



The Future of Travel Surveys

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1 Introduction on travel surveys

Travel survey is one of the most important methods of collecting the information required for transportation planning and decision making in the new millennium. Travel surveys are used to obtain information about an individual's socio-economic, demographic, their household (size, relationships), and their travel records on a given day/week. The travel diary normally includes the origin and destination location, trip duration, mode of travel, travel party and purpose of travel. Major travel surveys in the US metropolitan regions are conducted once a decade; Some metropolitan agencies, i.e. Puget Sound Metropolitan Council, conducted a transportation panel survey during 1989-2002 to monitor travel behaviors year by year.

The ultimate purpose of a travel survey is to develop and/or improve travel forecasting models and provide an opportunity for predictive analysis of daily travel patterns. Using travel surveys, metropolitan planning organizations will be able to predict travel demand in response to current or future social and economic trends and plan for investments in transportation-related projects [1]. One of the critical steps in travel survey design is to obtain a sample survey. The objective of a sample survey is to collect demographic information and the travel behavior of the target population by obtaining information on a representative sample of that population. The process of finding a representative sample includes: 1) identifying the target population which is the total units of interest to the survey; 2) developing a sampling frame which is a list of units that includes the target population and 3) drawing a representative sample of units from that frame[2]. One of the main challenges of conducting travel surveys is nonparticipation. Despite selecting a representative sample, many households or individuals do not participate. Nonparticipation can significantly affect the quality of collected data and any results obtained from survey data analysis. In recent surveys, several efforts have been made to improve participation rate. Mailed invitations

with several reminders, providing toll-free hot lines, offering money incentives, and conducting mixed-mode survey (a combination of telephone, mail, survey website, and smart-phone application for gathering data) are examples of some of the techniques for increasing response rate. knowing that a potential respondent may prefer one survey method better than the other, to achieve an acceptable participation, conducting mixed-mode surveys will give potential respondents greater options over how, where, and when to be surveyed[1]. The challenge of survey design is to collect detailed, accurate data more frequently while minimizing respondent burden and protecting individuals' privacy.

2 Research Statement

In recent years, predicting the complex travel behavior necessitate enhanced data collection techniques. The conventional travel survey requires an individual to recall their activities and report them through phone calls, paper/web-based forms, or interview-assisted methods [3]. Conventional surveys have several disadvantages mainly due to their reliance on memory and judgment of the participants. For instance, respondents may not feel encouraged to provide accurate and honest answers or they may not feel comfortable providing answers that present themselves in a unfavorable manner; their answer may not represent their actual activity simply due to the lack of memory, or even boredom; surveys with closed-ended questions may be less reliable than other question types; survey question answer options could result to unclear data because certain answer options may be interpreted differently by respondents, etc. [4]–[7]

Recent advancements in GPS-based positioning technologies and communication tools on smartphones have provided a new opportunity not only to obtain more accurate data but also to capture more details on individuals' travel behavior. The current study will evaluate emerging

methodologies to collect travel data and will determine how such methodologies can be applied to complement/supplement traditional survey methods.

3 Available travel survey datasets

3.1 National Household Travel Survey

The National Household Travel Survey (NHTS) is designed to collect information about daily travels generated by US households including urban and rural, multi-family or single-person households in 50 States and the District of Columbia. This survey obtains data of travel behavior for all modes of trips such as walking, cycling, trips by personal vehicle and trips by public transportation. The survey also collects information about trip purposes, i.e., trips to work, trips to school, recreational trips, family trips, etc. NHTS survey results help private and public sector to understand how travel behaviors changes when demographic, economic and cultural conditions change over time. The NHTS also help Federal and state agencies to examine the performance and adequacy of current transportation infrastructure, and to make careful decisions for future. The results of household travel survey can also be utilized to enhance or validate travel demand models at a regional level. Other applications of NHTS data can be in the fields of environmental study, energy consumption and social welfare[8].

