet Advertising Bureau
MAG	Maricopa Association of Governments
MMA	Mobile Marketing Association
MPO	metropolitan planning organization
MTI	Maryland Transportation Institute
NAI	Network Advertising Initiative
NHTS	National Household Travel Survey
NIST	National Institute of Standards and Technology
O-D	origin-destination
ODOT	Ohio Department of Transportation
PSRC	Puget Sound Regional Council
SANDAG	San Diego Association of Governments
SCDOT	South Carolina Department of Transportation
TNC	transportation network company
TRB	Transportation Research Board

CHAPTER 1. INTRODUCTION

The past decade has been one of significant change and evolution in technology, resulting in advances in survey methods, data collection technologies, and the emergence of new data sources. The net gain has been new opportunities and challenges for travel behavior data collection techniques. These opportunities and challenges include improvements and refinement in survey sampling and data collection technologies, the acceptance of the use of passive data in lieu of survey data to answer important transportation planning and policy questions, and the emergence of new legislation to guard citizens' privacy.

These technological advances and new data opportunities come at a time when survey research in general is rapidly adapting to address a changing society. Prior to the 1970s, most surveys were conducted in person. With the widespread adoption of in-home telephones in the 1970s, surveys followed that technology shift and became primarily phone-administered. The introduction and adoption of computers and the Internet led to today's multimodal survey environment that leverages mail, phone, and web survey options with a resurgence of in-person surveying and outreach to encourage participation among hard-to-reach populations that otherwise would not participate in surveys. While significant advances have been made in survey research resulting in higher-quality data available almost in real time, most survey programs still face rising costs, declining response rates, and coverage bias in the form of missing subsets of the population.

This report provides an assessment of changes in travel behavior data collection through an examination of the state of the practice in household travel surveys as well as by providing examples of where passive data are being used as a substitute for the survey data. The report structure is as follows:

- **Chapter 1. Introduction:** Provides a summary of the report contents.
- **Chapter 2. Household Travel Survey State of the Practice:** Summarizes current household travel survey methods for collecting travel behavior data.
- **Chapter 3. Passive Data Alternatives:** Provides examples of where passive data are being used in lieu of survey data.
- **Chapter 4. Privacy Laws and Regulations:** Presents an overview of privacy laws and regulations as they relate to travel behavior data collection.
- **Chapter 5. Opportunities and Implications:** Identifies areas for consideration in moving the travel behavior data collection practice forward.

CHAPTER 2. HOUSEHOLD TRAVEL SURVEY STATE OF THE PRACTICE

Advances in technology have changed the landscape of transportation policy and planning efforts and have increased the importance of access to real-time accurate travel behavior data. The rapid emergence of new travel modes, such as ride-hailing, dockless scooters, and autonomous vehicles, has put considerable strain on existing household travel survey programs to provide more current data to capture behavior and document usage of these new modes. As a result, some agencies are researching the best ways to migrate their current decennial survey programs to smaller, nimbler annual or biennial efforts.

This chapter provides an overview of changes in the technological landscape as it relates to survey research, followed by specific advances in the survey research industry enabled by or in response to societal changes resulting from those technology shifts. This is followed by an update on the state of the practice in household travel surveys, which both summarizes the changes and provides a few examples of where agencies have implemented these changes.

TRENDS AND INFLUENCES

The past decade has seen significant advancements in technologies, particularly those resulting in new mobility options. The following four specific advancements are frequently cited among policy and planning priorities and are anticipated to impact personal travel behavior:

- **Mobility as a service:** According to the University of Michigan Transportation Research Institute, "Mobility-as-a-service represents a paradigm shift in personal transportation and the transportation industry at the same time. Among other things, it enables the user to access, integrate and pay for a diverse range of transportation modes and services (both public and private) through a common information and payment platform. Just like your phone package includes text, data, email, and calls, your mobility package could include rail, bus, automated car share, bike share and ferry rides that are seamlessly connected."(1) Many household travel surveys include questions regarding the cost of each trip (for use in price-sensitivity tests as a part of model development). The integration of payment across these transportation options makes this particular data element more difficult, if not impossible, to capture as respondents may not be able to separate out the individual fares paid.

- **Shared mobility:** "Shared mobility is the shared use of a vehicle, motorcycle, scooter, bicycle, or other travel mode. Shared mobility provides users with short-term access to one of these modes of travel as they are needed."(2) Examples of shared mobility include bikesharing, carsharing, ridesharing, ridesourcing, and scooter sharing. The measure and analysis of shared mobility is a priority for many agencies, from both a planning and a policy perspective. While there is a lot of interest in these new travel modes, the reality is that their incidence of use is small and not offered uniformly across all regions or within a region across that study area. A focused sampling approach is needed to capture sufficient users/trips to properly assess these growing markets.

- **Business-to-consumer (B2C) deliveries:** From 2013 to 2018, B2C deliveries grew from 1.24 percent of the U.S. gross domestic product to 1.96 percent.[(3)] Accenture forecasts that B2C deliveries will quickly outpace traditional business-to-business deliveries given the growth of the digital consumer market.[(4)] This trend impacts household travel surveys in two ways. First, researchers are increasingly including a battery of questions within household travel surveys to measure B2C deliveries. Second, in order to determine the impact of the home deliveries on travel, the survey should include questions to get at induced demand: whether the delivered item represents a shopping trip not made or if that foregone shopping trip then was replaced with another type of trip (neither of which are concepts easy to word or convey to the general public).

- **Autonomous and connected vehicles:** The impact of vehicle automation on society was listed as one of the top 10 critical issues identified by the Transportation Research Board (TRB) in its 2019 report, *Critical Issues in Transportation 2019: Policy Snapshot*.[(5)] According to TRB, "driverless vehicles equipped with artificial intelligence may revolutionize transportation." Today's household travel surveys provide a space to capture attitudes and future purchase probabilities, to fuse with market forecast data for this emerging technology.

In addition to these advances, the past decade has also experienced a blurring of the line traditionally drawn between personal and commercial travel with ridesourcing (e.g., Uber and Lyft) bursting on to the scene and food delivery services now available in many cities. Whereas past surveys instructed respondents to not record any type of commercial travel, that same instruction would create significant data gaps for today's gig workers.