The national household travel survey has been the main source of travel behavior studies in the United States for almost half a century. The survey was previously conducted in 1969, 1977, 1983, 1990, 1995, 2001, 2009 and 2017. The most recent survey (NHTS 2017) has collected data from more than 129,000 households, which included a national sample, as well as additional add-on partner samples purchased by thirteen states or metropolitan planning organizations. The 2017 NHTS applied Address-Based Sampling with mail-back as the primary recruitment mode and

phone or internet as the secondary response mode [8]. Figure 1 illustrates the key variables collected in 2017 survey along with the relationships between the household, person, travel, and vehicle characteristics.

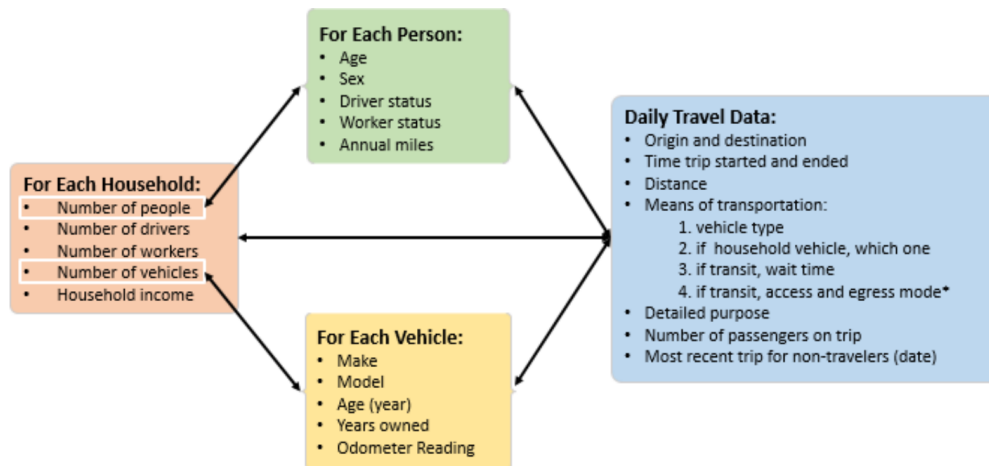


Figure 1- The core variables of 2017 National household travel survey. (Source: NHTS survey guide)

3.2 American Community Survey

The decennial census during 1960-2000 provided detailed and diverse information given its large sample size, but the frequency of data was an issue which was addressed by launching the American Community Survey (ACS) program in 2005 [9], [10]. ACS is a nationwide continuous survey conducted by the U.S. Census Bureau that collects data from January through December every year, and produces information on social characteristics (i.e., education, marital Status, fertility, etc.), economic characteristics (i.e., income, employment, Occupation), housing characteristics (i.e., occupancy and structure, housing costs, utilities, etc.), and demographic characteristics including sex and age, race, housing Units, etc. The ACS has an initial sample of approximately 3.5 million housing unit addresses and group quarters in the United States. The

Census Bureau mails questionnaires to a random sample of 295,000 addresses each month. The chance of an address to be selected each month is approximately 1-in-480, and no address should be drawn more than once every five years. The survey data is obtained through mail, internet, telephone calls and in-person interviews. Nearly one third of the addresses who do not respond to the survey by mail or telephone are randomly invited to participate in an in-person interview. Geography plays a significant role in Census Bureau activities including ACS which is famous for its ability to deliver estimates on small geographic levels such as census tracts and block groups. Geographic hierarchy in American Community Survey include states, counties, census tracts and Block groups that is the smallest building block [10]. Some of the examples of data products produced by the American Community Survey include:

- **Comparison Profiles:** Show data side-by-side from the five most recent years of the ACS.
- **Selected Population Profiles:** Include broad social, economic, housing, and demographic profiles for a variety of races, ethnic, ancestry, and country/region of birth groups.
- **Ranking Tables:** Include state rankings of estimates across 86 key variables
- **Subject Tables:** Provide more detailed ACS data, classified by subject.
- **Detailed Tables:** Provide access to the most detailed ACS data and cross tabulations of ACS variables.
- **Geographic Comparison Tables:** Compare geographic areas other than states (e.g., counties or congressional districts) for key variables. [10]

3.3 Census Transportation Planning Products

The Census Transportation Planning Products (CTPP) is a State DOT-funded annual program that generates special tabulations of American Community Survey (ACS) data. The CTPP data include where people live and work, their journey-to-work commuting patterns, and their socioeconomic and travel characteristics. Work trips are one of the most important considerations in planning

studies and the CTPP provides an adequate sample size to create a regional trip pattern. Moreover, the CTPP includes important variables such as mode choice and travel duration for work trips. The breakdowns of demographic characteristics such as occupation, household income and vehicle availability in small geographies (Census Tract level) make CTPP a distinct data resource for local transportation planning. A unique feature of the CTPP data is the freedom of users to generate customized results based on the areas of interest (i.e., census tracts) or demographic characteristics (i.e., minority, vehicle availability by household income). CTPP has been also used by MPOs and Departments of Transportation for validation/calibration of travel demand models [9].

3.4 NYMTC 2010-2011 Regional Household Travel Survey

NYMTC regional household travel survey (RHTS) collected weekday travel records of approximately 19,000 households across the 28 counties in New York, New Jersey, and Connecticut over a 24-hour period. The survey included a sub-sample of 1,930 households who used wearable Global Positioning System (GPS) devices. The primary goal of the survey was to support the development of travel demand forecasting models, particularly, New York Best Practices Model (NYBPM) and to provide the basis for the estimation and calibration of activity/travel behavior choice models. The data collected through traditional telephone recruitment, retrieval participation options, mail back and internet-based (website) methods. The main variables collected in RHTS are demographic variables for households and persons (including age, race, income, vehicle ownership, occupation, school/work location, etc.) and trip characteristics (such as origin, destination, activity, travel mode and trip party). The results of the survey are stored in eight relational database data files including household, person, vehicles, visited place, unlinked trips, linked trips, tour, and subtour (A tour defined as travel from home to a principal location, i.e., work, school, university, or other destinations) [11].

4 A summary of recent travel surveys conducted by MPOs across the US

A summary of the recent surveys conducted by multiple US metropolitan planning organizations is presented on Table 1. Most of the surveys implemented a three-stage survey design with combined data collection methods: 1- Screener Recruitment in which invitation packets with pre-incentive and a brief mail-back screening questionnaire were sent to the households; 2- Extended Questionnaire to obtain a complete roster of people, vehicles, and other detailed demographic and socio-economic information along with work and school locations; 3- Travel Data Retrieval Questionnaire[12]. While geographic coordinates of travel records can be estimated from respondent-provided information, their reported origin-destination and time may not be accurate. Therefore, most often a portion of survey participants are provided with GPS devices. In this case the ability to evaluate the number of trips, duration/ miles of travel during a 7-day period provides valuable opportunity for validating travel demand models.

Some of the recent surveys in 2019 (e.g., Chicago Metropolitan Agency, Puget Sound Regional Council) also offered an opportunity to use a smartphone app such as Westat's DailyTravel or rMove to record daily travel information over a 7-day period besides web-based survey. A survey app would normally collect larger amount of accurate data without significant burden on participants. Figure 2 represents an overview of data collection in PSRC travel survey 2019 [12], [13]. Some of the advantages and disadvantages of using a smartphone app for collecting travel data is also listed in Table 1.

One of the recent practices in travel survey design is running a social media campaign to maximize participation. The campaign includes Facebook, Instagram, and Google advertisements as well as outreach to influencers who are based in the survey region. The main goal of this campaign is to

encourage people to take the survey through social media advertisements. Although such campaign may induce bias in data, as younger population tend to participate more, in some MPOs like Chicago Metropolitan, it resulted in higher awareness about the survey app as well as more than 1,100 successfully completed surveys [12].