Understanding and capturing these rapidly evolving mobility opportunities require more frequent data than that captured through once-a-decade surveys. In addition to the increased interest in conducting household travel surveys more frequently, other evolutions include the use of multimodal surveys, the use of enhanced sampling frames, the introduction of probability-based panel studies, and further refinements in survey methods to enhance participation rates. These topics are explored more in the next section of this chapter.

STATE OF THE PRACTICE IN HOUSEHOLD TRAVEL SURVEYS

The methods used to conduct household travel surveys today range from the traditional one-day diary to multi-day smartphone Global Positioning System (GPS) surveys. The decision of which survey method to employ depends largely on the agency objectives, budget available, and survey contractor offerings. In this section, the state of practice with respect to household travel surveys is explored, with a focus on the migration to more frequent data collection cycles and the incorporation of enhanced address-based samples, multimodal survey designs, and the opportunities presented with the use of probability-based panel samples.

More Frequent Data Collection Cycles

Coinciding with the update of long-range transportation plans and related travel demand models, household travel surveys have historically been conducted roughly every 8 to 15 years. Some agencies continue to collect data on this cycle. For other agencies, the cost of these large-scale infrequent efforts required significant staff time to secure the funds and get up to speed with advances in survey practice in the time since the last survey. This led them to conduct smaller sample surveys more frequently. Examples include the Ohio Department of Transportation (ODOT), the Puget Sound Regional Council (PSRC), and the National Household Travel Survey (NHTS).

In 2015, ODOT launched a 10-year smartphone-based survey effort.[6] This study was based on an address-based sampling (ABS) frame, with the State divided in survey zones such that over the 10-year period, each zone would be surveyed (summing to a statewide survey database at the end of the 10 years). The design calls for 2,000 to 2,500 households to be surveyed each year. Households are encouraged to report 7 days of travel data using a smartphone GPS application or "app." Travel for those under the age of 16 are obtained by proxy.

In lieu of an annual survey, PSRC designed a 6-year survey program that collects data every other year.[7] The survey builds on a 2006 effort, with a pilot in 2014 and full survey data collected in 2017 and 2019 and the final wave planned for 2021 (contingent on funding). The 2017 survey included a mix of diary and smartphone GPS surveys, with the proportion of smartphone GPS surveys increased in 2019.

Perhaps the longest running travel survey, NHTS has been conducted every 5 to 8 years since 1969. Traditionally, NHTS has collected a national sample of approximately 25,000 households each cycle, with a significant number of additional surveys purchased by agencies through a pooled fund effort. In 2018, the Federal Highway Administration (FHWA) announced a new pooled fund effort to support the Next Generation NHTS.[8] Moving forward, FHWA plans to conduct NHTS as a smaller survey (that is, a smaller sample size and fewer questions asked) on a more frequent basis. FHWA plans to complement NHTS with a second data product of national origin-destination (O-D) flows based on passively generated data.

There are several benefits to conducting surveys more regularly. First, more frequent surveys allow agencies to measure the trends of emerging transportation options on a more regular basis. Second, the scaled-back survey questions decrease respondent burden, which will increase the response rate. Third, a higher response rate leads to a more cost-effective survey administration.

Multimodal Surveys

Prior to the 1970s, most surveys in the United States were conducted in person or by mail. As telephone ownership became more prevalent, surveys were then administered largely by telephone, first with responses recorded by paper and pencil then through computer-assisted telephone interviewing (CATI). With the advent and wide-scale acceptance of the Internet, the move to web-based surveys led to an increase in the use of multimodal surveys, which remain the state of the practice today. Multimodal surveys provide a variety of ways to respond to the survey (e.g., internet, mail, phone), with the results fed into the same master database.

Increasingly, household travel surveys today offer mail, phone, and web options but seek to collect travel behavior data through the use of a smartphone GPS app. Proprietary smartphone apps include the ability for answering questions (the same asked via mail, phone, and web survey options) but have the added component of prompting for verification and details regarding each stop detected in the GPS data streams from the participant's smartphone. These apps are thought to reduce respondent burden through the passive collection and detection of movements, with an algorithm to identify stops as possible trip ends.

The first large-scale smartphone-based survey in the U.S. was conducted by the Maricopa Association of Governments (MAG) in the Phoenix, AZ, metropolitan area.[(9)] This 2016–2017 survey of 7,000 households included non-traditional recruitment methods to improve participation among households with children and boost response rates among certain areas of the region. The survey included recruitment by mail and phone and collection and validation of travel data via the app. It also offered a paper diary option for those unable or unwilling to complete the survey by phone.

The San Diego Association of Governments (SANDAG) conducted a smartphone-based household travel survey at the same time as MAG.[(10,11)] This survey of 6,199 regional households included a multi-mode design that contained mail, phone, and web recruitment, with a smartphone app to collect week-long travel behavior movement/trips and offered a one-day diary for those respondents who did not have a smartphone available to them. Survey reminders were sent by mail, email, telephone, and within the app itself for the smartphone users.

Enhanced Sampling Frames

In an effort to mitigate non-response bias associated with telephone ownership patterns, household travel surveys began using ABS frames in the mid-2000s. At that time and still today, the source of the randomly sampled residential addresses is the U.S. Postal Service delivery sequence file. Early ABS frames were largely limited to the address and possibly the name of the resident, with the telephone number appended if that number was listed in the telephone directory. Over time, these ABS frames have evolved to include not only the name and landline phone number, but also cell phone numbers and email addresses associated with that address for a subset of records. Demographics are appended based on home location and proprietary techniques that mine consumer data to identify key household member demographics and attitudes.

The SANDAG effort utilized an ABS enhanced sample with door-to-door outreach to minority and low-income individuals.[(10)] This outreach was conducted by community-based organizations who partnered with SANDAG on the effort, with the community-based organizations providing a small stipend. The outreach was made to addresses from the original sampling frame where the census data for those areas matched those of the under-performing population groups. The in-person contact was found to improve response rates (as compared to areas of similar demographic composition that did not receive outreach visits). By focusing this effort on addresses that had been randomly sampled, the study was able to maintain its probability-based sample status.

In year 2 of the ODOT effort (introduced previously), ODOT tested the accuracy of enhancing its survey sample with income. The cost for adding estimated income to the sample was relatively low (1 cent per record). Testing showed that while the estimated income was not always a direct match, oversampling households at the lower income ranges did yield an increase in the ability to reach the lower income households.

Probability-Based Panel Studies

Given issues with response rates and non-response bias, the mainstream survey industry began to implement probability-based panel studies. These panels are comprised of individuals who were randomly sampled and offer the benefit of providing actual demographics prior to each survey being implemented across the panel. This allows for within-panel over- and under-sampling based on known participation levels for specific demographic groups, which has the statistical benefit of reduced error (and thus smaller post-collection weights needed). Two examples of these probability-based panels include the following:

- Ipsos' KnowledgePanel is a probability-based online panel with about 55,000 panelists or "members."(12) The sample is comprised of a random ABS sample and was drawn to match U.S. population parameters but is calibrated as needed to ensure a representative sample for each study. Households without Internet access are provided the necessary technology to participate in online data collection activities.

- The National Opinion Research Center's (NORC) AmeriSpeak is also a representative probability-based panel sample drawn from a national sampling frame that is based on the U.S. Postal Service delivery sequence file and enhanced to capture residences not included in the base file.(13) Households are recruited by phone, mail, and in person. This in-person recruitment improves the inclusion rates for young adults, lower income households, non-Internet, and other hard-to-reach populations.

These probability-based panel samples provide a new opportunity for agencies conducting travel surveys. Combined with the increasing trend to conduct smaller sample surveys more frequently, the cost-effective nature of the more streamlined survey questions, and enhanced sampling frames, it is possible to see the costs for household travel surveys either remaining steady or decreasing.

CHAPTER 3. PASSIVE DATA ALTERNATIVES

Billions of location data points are generated each day from mobile devices in the United States. These include cell phone record data with mobile-signal derived geographic locations, GPS location data from GPS sensors in navigators, phones and in-vehicle systems, and smartphone app location-based service data from positioning technologies in smartphones. In the past decade, mobile device location data have become available through various data providers for transportation planning and operations because they possess significant advantages over traditional data sources for travel monitoring and analysis (e.g., household travel surveys and O-D tables estimated from link-based counts).

Notable features of mobile device location data are continuous tracking, large sample size, and passive data collection without active user engagement (which translates into lower respondent burden). Typically, mobile device location data records contain latitude and longitude coordinates, time stamps, and additional information, such as heading, accuracy, acceleration rate, and environmental readings. Certain trip and traveler information (e.g., activity locations and trip ends, travel mode, purpose, and the socio-economic and demographical characteristics of travelers) is not directly available from raw mobile device location data but can be imputed with data fusion, statistical, and machine-learning methods.

It is also well known that the distribution of mobile device owners within any one passive data set is often biased and does not represent the underlying population distribution, which should be corrected using appropriate weighting schemes. Only a subset of the population in any geographical analysis unit owns a specific type of mobile device with service from a particular carrier, and on any given day, the number of sightings for each mobile device varies, influencing data quality and representativeness. Other noteworthy issues with mobile device data include different data availability and resolution in urban and rural areas, and data suppression due to privacy concerns and regulation.

The emergence of mobile device location data represents both an exciting development with great potential and many new challenges for researchers and practitioners. The aforementioned issues must be adequately addressed before applications in transportation policy decisionmaking, planning, and operations can become mainstream. This chapter summarizes current applications of mobile device location data where the data are used as alternatives to household travel survey data.

O-D TABLES

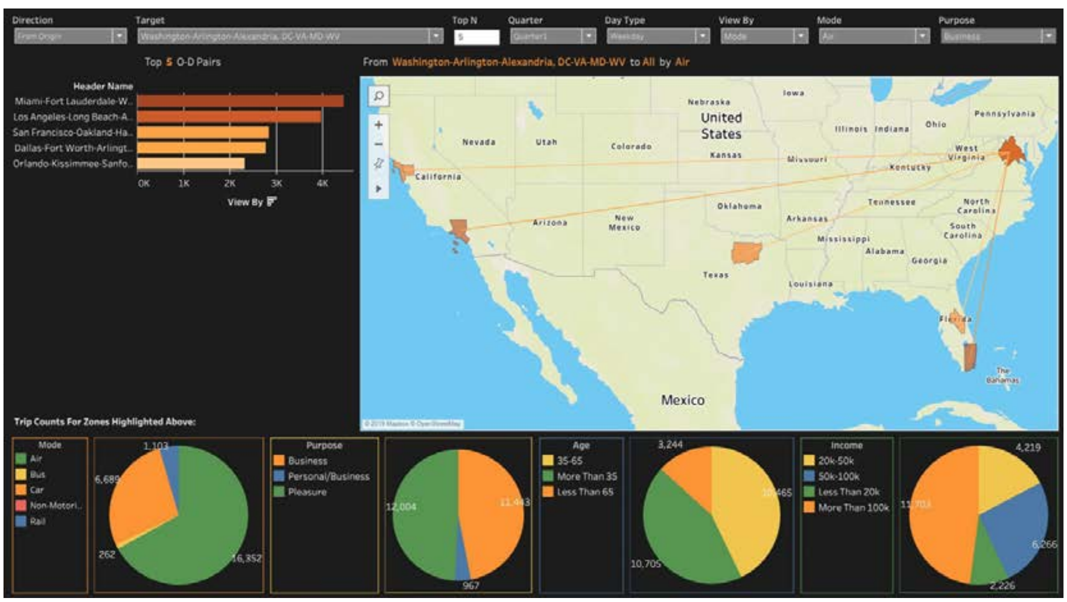
Mobile device O-D data products fill an important travel data gap, namely the lack of timely O-D information. Furthermore, many agencies and State transportation departments are using O-D tables produced from mobile device location data to analyze external-to-external, external-to-internal, and internal-to-external trips. This type of data was traditionally documented using household travel surveys and external station or cordon line surveys.

Among the O-D products, some include attributes such as day part segmentation, resident/visitor classification, short-/long-distance trip attributes, home/work classification, trip purpose, socio-demographic information, and travel mode. The applications of O-D products include understanding general travel patterns, monitoring travel trends, updating and validating travel demand models, and capturing external trips.