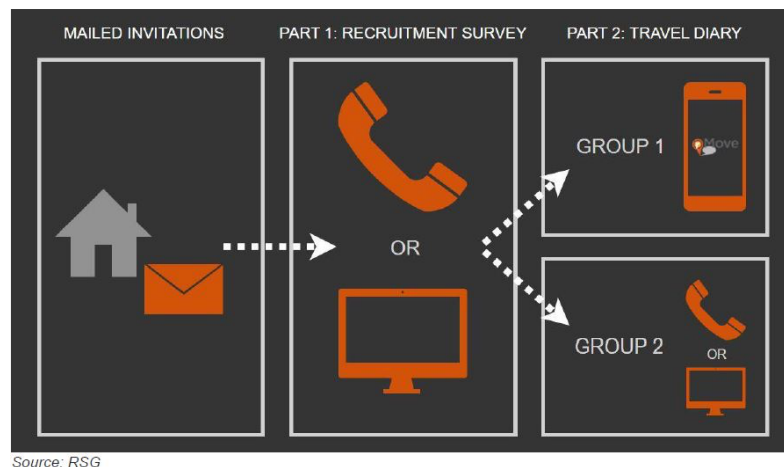


Figure 2- The schematic overview of PSRC three-stage travel survey

Table 1. Pros and cons of using a smartphone application to collect households' travel records

Advantages	Disadvantages
*Lower cost of collecting data for a longer period *More accurate data on travel time and Origin-Destination *Lower response burden and higher participation *Users can edit errors in travel records	*Cannot be used in poor network areas *May not capture underground commutes *Collected data can be lost if the app crashes *Sample Bias: Younger/high income households participate more

Table 2. A summary of recent Household Travel Surveys by MPOs across the US

MPO	The most recent survey	Previous survey	Sample size	Region of study	Data collection	Smartphone App	Remarks
Chicago Metropolitan Agency for Planning (CMAP)	Daily Traveler Aug. 2018-Apr. 2019	Travel Tracker 2007-2008	12,390 households	Northeastern Illinois	1- Screener Recruitment 2- Extended Questionnaire 3- Travel/Activity Data Retrieval Questionnaire	Westat's DailyTravel smartphone app	Household members (13 years and older) were asked to use DailyTravel app to capture GPS locations and confirm place details for a total of 7 days of GPS-based travel data
Michigan Department of Transportation (MDOT) & SEMCOG	Michigan Travel Count III April 2015	Michigan Travel Count II 2009	6,276 households (36,891 people)	Michigan State (randomly selected)	Two-stage incentive approach / GPS-based Prompted Recall (GPS+PR)	NA	Household members between the ages of 16 and 75 carried GPS for 3 consecutive days
Puget Sound Regional Council (PSRC)	Puget Sound Regional Travel Study April 2019–June 2019	2017	2750 household	four-county PSRC region & City of Seattle	combined data collection methods including smartphone, web-based, and telephone.	seven-day smartphone GPS diary using rMoves	63% households (over age 18) reported their travel for up to seven days using rMove and the other group was required to report their travel for one day online using rSurvey™
Colorado Front Range Metropolitan Planning	The Front Range Travel Counts Survey (FRTC) March 2009–Nov. 2009	2002	11200 household	North Front Range, Denver, Colorado Springs, and Pueblo	recorded all trips for a 24-hour period using a travel diary	NA	weekend travels were not collected
Colorado State-wide Travel survey	Potentially 2021	2009	NA	State-wide Colorado	A survey app will be implemented to collect and send GPS data	Potential of using Long-Distance Smartphone Application	Data collection on traditional motorized and nonmotorized modes (walk/drive to transit, drive-alone, carpool, walk, bicycle), transportation network companies (TNCs), and microtransit modes (scooters, etc.), and household travel substitution modes, such as grocery and restaurant deliveries, internet-order deliveries
Miami-Dade Transportation Planning Organization	Southeast Florida Travel Survey September 2016-May 2017	2015	1954 household	Miami -Dade county, Broward county, Plm Beach county	Recruitment survey, Web-based travel diary, Computer Assisted Telephone Interviewing, and 11% GPS subsample	NA	collected information of trips over a 48-hour period (no age limit)
Delaware Valley Regional Planning(DVRPC)	DVRPC HTS July 2012-September 2013	2000	9384 household	Bucks, Chester, Delaware, Montgomery, and Philadelphia counties in Pennsylvania; and Burlington, Camden, Gloucester, and Mercer counties in New Jersey	The CATI and web-based scripts as well as GPS sub-sample used to collect travel data w	NA	randomly selected household between the ages of 13 and 85 participated in GPS data collection