Use Case Example: 2017 FHWA Project[(14)]

In this Exploratory Advanced Research (EAR) project sponsored by FHWA, the research team at the University of Maryland's Maryland Transportation Institute (MTI) explored the modeling methods for tracking and predicting O-D travel trends based on mobile device location data. The challenges and potentials of all three major sources of mobile device data (cell phone, GPS, and smartphone apps) in developing O-D tables were studied. The team took advantage of mobile device data's large sample size, continuous observations, and significant temporal and geographical coverage to revolutionize the field of O-D trend analysis.

As the data do not include important individual- and trip-level features, the MTI team developed advanced machine learning algorithms, such as wide and deep neural network and random forest, to identify trips; impute important attributes, such as travel mode, trip purpose, and traveler socio-demographic characteristics; and expand the sample data to the population. The MTI team collaborated with various data providers and fed their data into the developed algorithms to produce O-D tables at both the national and metropolitan levels. A user interface was developed to allow users to analyze personal travel patterns (see figure 1).



Source: University of Maryland.

Figure 1. Screenshot. Data visualization dashboard developed for the FHWA EAR Mobile Device Location Data Project.

The team was able to produce O-D tables for person trips separated by travel mode, trip purpose, traveler socio-demographics, month of year, and time of day as well as O-D tables for truck travels separated by vehicle weight class, month of year, and time of day. Besides the national O-D products, the team also developed products for the Baltimore metropolitan area to showcase the capability of developing them for local agencies. The success of the project showed that the data are capable of capturing travel patterns for the use of agencies by producing the travel patterns from the data and validating them against ground-truth data.

Use Case Example: 2015 Texas A&M Transportation Institute Study[15]

The Texas A&M Transportation Institute conducted a study of external travel for the Capital Area Metropolitan Planning Organization using GPS data acquired from INRIX and cellular data acquired from AirSage for spring 2015. The Texas Department of Transportation acquired O-D data for that time, which were used to produce external-to-external, external-to-internal, and internal-to-external travel data for passenger vehicles and trucks. The main objective of this study was to use passively collected mobile device location data to develop travel O-D matrices of external trips for the regional travel demand model. The study also compared the results obtained from GPS data and the results obtained from cellular data.

NON-MOTORIZED STUDIES

Emerging data collection technologies promise new opportunities in non-motorized studies as they can provide massive amounts of multimodal travel information about a broad and diverse sample of the population with fewer time and resource constraints than traditional household travel surveys. The emerging data can be classified as passive data or active data, where active data requires users' active input and efforts and passive data requires no/little input. Various applications have been developed to collect this emerging data source for the evaluation of pedestrian and bicyclist demand and movements.

Use Case Example: *Exploring Bike Infrastructure Opportunities in Dallas*[16]

StreetLight Data prepared a report for Dallas, TX, officials to inform them about a StreetLight Data tool for evaluating bike infrastructure needs. The StreetLight Data team used their O-D data to understand the travel patterns of bicyclists in Dallas, TX, to help officials prioritize corridors for bike infrastructure. Their tool also allows decisionmakers to overlay demographic information and observe who uses a certain bike facility. The results can also be summarized by time of day to obtain the temporal demand of biking.

BUSINESS AND MARKETING ANALYTICS

The same mobile device location data collected by smartphone applications for use in household travel surveys can also be used to reveal valuable information about the current and potential customers of a business. Various advertisement and marketing companies utilize these data to design advertisement campaigns that can efficiently target relevant audiences. The contents and advertisements can be designed based on the user's current or previous locations. These efforts require users to opt in to share their locations. The location data are then used in real time to serve an advertisement or push notification or used later to create a historical audience or visitor data. The location data can show store visit, dwell time at store, store visit frequency, and store loyalty, among others, to better understand the consumer journey, improve current customer experience, and target future customers.

Use Case Example: Site Selection for Businesses Using INRIX Data[17]

INRIX uses location data to help business owners enhance their knowledge about customers and make accurate decisions about their store locations. Companies can pinpoint potential locations and analyze current profitability through a set of INRIX tools. Using real-time, historical, and predictive information, business owners can determine how many people pass each potential location by time, population group, and origin.

ACCESSIBILITY STUDIES AND LAST MILE ANALYSIS

Traditional data sources for accessibility studies are household travel surveys that often cover a very small percentage of the population and a single day of travel behavior. Mobile device location datasets include information about the travel behavior of a larger fraction of the population. Each mobile device, with consistent anonymized device IDs, leaves a digital location trace, formed by frequent location pins with time stamps. The collected location data can then be used to identify the mobility pattern and the activity space of each device. The numerous locations provided by each mobile device each day are sufficient for the identification of most trips and activity locations (e.g., food market, job location, and health care destinations). Recent advancements in machine learning and computing have offered reliable and affordable computational methods for the imputation of travel mode, trip purpose, and socio-economic characteristics of each trip identified from the mobile device location data. This innovation enables researchers to apply mobile device location data to study accessibility by different travel modes, residential communities, and income groups.

Last-mile analysis is another related application of the mobile device location data. “Last-mile” is a term used in supply chain management and transportation planning to describe the movement of people and goods from a transportation hub to a final destination. The mobile device location data can help better understand how people access/egress their main travel mode using observed location data and travel mode imputation. The insights generated from the mobility big data serve as a crucial indicator for improving the last-mile connections. Apart from that, the mobility big data are also used for urban last-mile delivery studies. The mobility big data can help delivery companies in identifying key customer behaviors to provide better delivery services.

Use Case Example: Study of Accessibility Equity Using Mobile Device Location Data[18]

In this research project, the MTI team studied the accessibility to basic lifeline opportunities, such as jobs, healthy food, and healthcare, among different population groups and neighborhoods in the Baltimore, MD, and Washington, DC, regions, with a focus on disadvantaged population groups and underserved communities. The study is the first of its kind in utilizing observed multimodal travel big data from individual mobile devices to systematically study accessibility for underserved population groups.

Anonymized passively collected mobile device location data used in this project revealed day-to-day travel patterns of more than 40 percent of the entire population in the entire Nation, including the Baltimore, MD, and Washington, DC, regions for an entire year. This data source with very high sampling rates, combined with point of interest data and census data, allowed the

MTI project team to analyze how residents in each socio-demographic group and in each neighborhood actually travel to work, purchase food, and seek health care services. Research findings directly identify accessibility gaps among various population groups and neighborhoods and, more importantly, identify feasible solutions to improve accessibility for disadvantaged population groups and underserved communities. Accessibility and equity measured from mobile device big data are compared with traditional measures. The product of this research project is an interactive data analytics and mapping toolbox that can be used to query these data-driven accessibility measures for improved understanding and decisionmaking.

Use Case Example: Connecting Sacramento Accessibility Study[(19)]

This study utilizes data sources, such as passively collected location data, to understand how useful such data sources are in informing transportation decision making and improving transportation issues, especially issues related to people's accessibility to existing transit. The study seeks to find ways to increase transit ridership. Light rail trip data fused from multiple data sources were used in this study to understand travelers travel pattern and accessibility to transit.

DEMOGRAPHIC ANALYSIS AND EQUITY STUDIES

Many transportation policies are targeted toward a specific population segment. The evaluation of such policies requires data about the movements of people belonging to that segment, which was traditionally collected through household travel surveys. However, surveys are costly to collect and limited in sample size. Census data tell us about the general pattern of human settlement and migration, but they rarely cover where people spend their time or where and how they travel. Interviews and surveys provide analysts with more details, but these are limited by scale and self-reporting errors and often do not provide a dynamic picture.

Data limitation has been an important obstacle in understanding population-related topics, such as immigration, urbanization, environmental impact of population growth, or spread of disease. Mobile device technology provides a solution to this problem. From the demographic perspective, mobile devices provide a new source of data to answer traditional questions while also presenting new ways to formulate and think about demographic questions. Studying the travel patterns of a certain population segment requires imputation of the socio-demographics. Statistical and machine-learning methods have helped researchers assign socio-demographic information to mobile devices through integration with census information.

Use Case Example: Analysis of Metro Ridership among Millennials in Washington, DC[(20)]

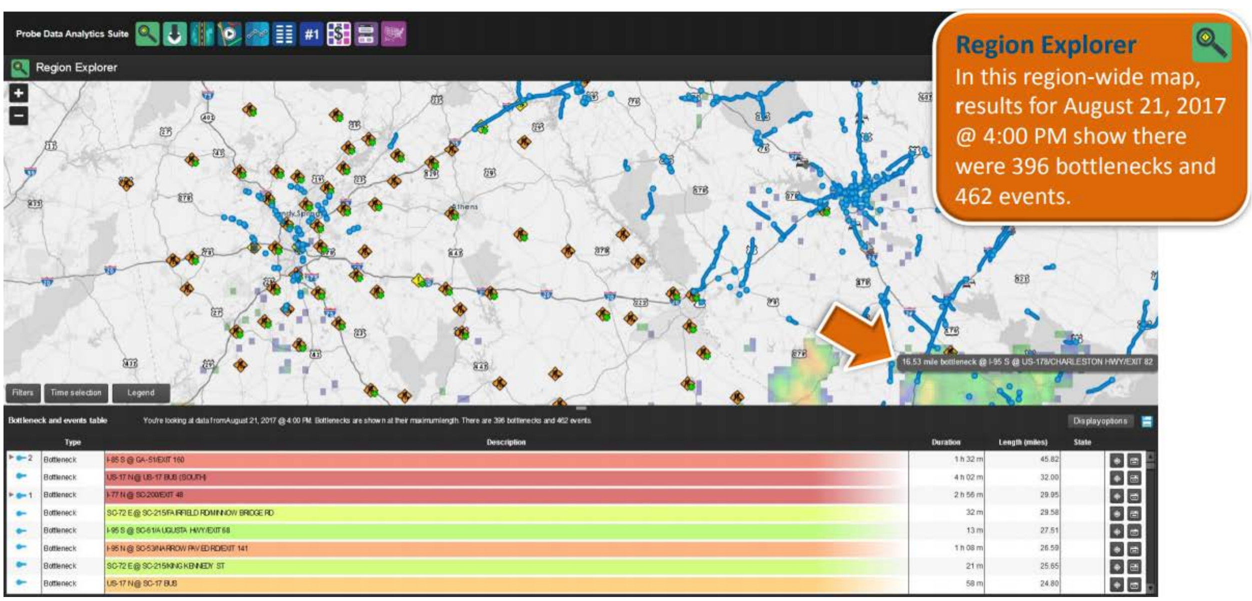
The Washington, DC Metro had a period of crisis after an emergency mid-week subway system-shut down in March 2016. The Washington Metropolitan Area Transit Authority made an effort to improve the reliability of Metro by making many improvements, which required multiple subway track closures. TERALYTICS analyzed 2 years of data to study Metro ridership and answer the question about which riders would come back to Metro after the improvements were completed. The analysis of weekday Metro users who lived or worked in the Washington, DC, area indicated that the younger people are less likely to return to Metro. The analysis of weekend data also showed similar results.

TARGET LOCATION/SPECIAL EVENT ANALYSIS

Mobile device location data can be filtered to study the travels to a specific geography or for a special event. Such data can help planners study travel patterns of visitors, separated by demographics to gain better insights about past experiences or events. Such data can also be used in real-time to manage and coordinate current events. The seasonality and continuity of the mobile device location data enable researchers to study the seasonal and temporal aspects of travel. The data can also be used to identify main population attractors and gain insights about their visitors.

Use Case Example: Study of 2017 Total Eclipse Using CATTLab's RITIS Platform[21]

The solar eclipse on August 21, 2017, inspired many people to travel to watch the full eclipse over specific areas of the U.S. South Carolina was among the States that experienced a full eclipse. The South Carolina Department of Transportation (SCDOT) expected a significant increase of travel, especially on their major corridors such as I-95, I-77, and I-26. SCDOT made a traffic management plan for the event. CATTLab conducted a before/after review for SCDOT to evaluate their performance in mitigating the congestion during the event. The RITIS Region Explorer tool was used to compare bottlenecks before and after the event (see figure 2). The tool was able to identify areas with the most bottlenecks. CATTLab also used the Congestion Scan tool on major corridors to compare the traffic speed of the eclipse days with the days before the eclipse using speed heatmaps. Other RITIS tools, such as Trend Map, Performance Chart, and User Delay Cost Analysis, were also used to create an animated map of changes, plot traffic metrics over the course of the event, and calculate the financial cost of the congestion caused by the eclipse.