5 Passive data collection methods for travel analysis

Over the past few years, changes in population demographics and increased personal mobility has resulted in higher costs of conducting traditional surveys. The cost of household surveys generally varies between \$150 and \$300 per household, depending on the collection methods and the technology used[14]. Additionally, people have become unwilling to participate in lengthy questionnaire and they may choose to skip the survey or shorten their answers to lower their burden. New data sources and collection techniques have provided larger sample size and longer temporal coverage, which yields opportunities for more dynamic research in the field of transportation planning. These data sources can be based on Wi-Fi positioning system, GPS, smartphone apps, cellular network data, etc. In all these data sources, travel information is collected passively (and non-disruptively) by a range of devices. Despite the large amount of individual-level information and lower response burden, there are challenges associated with collection and processing and analyzing some forms of passive data [15]. Some of these limitations include:

- Data gap and missing information
- The absence of demographic or socio-economic information
- Trip purposes are not explicitly recorded
- In some cases, substantial data processing is required to extract travel information from activities such as texting, making phone call, etc.[16]

Passive data refers to the information collected explicitly without interaction from a person. There are two types of passive data. The first category of passive data (type 1) is almost the equivalent of a travel diary, but data is collected through a device in order to increase responses from surveys. For instance, an individual use a pre-designed smartphone app that collects information about start

and end point of their trips and other trip information. In this case, the collected data is more accurate, and complete. The Maricopa Association of Governments (MAG) and the San Diego Association of Governments are two MPOs that conducted almost 100% smartphone-based household travel survey in 2016–2017. The second type of passive data refers to the information collected for purposes unrelated to transportation (such as making a phone call, using a social-media app), but may be useful for studying some futures of travel behavior. For example, a mobile application may collect the location of its users to provide information about their surrounding area. In this case, the application developer will have a dataset containing locations/activities of users at each time of the day[17] . The second type of passive data technically provides larger sample size as the information is collected constantly. However, sample size can vary by technology and data provider. It should be noted that passive data type 2 may not include all the required information for analyzing travel behavioral patterns among different demographics. Table 3 summarized the list of companies currently collects location-based data from their customers or clients.

Table 3. The list of companies collecting positional data. Source: Federal highway Administration[17]

Data Providers	Remark	Cell Tower Triangulation	GPS vehicle	Wifi Positioning System/LBS
AirSage	AirSage™ is selling historical data covering dates up to 2017 from either Verizon™ or Sprint		Other	Primary
StreetLight Data (partners with Cuebiq and INRIX)			Primary	Primary
HERE			Primary	
INRIX			Primary	
ATRI			Primary	
SkyHook				Primary
Cuebiq				Primary
SafeGraph				Primary
Twitter	Has an API that researcher can collect their own data			Primary

6 Big data options for travel analysis

6.1 Call detail Records (CDR)

Call detail records are commercial cellphone data that is generated by telecommunications devices. CDR include the details of an incoming or outgoing call, text message, or a connection to internet browser, an app, or e-mail. CDRs are available because most telecommunication services keep these records for billing purposes. A total of 95 percent of individuals in the United States own a

cellphone, so CDR offers a very large sample size. A cellphone location can be detected through two types of signals:

- Active signals: when users make calls, send text messages, or use the web.
- Passive signals: when users receive calls or text messages; this type of signal can also be received from social-media apps, music apps, news apps, etc.

The home and work locations (trip purposes) can be inferred by tracking a device's location during the day and overnight across several days/weeks. Since locations are estimated by triangulation methods (when a cellphone connects to multiple towers), the accuracy of locations in CDR data is low. CDR data does not include socioeconomic demographic information of cellphone users. However, households or individuals' characteristics can be inferred by matching the device's home location to U.S. Census data. The size of CDR data depends on the amount of cellphone usage (e.g., calls, texts, apps) and the frequency of interaction with towers. In summary, CDR challenges include:

- Low accuracy: Spatial precision can vary between 50 to 300 meters.
- Unreported trips: Since users may not use cellphone a lot for call/text during all their travel; or the cell phone device may not have signal especially in rural areas
- CDR data does not include demographic characteristics of travelers
- Determining the origin or destination of the trip is difficult in mixed land-use
- Travel mode and size of the traveling party cannot be inferred

Although CDR data cannot be used as a traditional survey, but it is useful for identifying seasonal and annual trends in travel, and for updating/validating travel demand models[14], [17].

6.2 Global Positioning System (GPS)

Global Positioning System or GPS uses signals from satellites to determine coordinates on the Earth's surface. GPS traditionally was used to provide information about velocity for different forms of travel. GPS-enabled devices (e.g., mobile phone, in-vehicle GPS) which provide navigation services to many users can be a great source of locational data for transportation planning. GPS can provide highly accurate spatial and temporal data (generally within 4m) on travel activity and differentiates between personal and commercial trips. However, it's sample size is normally lower than other passive data. GPS data can also induce bias in travel analysis because travelers may not use GPS all the time, and only use it for traveling to unknown locations. Another challenge with GPS data is the extremely time-consuming data processing.

6.3 Location-based Services (LBS)

The proper functionality of several smartphone applications relies on location information. Some of the examples of such apps include maps, ride sharing apps, apps for ordering food, commuting apps, etc. Depending on the cellphone settings, the app obtains location information through GPS or Wi-fi positioning system (WPS). Application developers can resell these location-based data source in several forms. Basically, Location-based Services combine geospatial technologies and communication technologies to provide a database of locational information. LBS data have better spatial accuracy than cellular data (5-25 spatial precision) and travel purpose/mode can be inferred on an aggregated basis. Although LBS data do not provide demographic information of users as a conventional household travel survey, but the combination of a relatively large sample size and GPS-quality spatial precision, makes it a great choice for improving or substituting expensive surveys. One of the advantages of LBS data is its ability to provide information about visitors'

travel behavior and travel patterns during spatial events in a given region. Number of visits to an area, duration of stay, overnight stay locations and activity locations are among the information that can be obtained through LBS but are not normally collected in a traditional household travel survey.

Table 4 and Table 5 compares three big data sources in terms of travel analysis.

Table 4. The summary of features of big data sources.[18], [19]

Data	Frequency of Data Ping	Sample Size	Personal/Commercial trips
Cellular Tower	every 15 minutes-hours	~10% of population for small telecoms; ~25-30% for large telecoms	Does not differentiate personal and commercial trips
Navigation-GPS	every 1 sec- 1 min	~1-4% of personal trips; ~10-12% of commercial trips (for INRIX)	Differentiates personal and commercial trips
Location-Based Services	Varies by location	25 million US devices in	Blends personal and commercial trips

Table 5. Strengths and limitations of big data sources for travel analysis.[18],[19].

Data	Strength	Limitation
Cellular Tower: from cellular tower “triangulation” (50-300 m spatial precision)	Very large sample size more than 25M devices Inferred home and work locations	• Poor spatial precision • Personal and commercial trips are not separated • The mode of travel cannot be inferred reliably • Poor coverage in rural areas
Navigation-GPS: cars and trucks (3- 5m spatial precision)	Precise location Very frequent pings Personal and commercial trips	• lower sample size • Vehicular mode cannot be inferred
Location-Based Services: (5-25m spatial precision)	Large sample Frequent ping rate	• Less suppliers • Sample size varies across data providers • Ability to infer trip purpose and trip modes on an aggregated basis

7 Summary and recommendations

This study evaluated the potentials of big data sources including Cellular Network Data, GPS and Location-based services for the purpose of travel studies. The most common challenge of such passive data sources is the absence of demographic or socioeconomic information, which are the key inputs to most traditional travel demand models. In most forms of big data, travel purpose, travel mode and size of travel party cannot be directly extracted or even inferred. In some data sources such as LBS, work and home locations can be inferred, but non-home or non-work trips are typically difficult or impossible to be inferred. GPS data offers the most accurate spatial precision, but the raw data require substantial data processing to become available for analysis. Despite this limitation and challenges, the emerging data sources still offer so many benefits and can be used to enhance/update travel demand models, analyze travel behavioral trends across a region and to study travel patterns during spatial events. Before doing any analysis on a data source from a third-party provider, we need to ask: What is the source of raw data? Is it CDR, app-based LBS or in-vehicle GPS, etc.; What data processing or cleaning are initially performed on raw data and how much of sample has remained?; How many completed daily travels have been collected in any given region?; What techniques have been used for expanding the sample?; Finally, is there a potential geographical/demographical bias in the data and how should be addressed?