Source: University of Maryland.

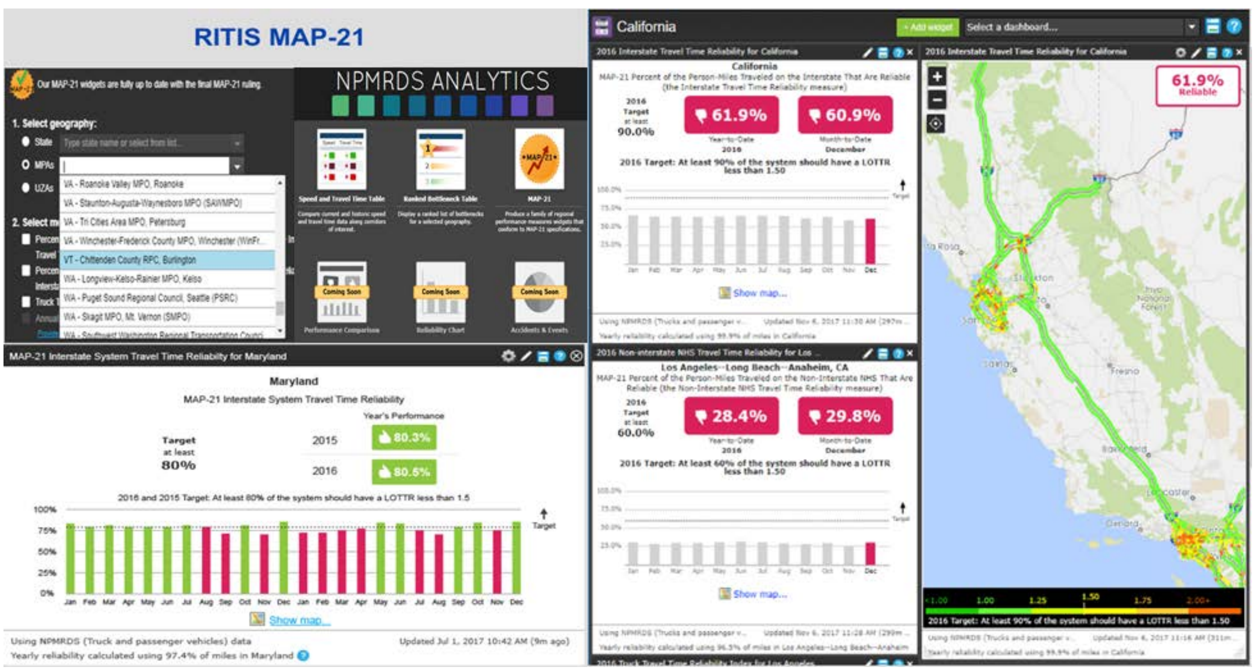
Figure 2. Screenshot. RITIS Region Explorer tool used to study the eclipse event.[21]

PERFORMANCE METRICS, MONITORING, AND MANAGEMENT

Most of the transportation network users carry at least one device that is continuously recording their location. These devices can act as probes for measuring speed, travel time, travel time reliability, and other performance measures. For instance, the consecutive observations of one device can be used to calculate the speed of the device at a given segment. The benefits of probe data over the traditional approaches include better continuity, larger temporal and spatial coverage, and lower cost. Mobile device location data can provide continuous networkwide performance measures without the installation and maintenance cost of typical detectors.

Use Case Example: MAP-21 Reporting Tools and the National Performance Management and Research Data Set (NPMRDS)(22)

The NPMRDS was created from probe data, commissioned by FHWA, and produced by CATTLab. It can be used by agencies free of charge to comply with the MAP-21 performance reporting requirements. The CATTLab tool includes capabilities to compute, visualize, and download the required performance metrics. The American Association of State Highway and Transportation Officials (AASHTO) awarded a contract to the team led by CATTLab to make the set of tools available to agencies through an AASHTO pooled fund study.



Source: University of Maryland.

Figure 3. Screenshot. RITIS Map-21 NPMRDS tool for performance reporting.(23)

TRANSPORTATION NETWORK COMPANIES (TNCS) AND OTHER EMERGING MODES

There are various applications of mobile device location data in shared mobility, including shared vehicles and ride-sourcing/ride-hailing. Emerging micro-mobility, such as scooters and dockless bikes, have been blending into our lives. It is necessary for agencies to enforce an appropriate set of rules for the micro-mobility to reach mobility, safety, equity, and environmental sustainability goals. Location data produced from the devices can help agencies in deciding how riders should park the devices and how they can ride safely. The collected data can also be used toward the design and management of parking zones, the regulation of people's riding speed, and the planning for integrating micro-mobility with current transit systems. Besides the micro-mobility, TNCs, such as Uber and Lyft, are also attracting a lot of travel demand. TNC vehicle locations are continuously being recorded by the navigation applications. These location data can help in understanding the TNC demand and market share. Even though data from TNCs are usually difficult to obtain, other location-based services data can provide an alternative to analyze the trips made by TNCs. This can be done by the identification of TNC vehicles among the available devices using their different travel patterns. Similar identification can also be used to identify the commercial use of personal vehicles.

Use Case Example: Study of TNC Trips and their Relationship with Congestion[(24)]

The San Francisco County Transportation Authority estimated TNC trips from vehicle location data passively gathered from the app application programming interfaces. They sought to identify the extent to which TNC trips contributed to the increased congestion relative to other possible factors, such as employment growth and changes to the transportation system. The agency had some statistical findings regarding TNC trips, and it measured the influence of TNC trips on the roadway congestion in San Francisco, CA.

DISASTER-RELATED STUDIES

Lack of proper person-level data on travel behavior during disasters, such as hurricanes and floods, has been a major limitation in disaster-related studies. In case of disaster evacuation, post-disaster surveys are traditionally used to collect information regarding various evacuation decisions (i.e., decision to evacuate or not, departure time of the evacuation, destination choice, primary travel mode used for the evacuation, route choice, and reentry time decision). Although this type of survey is rich in terms of recording evacuees' decisions and revealing their preferences during the disaster, such surveys are costly, implemented for a small number of respondents, time-consuming, and not capable of providing real-time information. With the increasing availability and popularity of big-data, new approaches are now available to tackle old problems. Billions of location data points are being passively collected from mobile devices, producing an anonymized blueprint of people's movement patterns. Once privacy concerns are addressed, one can refer to passively collected location data to observe the movement pattern of millions of people before, during, and after any disastrous event, such as a hurricane.

Use Case Example: Mapping Puerto Rico's Hurricane Migration with Mobile Phone Data[25]

The U.S. Census Bureau is the main entity responsible for keeping track of migration flows, but in the case of Puerto Rico, neither the State nor the Federal Government kept track of how many residents migrated after Hurricane Maria, which destroyed many parts of the State. TERALYTICS analyzed where, when, and how Puerto Ricans have migrated from August 2017 to February 2018 based on a sample of 500,000 smartphones. The analysis illustrated the usefulness of location data in guiding disaster relief efforts and disaster planning.

CHAPTER 4. REVIEW OF DATA PRIVACY LAWS AND REGULATIONS RELATED TO MOBILE DEVICE LOCATION DATA COLLECTION AND APPLICATION

This chapter summarizes data privacy laws and regulations related to mobile device location data collection and application. Laws and regulations reviewed include the *Federal Information Security Modernization Act* (FISMA), the General Data Protection Regulation (GDPR), the *California Consumer Privacy Act* (CCPA), and three resulting examples of industry self-regulation.

FISMA

As a part of the *E-Government Act* in 2002, FISMA was enacted as a U.S. Federal law for all Federal agencies to implement policies and programs to govern and protect their information and reduce the security risks to an acceptable level in a cost-effective manner.(26) FISMA was one of the earliest acts that highlighted the importance of information security both to the national economic and security interests of the United States. As a part of this act, all Federal agencies are required to develop, document, and implement an agency-wide program to protect the information and information systems that are essential for agency operations or considered as the assets of the agencies. This act also recognized the necessity of protecting information provided or managed by another agency, contractor, or other sources.(27) FISMA went under reform and has been replaced by FISMA 2014 (also known as FISMA Reform).(28)

FISMA 2014 requires agencies to pursue privacy controls considering various aspects including analysis of privacy impact and risk assessment, establishment of requirements for third-party contractors, and continuous monitoring of their privacy program. The National Institute of Standards and Technology, with its statutory responsibilities under FISMA 2014, is responsible for developing all FISMA publications, including information security standards and guidelines for all agency operations and assets.(27)

As societies are becoming increasingly alert about their privacy and want their privacy to be respected, governments around the world are imposing new privacy protection regulations and laws for industries to address growing privacy concerns. GDPR and CCPA are examples of newly introduced laws. In the United States, After CCPA was passed in 2018, the movement has kept its momentum, and several States are now proposing similar legislation to protect the privacy of users in their States (e.g., Connecticut, Illinois, Louisiana, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Jersey, New Mexico, New York, North Dakota, Pennsylvania, Texas, and Washington).(29)

A brief description of GDPR and CCPA and the mandatory regulations they add are presented in the following sections.

GDPR

GDPR was approved and adopted by the European Union (EU) Parliament in April 2016, and it came into force on May 25, 2018.(30) It is a regulation on data protection that applies to all entities processing the personal data of residents of EU member nations regardless of whether or not the activities take place in the EU.(31) It applies when data processing has connections to professional or commercial reasons instead of purely personal reasons.[31] The entity could be an individual, a company, or an organization.[32] Personal data means any information regarding an identified or identifiable person, such as name, identification number, device identification, location, Internet Protocol address, etc.[31] In GDPR, both the rights of the data subjects and the duties of the data controllers and processors are fully declared. The three main entities addressed in the legislation include:

- Data subjects are those individuals from which the personal data are derived. Data subjects have the rights to access, rectification, erasure, restriction of processing, data portability, and object.
- Data controllers are the entities, alone or jointly with others, that determine the purposes and means of the processing of personal data.[31] They must set up appropriate technical and organizational measures to satisfy the requirements of the regulation and make sure of the protection of the rights of the data subject.[31]
- Data processors are entities that process the personal data on behalf of the controller.[31] They shall be governed by a contract or other legal acts, which sets out the subject matter, the duration, nature and purpose of the processing, the type of personal data, the categories of data subjects, and the obligations and rights of the controllers.[32]

CCPA

The California Attorney General released the proposed regulation under CCPA on October 10, 2019. CCPA was introduced and signed into law on June 28, 2018, as Assembly Bill 375. This law will be effective on or before July 1, 2020.[33] CCPA provides Californians with groundbreaking rights on protecting the privacy of their personal information by enforcing the following key requirements:[34]

- Businesses are required to disclose their practices to data collection and sharing.
- Even if the businesses do not collect information directly from consumers, they must either contact the consumers directly to disclose the selling practices and the right to opt out or contact the source of the personal information to verify the disclosure of data collection and sharing practices to consumers before it can sell the consumers' personal information.
- Consumers have a right to know about their personal information collected, disclosed, or sold.
- Consumers preserve the right to request for their data to be deleted.
- Consumers preserve the right to withdraw from sharing of their personal information.
- Businesses shall provide two or more designated methods for consumers' submitting requests to know and delete, and to opt out.

- Businesses shall confirm receipt of the requests to know and delete, explain to consumers how they will be processed, and respond to the requests.

- Businesses shall establish, document, and comply with a reasonable method for verifying that the person making a request is the consumer about whom the business has collected information.

- Businesses shall establish, document, and comply with a reasonable method for verifying that the person affirmatively authorizing the sale of the personal information about the child is the parent or guardian of that child.

- Businesses are constrained from selling personal information of consumers under the age of 16 without explicit consent.

- Service providers shall not use personal information received either from a person or entity it services or from a consumer's direct interaction with the service provider for the purpose of providing services to another person or entity.

The proposed regulations will address some of the main concerns and issues raised by CCPA, and the Department of Justice will be responsible for enforcing this law.