References

- [1] R. Griffiths, W. Council, G. A. J. Richardson, and M. E. H. Lee-Gosselin, “Travel Surveys,” 2000.
- [2] M. Zimowski, R. Tourangeau, R. Ghadialy, and S. Pedlow, “NONRESPONSE IN HOUSEHOLD TRAVEL SURVEYS,” 1997.
- [3] W. Bohte and K. Maat, “Deriving and validating trip purposes and travel modes for multi-day GPS-based travel surveys: A large-scale application in the Netherlands,” *Transportation Research Part C: Emerging Technologies*, 2009, doi: 10.1016/j.trc.2008.11.004.
- [4] J. Wolf, S. Bricka, T. Ashby, and C. Gorugantua, “Advances in the Application of GPS to Household Travel Surveys,” *Household Travel Survey*, 2004.
- [5] H. Safi, B. Assemi, M. Mesbah, and L. Ferreira, “An empirical comparison of four technology-mediated travel survey methods,” *Journal of Traffic and Transportation Engineering (English Edition)*, vol. 4, no. 1, pp. 80–87, Feb. 2017, doi: 10.1016/j.jtte.2015.12.003.
- [6] T. L. Forrest and D. F. Pearson, “Comparison of trip determination methods in household travel surveys enhanced by a Global Positioning System,” 2005. doi: 10.3141/1917-08.
- [7] J. Auld, C. Williams, A. Mohammadian, and P. Nelson, “An automated GPS-based prompted recall survey with learning algorithms,” *Transportation Letters*, 2009, doi: 10.3328/TL.2009.01.01.59-79.
- [8] “2017 National Household Travel Survey Data User Guide,” 2018, Accessed: Oct. 04, 2021. [Online]. Available: <https://nhts.ornl.gov/assets/2017UsersGuide.pdf>
- [9] J. Seo *et al.*, “The CTPP Workplace Data for Transportation Planning: A Systematic Review”.
- [10] U. Census Bureau, “American Community Survey Information Guide”, Accessed: Oct. 03, 2021. [Online]. Available: <https://www.census.gov/programs-surveys/acs/about/information-guide.html>

- [11] NYMTC; NJTPA, “2010/2011 Regional Household Travel Survey,” 2014.
- [12] Westat, “2018-19 My Daily Travel Methods and Final Survey Report,” 2020.
- [13] P. Sound Regional Council, “PUGET SOUND REGIONAL COUNCIL 2019 PUGET SOUND REGIONAL TRAVEL STUDY Final Report |,” 2020.
- [14] National Cooperative Highway Research Program, “Cell Phone Location Data for Travel Behavior Analysis,” Transportation Research Board, Jul. 2018. doi: 10.17226/25189.
- [15] L. Willumsen, “Use of Big Data in Transport Modelling Discussion Paper,” 2021.
- [16] K. E. Zannat and C. F. Choudhury, “Emerging Big Data Sources for Public Transport Planning: A Systematic Review on Current State of Art and Future Research Directions,” *Journal of the Indian Institute of Science* 2019 99:4, vol. 99, no. 4, pp. 601–619, Oct. 2019, doi: 10.1007/S41745-019-00125-9.
- [17] Federal Highway Administration, “Collecting Multimodal National and Metropolitan Behavior Data,” Jul. 2019.
- [18] “Enriching Household Travel Surveys with Big Data Metrics,” 2019. Accessed: Oct. 12, 2021. [Online]. Available: <https://learn.streetlightdata.com/big-data-travel-surveys-white-paper>
- [19] “Our Methodology and Data Sources,” 2019.