EXAMPLES OF SELF-REGULATION

Digital Advertising Alliance (DAA)

In addition to the abovementioned regulations and laws at the Federal and State levels, the Federal Trade Commission started to look into Internet advertising platforms in 2009 and suggested that industries should develop their own guidelines for self-regulation. Therefore, several advertising agencies, related networking initiatives and alliances, and the Better Business Bureau gathered together to form DAA to initiate the Self-Regulatory Program for Online Behavioral Advertising.[35]

Since then, DAA has established policies and programs to enhance responsible privacy practices across industry sectors associated with digital advertising through principles that apply to data collected in various environments, such as desktops or mobile apps. DAA launched the AdChoices program in October 2010, which now has over 200 participants including AOL, AT&T, Bloomberg, Google Inc., Microsoft, General Motors, Facebook, Yahoo, and many other companies in the United States, Canada, and across Europe.[35] DAA describes the application of self-regulatory principles of transparency and accountability to political advertising, transparency and control to data used across devices, mobile environment, multi-site data, and online behavioral advertising.

Mobile Device Location Data Providers' Commitment to Data Privacy

Data providers are currently coping with the existing data privacy regulations and laws and are preparing themselves to comply with the new rules. In this section, approaches of mobile device location data providers Cuebiq and Reveal Mobile are discussed briefly.

Cuebiq Privacy Policy

There are four key principles included in Cuebiq's privacy program, which include the following:(36)

- **Consent:** Cuebiq considers consent as one of the most import privacy-compliant methods in order to gain a legal basis for collecting and processing this type of location data. In practice, Cuebiq will ask for the agreement from users on sharing the location before collecting it.(37)

- **Transparency:** Before asking for precise location consent, Cuebiq, together with its third-party partners, are tied to the same consent, which is to offer greater transparency as to the scope and purpose of data collection. All app partners are required to clearly state and articulate their relationship with Cuebiq in the privacy policy, enabling users to easily find clear and transparent descriptions of what information is being collected and how it is being used.(37)

- **Control:** Users can easily opt out of location sharing at any time and even erase the previously collected information.(37)

- **Accountability:** Cuebiq is certified by TrustArc and Trustworthy Accountability Group and has recently registered in the Privacy Shield Framework. Cuebiq is also one of the location providers to become a member of Network Advertising Initiatives (NAI).(38)

Reveal Mobile Privacy Policy

Reveal Mobile joined the Mobile Marketing Association (MMA) and the Internet Advertising Bureau (IAB) to ensure best practices around location data collection were being followed. Reveal Mobile also serves on the MMA's Privacy Committee and the IAB's Public Policy Council to be compliant with any new regulations, and are prepared for new regulations, like the previous EU's GDPR.(39)

Reveal Mobile handles the privacy issues from the following dimensions:(40)

- **Privacy for people:** Reveal Mobile anonymizes data by putting the data into aggregated groups without collecting any personal details. It does not receive any of the data when users choose to opt out of location sharing. People can also opt out of data collection directly with Reveal Mobile.

- **Working with customers:** Reveal Mobile reviews contracts to ensure both itself and its partners are following the industry's best practices and regulations. It provides sample language that customers can use to notify their end-users about data collection. Reveal Mobile also reviews its partners' privacy policies.

- **Following industry regulations and best practices:** Every year, Reveal Mobile undergoes a privacy audit with NAI to ensure the privacy compliance of its company. In 2015, Reveal Mobile reviewed and employed the practices of several data privacy agencies, consultants, and legal advisors such as the MMA, IAB, NAI, and the California Attorney General's office. Reveal Mobile joined MMA and IAB and serves on MMA's Privacy Committee and IAB's Public Policy group. Also, it is a member of the Future of Privacy Forum. Reveal Mobile hired a third-party data privacy consultant to work as a data protection officer and to help further assess privacy compliance and security practices, documenting the entire approach from start to finish.

CHAPTER 5. OPPORTUNITIES AND IMPLICATIONS

With each new relevant technological introduction, agencies conducting household travel surveys today experience a much different experience than those conducting these surveys even 5 years ago with respect to established practices using multimodal data collection methods (mail, web, GPS, and phone as a backup). In an effort to capture and measure emerging trends and mobility options, many agencies are considering migrating to smaller surveys conducted more regularly. Other agencies are focusing on leveraging alternative data sources to improve sampling as well as reduce survey burden by filling in the blanks regarding key demographics and motive, if not replacing the need for a travel survey entirely with new passive data products. There is not a “one size fits all” model when it comes to survey methods and technologies, more which combination is best to meet the agency goals and available budget.

With each new opportunity, testing is required to ensure that the advancement improves how surveys are conducted (both methods and technology). The more frequent surveys provide an opportunity to pilot test these methods/ technologies and refine the design to achieve survey objectives and can smooth out the heavy peak in budget and resources that are associated with conducting large scale surveys on a less frequent basis. While there is a general trend towards smaller and more frequent data collection cycles, some agencies prefer to maintain the practice of conducting travel surveys every 8 to 15 years.

Passive data sources have the potential to completely replace some survey efforts, particularly where the goal is to obtain O-D flows. However, passive data lack the demographic and underlying details, like purpose and mode that provide the overall context in which travel takes place. In addition, passive data require quality control, processing and imputation; the underlying algorithms to accomplish this are not always clearly documented.

Ultimately, newer technology provides an opportunity for significant advances in the collection of travel behavior data collection, and with those advances then comes the ability to reduce respondent burden, suggesting that the cost of conducting these surveys may also decrease. At the same time, the changes in methods impacts the ability to distinguish between actual changes in travel and methodological innovation used to collect or summarize the data. The industry overall could benefit from continued tracking of best practices as well as providing agencies with guidance on which technologies and approaches align with various survey program requirements.

The emerging legislative impacts on survey research and the use of passive data for transportation policy and planning requires more consideration and may require modification of requests for proposals to ensure survey contractors will be in compliance with relevant legislation. In addition, the restrictions on the compilation of passive data may create biases in those data sets based on who provides consent. The adoption of these new rules should be carefully tracked and best practices should be discussed at industry-wide gatherings.

The state of the practice for collecting and compiling travel behavior data continues to evolve in response to technological advances, with the implementation varying based on agency needs and budget. Emerging privacy laws should be monitored and best practices should be shared.

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